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PERPENDICULAR BIASED FERRITE TUNED CAVITIES FOR THE FERMILAB BOOSTER*

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Abstract

The aging Fermilab Booster RF system needs an upgrade to support the future experimental program. The important feature of the upgrade is a substantial enhancement of the requirements for the accelerating cavities. The new requirements include enlargement of the cavity beam pipe aperture, increase of the cavity voltage and increase in the repetition rate. The modification of the present traditional parallel biased ferrite cavities is rather challenging. An alternative to rebuilding the present Fermilab Booster RF cavities is to design and construct new perpendicular biased RF cavities, which potentially offer a number of advantages. An evaluation and a preliminary design of the perpendicular biased ferrite tuned cavities for the Fermilab Booster upgrade is described in the paper. Also it is desirable for better Booster performance to improve the capture of beam in the Booster during injection and at the start of the ramp. One possible way to do that is to flatten the bucket by introducing second harmonic cavities into the Booster. This paper also looks into the option of using perpendicularly biased ferrite tuners for the second harmonic cavities.

INTRODUCTION

The Booster currently runs at a maximum repetition rate of ≈7 Hz and 5e12 protons per pulse, corresponding to 1e17 protons/hour. Intensity is limited by beam losses, while repetition rate is limited by cooling of the RF cavities. However, the future demands on protons from the Booster require another doubling (or better) of the total throughput. In an effort to fulfil this commitment a proton improvement plan (PIP) is being enacted [1]. In particular an increase of the repetition rate up to 15 Hz is included in the plan.

In fact, the increase from the current 7 Hz repetition rate to 15 Hz increases the power dissipation in the RF system of the proton source. To ensure a reliable operation at the required higher duty factors, the present design of Booster cavities is being carefully examined to study the ways to rebuild the cavities and upgrade their functionality [2].

An alternative to rebuilding the present Fermilab Booster RF cavities is to construct new perpendicular biased RF cavities similar to the Los Alamos/SSC/TRIUMF design. This type of cavity offers three clear advantages. First, higher peak accelerating voltage will require less number of cavities in the ring. Secondly, the accelerating gradient is at least two times the 29 kV/m anticipated in the modified Booster cavity. This reduces the total length of the RF straight sections. Thirdly, the use of perpendicular biased garnets instead of the present Ni-Zn ferrites reduces the RF losses in this cavity design by at least a factor of two [3,4]. This alternative design is discussed in the paper.

It is desirable for better Booster performance to improve the capture of beam in the Booster during injection and at the start of the ramp. One possible way to do that is to flatten the bucket by introducing second harmonic cavities into the Booster. This paper also looks into the option of using perpendicularly biased ferrite tuners for the second harmonic cavities

BOOSTER ACCELERATING CAVITY

TRIUMF Cavity Simulation

The TRIUMF perpendicularly biased ferrite tuned cavity was chosen as a prototype for our evaluation of the Booster cavity by several reasons. First of all it has parameters close to the Booster requirements. The cavity design is fully proven, since the cavity has passed successfully the most complete high power tests [5]. The design is well documented, so it was possible to develop CST Studio Suite model using exact drawings of the cavity. The latter was important for verification of our study. The cavity and its CST model are shown in Fig. 1.

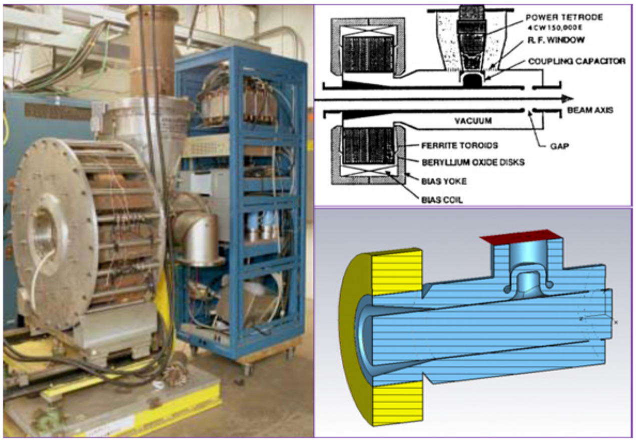

Figure 1: TRIUMF perpendicularly biased ferrite tuned cavity and its CST MWS model.

