Effect of curved rf windows on Study 2a performance

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We examine several effects of realistic rf window designs on the Study 2a performance. Reducing the window radius from 25 cm, as assumed in Study 2a, to 21 cm decreases the μ/p into the accelerator acceptance by ~6%. Changing the flat rf windows assumed in Study 2a to the curved windows currently being used has no statistically significant effect on the performance.

1. Introduction

The latest MUTAC review [1] raised the question whether the radial electric rf fields arising from the curved window shape used in our prototype 201 MHz rf cavities have a significant effect on our simulated cooling performance. We look at this question here in terms of the effects on the Study 2a front end performance.

2. Superfish cavity models

The Superfish modeling was done using version 7.16 of the code. All the cavities were designed to have a resonance frequency ~201 MHz. All the models assume cylindrical symmetry and thus ignore any asymmetries in the cavity fields due to couplers, tuners, etc. The models were initially set up to have a spatially-averaged longitudinal field on-axis of 1 MV/m. All the fields are later scaled up by a constant gradient factor in ICOOL. The fields were stored on a 5 mm grid at one instant of time. The Study 2a design was originally done in ICOOL using an analytic model of a 50 cm long pillbox rf cavity. Our goal here is to compare this model with the fields from the actual 201 MHz cavities constructed as part of the Mucool/MICE program [2]. These cavities are ~42 cm long on-axis and have curved side walls. In addition the present beryllium window for the cavity has a curved shape that has been optimized to give minimum thickness near the beam axis. The actual MICE cavity will have parallel curved windows, so that temperature induced variations in the thin windows will not detune the cavity resonance frequency.

Five Superfish cavity models were made for this study:

- 50 cm long pillbox
- 42 cm long pillbox
- realistic cavity with flat windows
- realistic cavity with bowed-out curved windows
- realistic cavity with parallel curved windows

Four of these models are shown in Fig. 1.

