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PXIE MEBT
BUNCHING CAVITY

Fermilab Specification: ED0000038

Revision	Date	Description	Originated By	Approved By
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1. Scope of work

PXIE experiment is set to verify basic concepts of the Project X (PX) proton linac front end design. The main goal of this design is to ensure that emittance growth of high-intensity proton beam in the low energy section of the PX linac does not lead to an unacceptable increase of the beam loss in the high energy section of the linac. One of measures that can limit the increase of the emittance is making sure that the longitudinal size of proton bunches is kept within certain margins; bunching cavities are introduced in the MEBT section of PXIE to control this size. Three bunching cavities will be used in the MEBT section; four cavities will be built to have one spare assembly with the first cavity used as a prototype.

Functional requirements for the bunchers are stated in the document PX-doc1071-v2 (07/16/2012) [1]. Beside the 162.5 MHz cavity frequency and the 30 mm minimum bore diameter, which define main geometric features of the cavity, the next requirements of the FRS make the most significant impact on the cavity design:

- CW operation with ~1.5 kW power loss at the specified maximum accelerating voltage of 100 kV;
- $3 \cdot 10^{-8}$ torr vacuum at the nominal accelerating voltage of 70 kV;
- 100 kHz frequency tuning range.

Some features of the design, e.g. position and orientation of the power coupler, location of cooling loops on the cavity body, and the cavity support structure can only be finalized after the rest of the design features are defined.

The goal of this document is set the scope of corresponding design activity and to specify main features of the design that would ensure meeting the requirements established in the FRS.

2. General description of the assembled bunching cavity

The geometry of the bunching cavity is defined by the frequency, velocity of the charged particles in the transport section of MEBT ($\beta = 0.067$), maximum accelerating voltage (100 kV), minimum beam aperture (30 mm), and by the requirement to minimize the cavity flange-to-flange length. This geometry was developed in the process of several iterations of the RF and mechanical analysis, including analysis of several cooling options and the choice of the assembly and QC sequence. The geometry of the cavity can be modified if the changes promise better functionality or manufacturability. Each proposed change of the cavity shape must be discussed and approved before it is implemented.

Each bunching cavity, as assembled in beam line, integrates the next components:

- **RF structure**
- **Tuners**; current approach is to use existing tuners made for HINS. Assembly drawing number is 5520.000-ME-458618
- **Power coupler**; current approach is to use existing power coupler made for HINS. Assembly drawing number is 5520.000-MC-440850
- **Pick-up electrode**; current approach is to use existing pick-up electrodes made for HINS based on the double-ended SMA coaxial connector
- **Vacuum gages** mounted at the vacuum port and near the top of the the stem part of the cavity. The type of the vacuum transducers is to be specified by the MEBT design manager so that right flanges could be used on the cavity body

- **Provisions for cavity alignment and fiducialization** on the cavity body to facilitate accurate installation of the cavity in the beam line. The cavity support structure and the location of the fiducials will be agreed with the MEBT design team.

Schematic layout of the assembled cavity is shown in Fig. 1.