The CST model of the TRIUMF cavity was simplified and didn't include BeO disks, solenoid, RF windows, power amplifier and other details. Trans-Tech G810 YAG ferrite in the model was a single solid toroid instead of separate disks. The internal bias magnetic field in the ferrite was strictly longitudinal and uniform throughout the tuner.

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Initial frequency of the CST model was higher than the experimental value by 5 MHz due to these simplifications or/and probable differences between the drawings that we used and the real cavity. The length of the coaxial part of the model was slightly increased to adjust the operating frequency. After this re-tuning was done, the model reproduced the experimental tuning curve of the cavity reasonably well (see Fig. 2), showing simulations with CST is a reliable design tool.

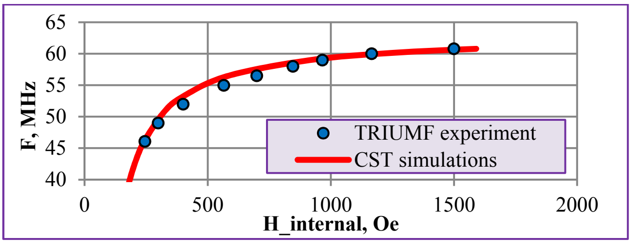

Figure 2: Tuning curve of the TRIUMF cavity.

RF Design of Booster Accelerating Cavity

The main parameters for the new Booster accelerating cavity are as follows:

Frequency tuning range	-	37.8÷53 MHz;
Beam aperture	-	83 mm;
Accelerating voltage	-	60 kV (or higher);
Repetition rate	-	15 Hz.

Frequency tuning range of 15.2 MHz is larger than the range of 14.7 MHz (46.1÷60.8) MHz for the TRIUMF cavity. The capability of the design to provide this tuning range was the first step of the evaluation. Other parameters reflect new requirements for Booster cavity: 1) 15 Hz repetition rate is an ultimate goal of the PIP plan to increase proton throughput; 2) a bigger beam aperture is to avoid particle losses at the cavities resulting in excessive activation at future high duty factor; 3) a higher voltage is to reduce number of the cavities in the Booster.

RF design of the Booster accelerating cavity that meet the main requirements is shown in Fig. 3. The beryllium oxide disks are back in the design, Fig. 3 also shows the changes of the main cavity dimensions compare to the TRIUMF prototype.

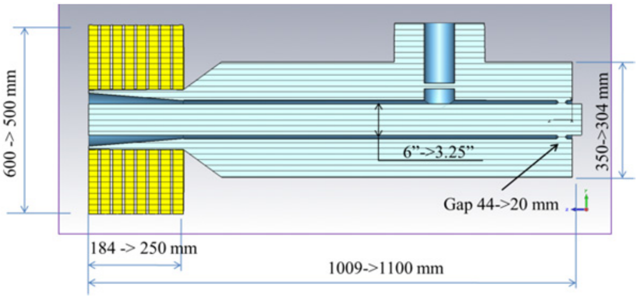

Figure 3: CST MWS model of the Booster accelerating cavity.

The tuning curve of the cavity for uniform bias magnetic field is shown Fig. 4. The required tuning range 37.8÷53 MHz is achievable, though extra ferrite disks and higher magnetization compare to the TRIUMF prototype were used.

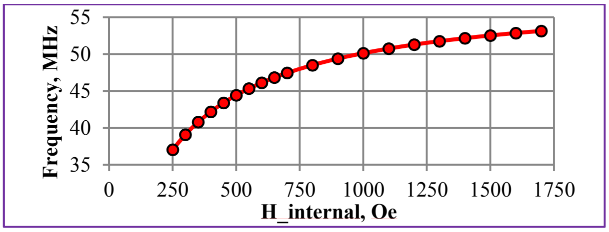

Figure 4: Tuning curve of the Booster accelerating cavity.

Thermal Analyses

Essential limits for perpendicular biased ferrite tuned cavities are determined by thermal losses in the ferrite garnet [6]. The CST model for thermal analyses is shown in Fig. 5.