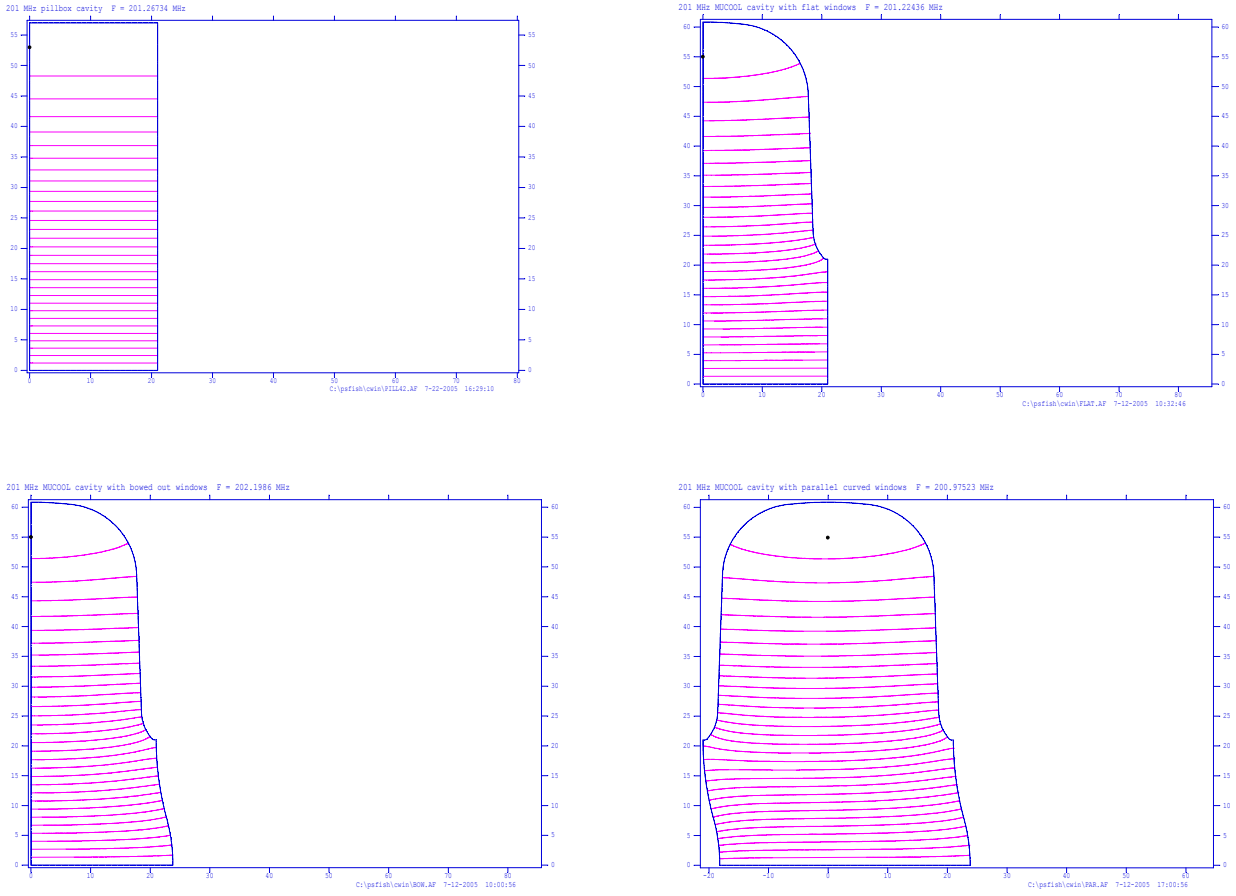

Figure 1. Superfish cavity models. Upper left: 42 cm pillbox, upper right: realistic cavity with flat windows, lower left: realistic cavity with bowed windows, lower right: realistic cavity with parallel windows.

All of the realistic cavity designs have time-varying radial electric fields and variations in the axial electric field on-axis. Peak values for these quantities are listed in Table 1.

Table 1. Field variations in realistic cavity models

model	δE_Z [%]	peak E_R
FLAT	+2 / -3	0.14
BOW	+12 / -30	0.21
PARALLEL	+43 / -38	0.17

For the flat and bowed windows the deviation in the axial E_Z at a fixed time was positive at the center of the cavity and negative at the windows. For the parallel curved windows the deviation was positive at the left window, which curves inward, and negative at the right window. The radial electric field grows initially as the radius increases. We show in Table 1 the value at z = 20 cm and r = 20 cm, which is inside the beam acceptance and near the corner of the window. The magnitude listed is in MV/m when the average axial field is 1 MV/m. The radial field used in the simulations will also be scaled up by the actual gradient that is used.

3. ICOOL simulation results

In order to use the Superfish cavity information ICOOL was modified[1] to directly read the output of the SF7 Superfish postprocessor. Study 2a assumed 50 cm long cavities with 25 cm beam radial aperture. Fig. 2 shows a comparison of the number of muons in the accelerator acceptance for three models. The analytic pillbox model is the standard ICOOL rf cavity model. The Superfish pillbox model uses fields stored on a 5 mm r-z grid. The realistic Superfish cavity models are ~42 cm long, so we also examine a shorter Superfish pillbox. In this case we scale up the gradient in the cavity to give the same integrated field on-axis.

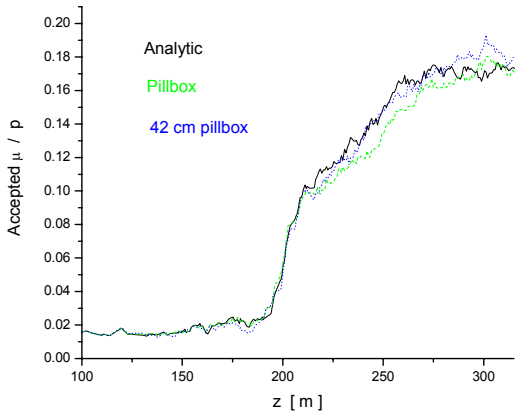

Figure 2. Performance of Study 2a front end for 25 cm radial acceptance

[1] Using this feature requires ICOOL version 2.90 or higher.

Note that although Fig. 2 shows the performance out to 315 m, the actual length of the Study 2a channel is 295 m. There is no statistically significant difference in the performance of these three models.

The windows on the realistic cavities have a maximum radius of 21 cm. For comparison we also examine a Superfish pillbox model with a 21 cm radial cut off in ICOOL. We also consider the Superfish realistic cavities with flat, bowed, and parallel curved windows. The performance of these models is shown in Fig. 3.

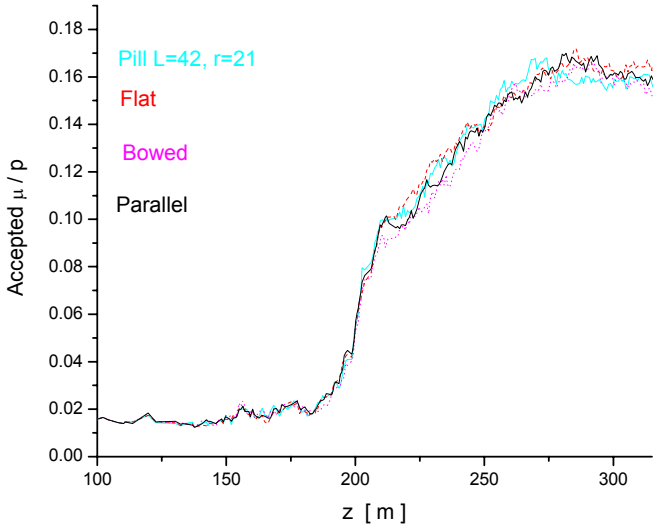

Figure 3. Performance of Study 2a front end for 21 cm radial acceptance

There is no statistically significant difference among the three realistic cavity models and also no difference from the pillbox model. We do see however a 6% drop in performance compared with the 25 cm radius case in Fig. 2.