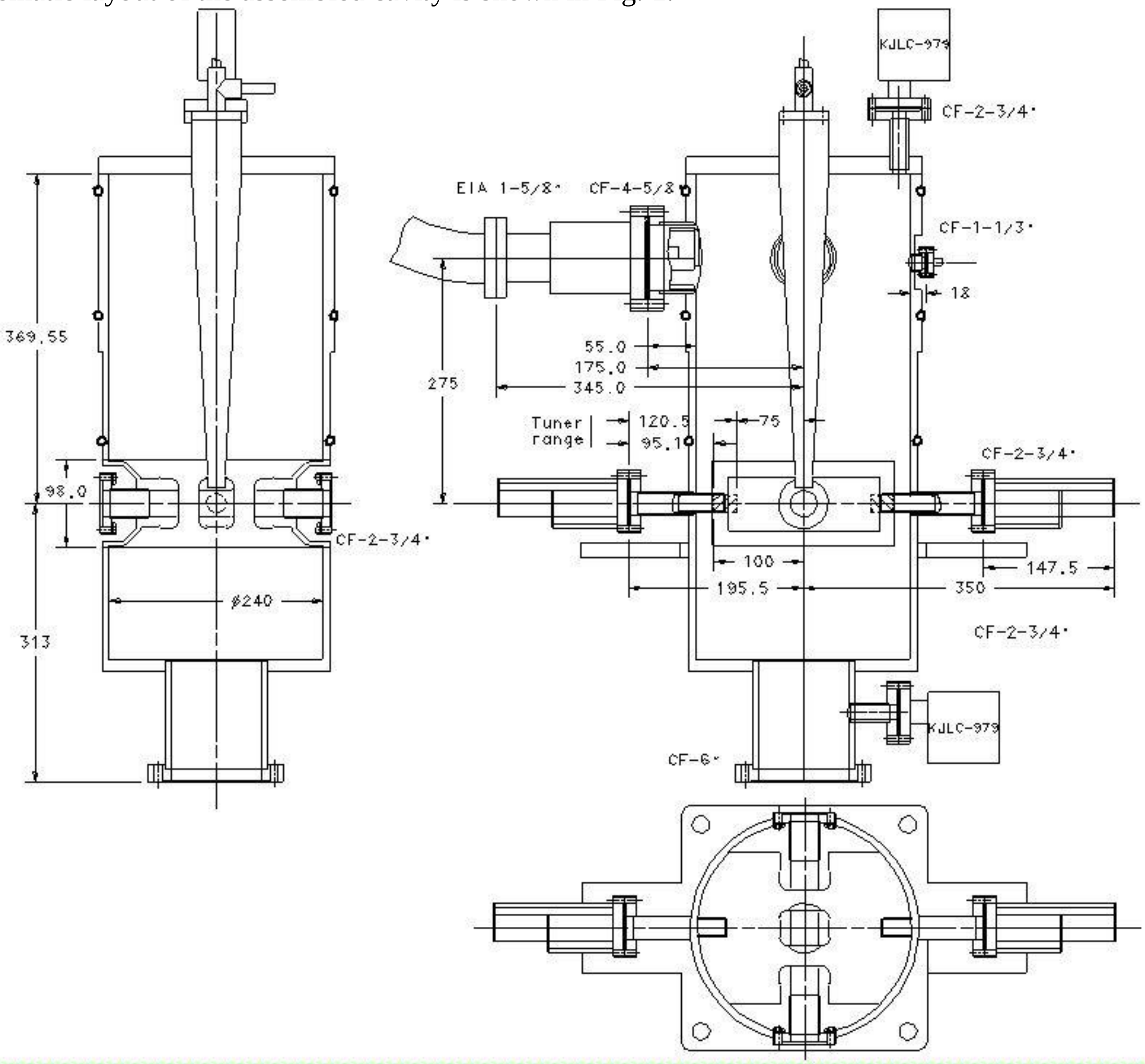

Fig. 1. Schematic layout of the assembled cavity

Main subject of this design effort is the **RF structure**, although the mentioned support structure and the cavity alignment fiducials must be considered as integrated part of the cavity body. Fig. 2 shows schematic of the RF structure with proposed naming agreement.