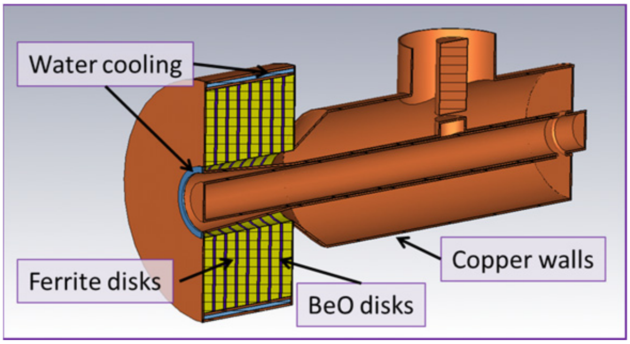

Figure 5: CST model for thermal analyses.

Only RF magnetic volume losses in the ferrite were taken into account. Averaged over the Booster cycle they defined thermal losses of ≈ 9 kW. This is much less than ≈33 kW for the existing cavities with parallel bias at repetition rate of 15 Hz [2]. But the problem of cooling is still serious, because mechanically it is difficult to remove heat from the centre of the ferrite stack (see Fig. 6). The temperature of the central disks rises very sharply with increase of accelerating voltage – for V=100 kV (highly desirable), the peak temperature would be 150°C which is too close to the Curie point of ≈200°C for G810 garnet.

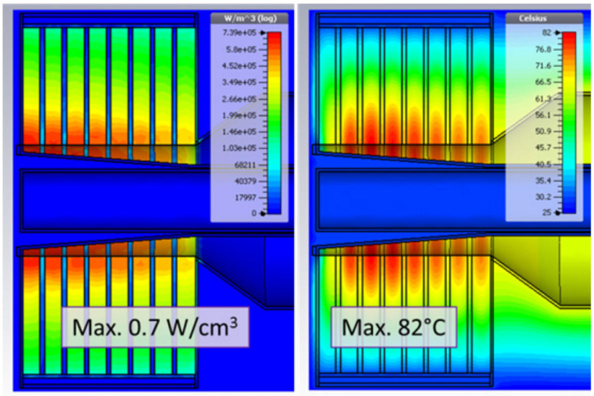

Figure 6: Magnetic thermal losses and temperature distributions in cross-section of the ferrite tuner.

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SECOND HARMONIC CAVITY

One possible way to improve the capture and retention of beam in the Booster during injection and at the start of the ramp is to flatten the bucket by introducing second or third harmonic cavities into the Booster [7].

The required tuning range for the second harmonic cavity is 76.75÷105.35 MHz. Due to the higher frequency, the cavity is relatively small which makes cooling more difficult. In order to make this thermal problem less severe a tuner design has been modified to create additional space for cooling channels and to re-distribute RF magnetic losses away from the ferrite stack centre (see Fig. 7).

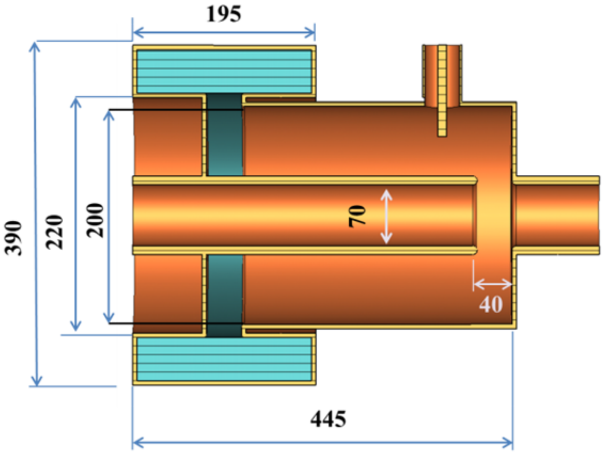

Figure 7: CST RF model of the second harmonic cavity.

The CST model of the second harmonic cavity is more developed and includes a solenoid to create a bias magnetic field. The resonant frequency of the cavity vs solenoid current (tuning curve) is shown in Fig. 8.