Table 2 gives a numerical summary of the simulation results at 295 m.

Table 2. Simulation results for Study 2a

model	L [cm]	R [cm]	Accepted μ / p
analytic	50	25	0.171 ± 0.006
pillbox	50	25	0.168
scaled pillbox	42	25	0.179
scaled pillbox	42	21	0.158
FLAT	42	21	0.161
BOW	47.62	21	0.158
PARALLEL	44.81	21	0.164

The last column of the table shows the value of μ/p that fits in the assumed accelerator normalized transverse acceptance of 30 mm and normalized longitudinal acceptance of 150 mm. The error shown is typical of the uncertainty in all the simulation results. The three 25 cm radius models give statistically similar results, as expected. In addition there

is no statistical difference among the four 21 cm radius examples. There is no evidence that the curved windows degrade the channel performance.

We also looked for evidence that the curved windows might have affected the radial or angular distribution at the end of the channel. It is possible that the distributions with curved windows could still fit in the accelerator acceptance, but be more concentrated at large radius or angle. The radial distribution is shown in Fig. 4.

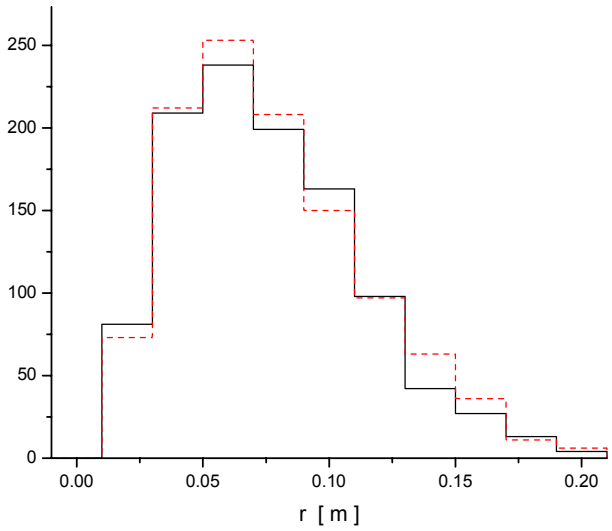

Figure 4. Radial distributions at the end of the channel for the pillbox cavity (solid black) and the realistic cavity with parallel curved windows (dashed red). The horizontal axis is offset. The first bin actually starts at zero.

There is a slight tendency for the distribution from the curved windows to move to larger radius. The angular distributions are compared in Fig. 5.

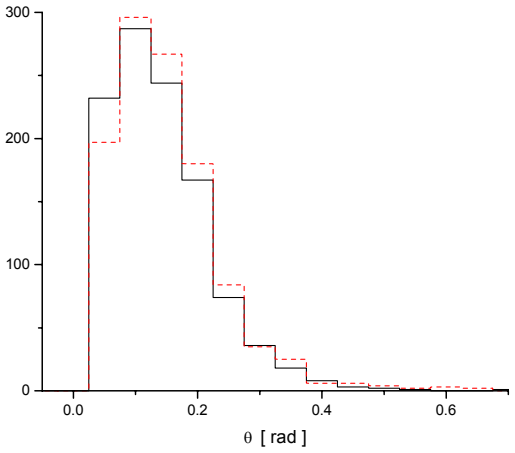

Figure 5. Angular distributions at the end of the channel for the pillbox cavity (solid black) and the realistic cavity with parallel curved windows (dashed red). The horizontal axis is offset. The first bin actually starts at zero.

Again there is a slight tendency for the distribution from the curved windows to move to larger angles. In any case the shift in the distributions from the curved windows is so small that it is not important.

4. Conclusions

Decreasing the Study 2a channel radius from 25 to 21 cm would entail a loss in performance of ~6%. The effects of the curved rf windows are statistically insignificant for the Study 2a front end.

Acknowledgements

We would like to thank Derun Li for providing the Superfish BOW model, which contained a description of the shape of the curved windows. We would also like to thank Mike Zisman for some useful suggestions.

References

[1] MUTAC committee report on the Muon Collaboration 2005 review, LBNL, April 25-26, 2005, page 16.
[2] Derun Li et al., A 201 MHz rf cavity design with non-stressed pre-curved Be windows for muon cooling channels, Proc. 2003 Particle Accelerator Conference, p. 1243-1245.