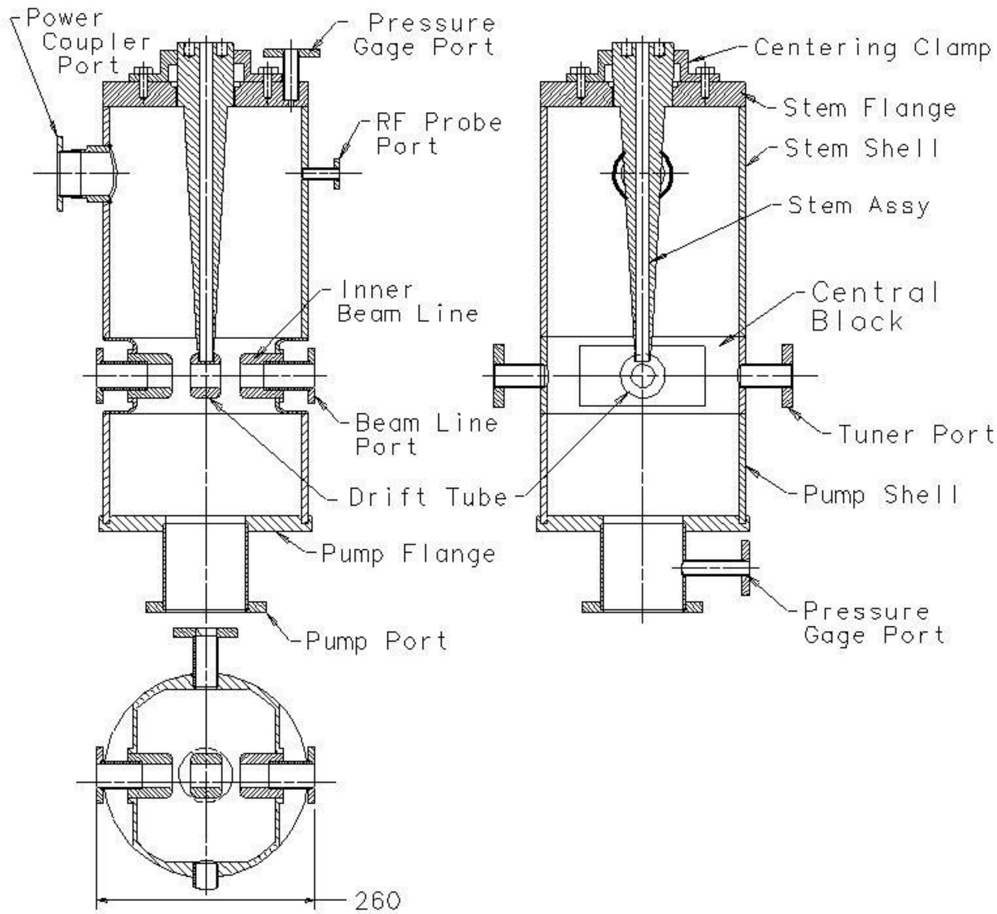

Fig. 2. Buncher cavity: component naming agreement

The RF structure of the Buncher cavity consists of the next parts and sub-assemblies:

- **Central Block** with two **Beam Line ports** and two **Tuner ports**.
- **Stem Assembly** with the **Drift Tube** brazed in and the **Cooling Insert** assembly (not shown in Fig. 2) installed and hydraulically sealed at the Stem Assembly top surface.
- **Stem Shell** with ports for the **Power Coupler** and the **RF Probe.**
- **Stem Flange** with a **Centering Clamp** for the **Stem** alignment during brazing and with a **Pressure Gage Port.**
- **Pump Shell** with a **Pump Port** and a **Pressure Gage Port**

These parts and subassemblies are joined together by welding and/or furnace brazing.

It is assumed that precision of RF modeling and accuracy of fabrication can ensure that the cavity frequency falls within the range that can be handled by the tuners used as a part of the cavity final assembly. Main geometric parameters of the Buncher cavity, which define the cavity's RF properties and satisfy requirements related to using the cavity as a part of a PXIE beam transport section, and are shown in Fig. 3.