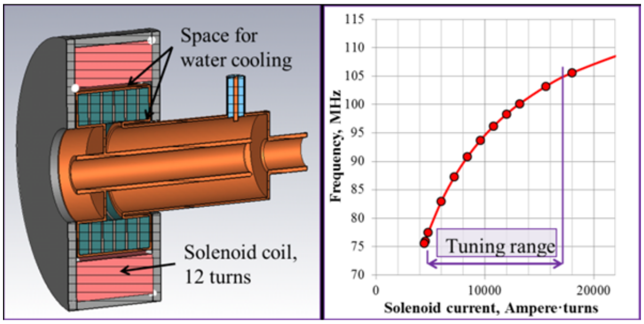

Figure 8: Complete CST model of the second harmonic cavity and its simulated tuning curve.

As before, only the RF magnetic volume losses in the ferrite were averaged over one Booster cycle to define the thermal losses. The specific ramps for frequency and field amplitude of the second harmonic cavity were taken into account. The thermal losses in the ferrite derived this way were 14 kW at V=100 kV and repetition rate 15 Hz. This result differs just by several percent from the case with uniform bias field.

Since BeO is a harmful material it was decided to replace it by aluminum nitride (AlN) in spite of ≈30% reduction of thermal conductivity of cooling disks. Due to the generally improved cooling scheme, the temperature rise in the ferrite was still reasonable (see Fig. 9).

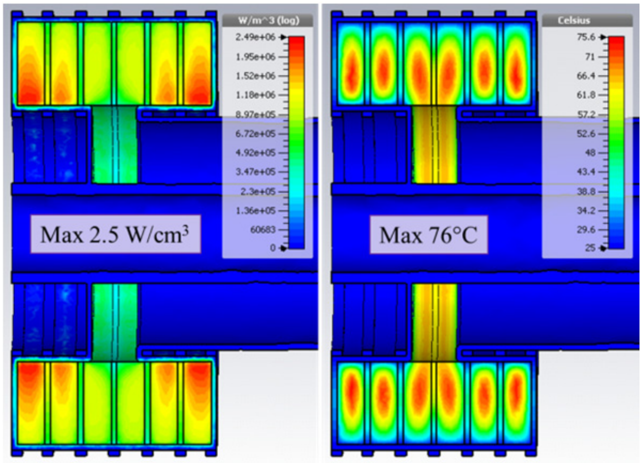

Figure 9: Magnetic thermal losses and temperature distributions in the cross-section of the ferrite tuner.

CONCLUSION

The results of the preliminary design of the Booster accelerating and second harmonic cavities with perpendicular biased ferrite tuners are promising. The thermal problem is of major concern, because it limits the accelerating voltage. The increase of the injection energy of the Booster from 400 MeV up to 800 MeV, as it is planned in the second stage of PIP, may resolve this problem.

REFERENCES

[1] Proton Improvement Plan website, http://www-ad.fnal.gov/proton/PIP/PIP_index.html
[2] M.Awida et al, “MultiPhysics Analysis of the Fermilab Bosster RF Cavity”, THPPC030, IPAC12, New Orleans, USA, 2012
[3] Fermilab Booster Rookie Book, http://wwwbdnew.fnal.gov/operations/rookie_books/Booster_V4.1.pdf.
[4] R.L. Poirier et al, “Parallel Bias vs Perpendicular Bias Of A Ferrite Tuned Caivty For The TRIUMF Kaon Factory Booster Ring”. In Proc. EPAC 1988, Rome, Italy, pages 1321–1323, 1988.
[5] R.L. Poirier et al, “AC Bias Operation of the Perpendicular Biased Ferrite Tuned Cavity for the TRIUMF KAON Factory Booster Synchrotron”, In Proc. PAC 1991, San Francisco, USA, May 1991, pp.2943-2945.
[6] V.E.Shapiro and R.L.Poirier, “Magnetic Loss and Instabilities in Ferrite Garnet Tuned RF Cavities for Synchrotrons”, TRIUMF, design note TRI-DN-93-K224, 1993.
[7] D.Johnson et al, “Injection Design for Fermilab Project X”, Proceedings of HB2012, TUO1B02, Beijing, China, 2012