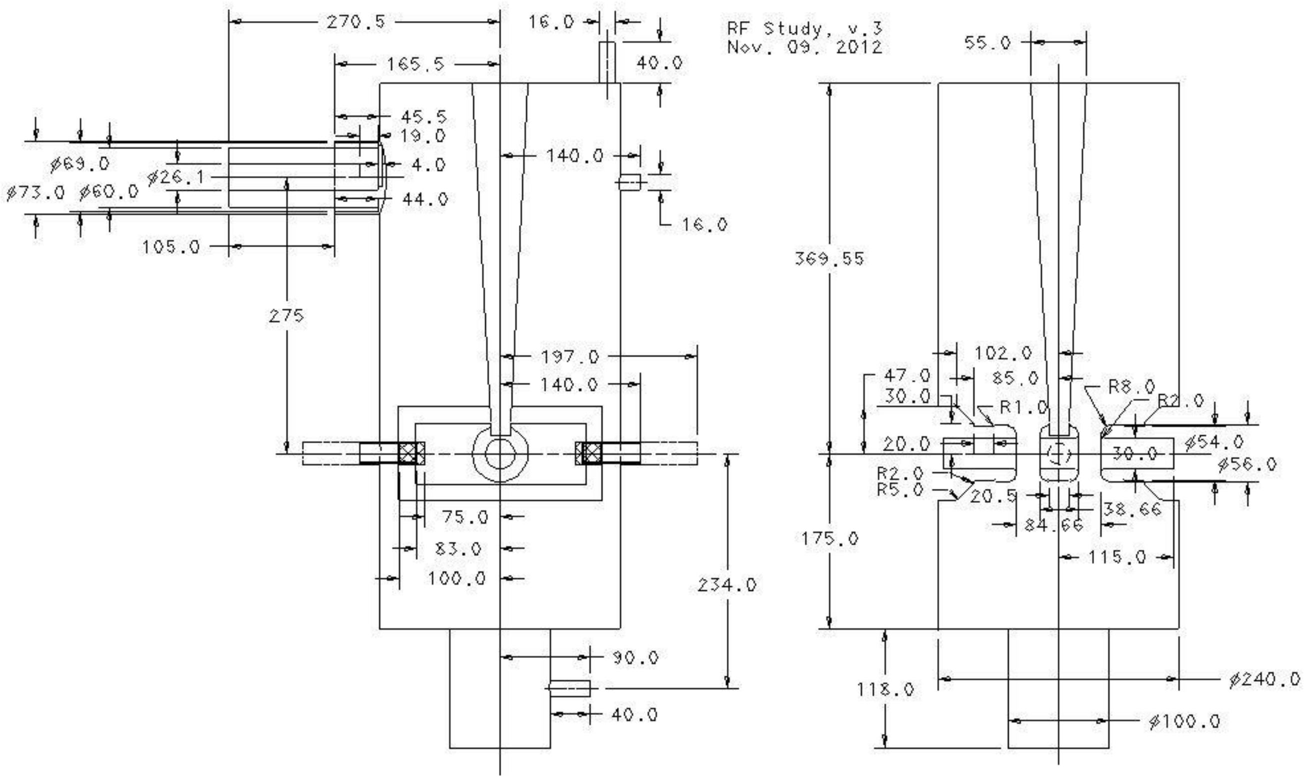

Fig. 3. Buncher cavity geometry suggested for implementation.

The features of the central block design in figures 1 to 3 are result of an attempt to reduce the flange-to flange length of the cavity without changing configuration of the drift space, which mainly defines electrical and optical properties of the cavity. Each accelerating gap is 23 mm long, and the distance between the median planes in each gap is 61.66 mm. This fully defines the length of the drift tube: 38.66 mm.

Possible approach to the design of the cavity, as well as recommended assembly procedure, is described in details in [2].

The cavity is made using Oxygen-Free High-Conductivity Electrolitic Copper (Cu-OFE): C10100. Fabrication process can include forging; the parts must be annealed before the final machining. Surface roughness must not exceed 3.2 µm on the inner surfaces of the cavity. The surface of the stem, as well as the drift tube and the inner beam line elements must be machined with a 1.6 µm maximum roughness.

Sharp corners must be treated with scraping tools; using abrasives or processes that may leave inclusions on inside surfaces must be avoided. For this reason, extreme care should be used during fabrication of these surfaces since any scratch, pit, bevel or groove may not be polished away with traditional techniques.

Figures below show artistic views of the buncher, the tuner, the power coupler, and the feedthrough for the pickup electrode.

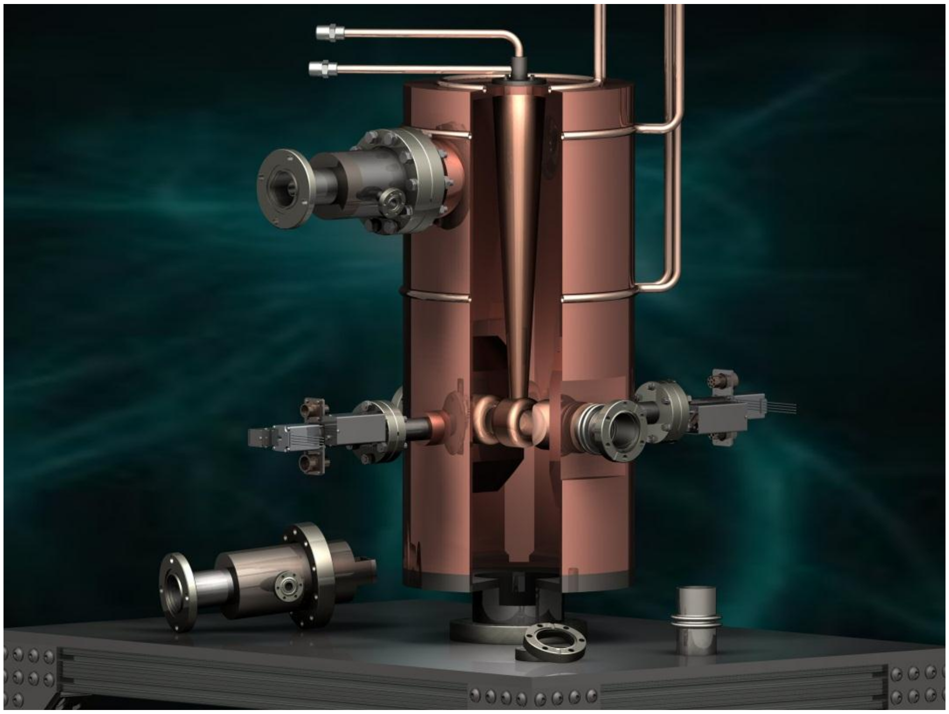

Fig. 4. Assembled buncher cavity.

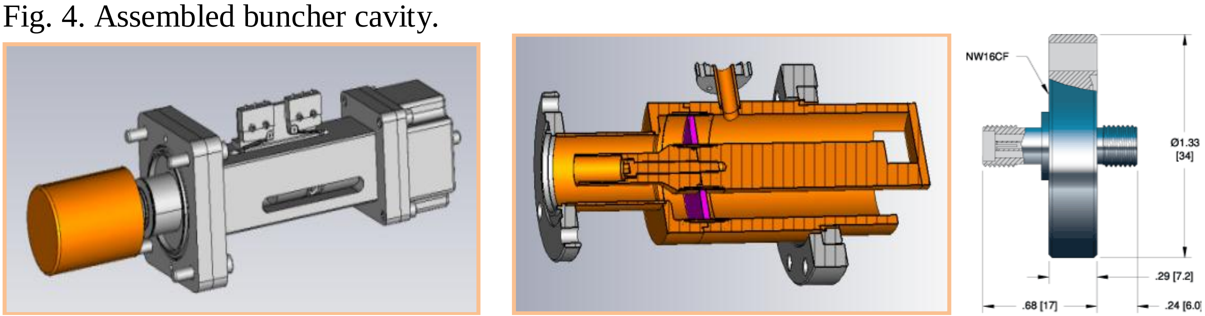

Fig. 5. Tuner (a), power coupler (b) and RF probe port (c).

3. Provisions for Water Cooling

As the surface of the stem and of the stem shell of the cavity carry significant RF current, water cooling must be used to keep the temperature of the cavity at the specified level (35° C, in accordance with [1]). The outer shell will be cooled using several loops of copper pipe brazed in special nest grooves made in the body of the stem shell of the cavity. Position of the loops will be determined at the design stage. This water cooling circuit must be independent of the central stem cooling circuit in this case.

Cooling of the central stem is made by using a coaxial counter-flow scheme. This scheme is realized by making a bore in the Stem and inserting a centered water supply pipe in this bore. The insert must be made with the option of easy removal for cleaning if clogged. Fig. 6 shows schematic of this design approach.

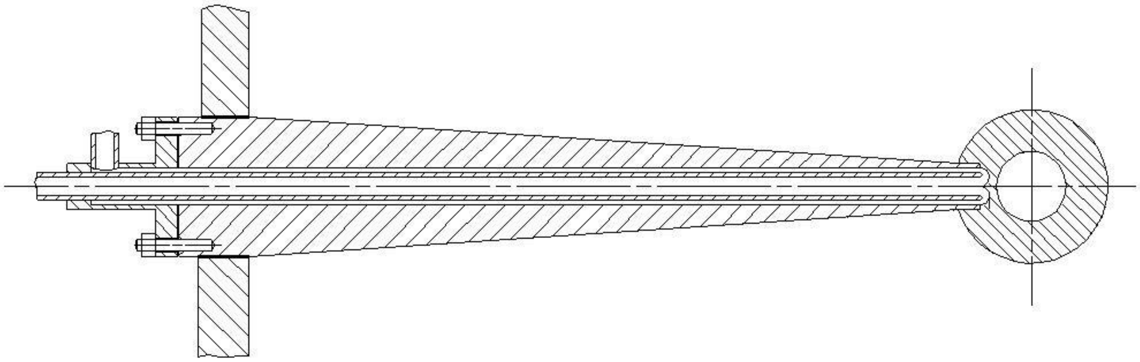

Fig. 6. Central stem cooling approach

Hydraulic and thermal properties of this assembly were calculated and the results agreed well with measurements made on a mockup of the device [3].

4. Connection flanges

Because the requirement for the working pressure is to have it below $3\cdot10^{-8}$ torr with the beam in the beam line and with nominal accelerating voltage, an option of in-situ baking must be included in the technical requirements for the design. The baking temperature of ~120 °C is postulated to ensure proper degassing of copper surfaces of the cavity; this leads to the requirement of having copper gaskets at the points of connection of the cavity to the beam line and where auxiliary equipment is attached to the cavity. Con-Flat (CF, or equivalent) flanges made of stainless steel (304) will be used.

5. Fabrication and Assembly Procedure

The cavities will be fabricated by combining machining, brazing, and welding with intermediate QC step performed at Fermilab or at a vendor's site. An example of the cavity assembly procedure is described in [2]; different approaches can also be considered that suggest better manufacturability or quality of the final product.

Tolerances for machining and assembly of all parts in the RF structure will be set to ±0.1 mm, with some critical components tolerances of ±0.025 mm.

For brazing the parts of the assembly that constitute the RF structure, only high quality gold and silver based alloy can be used. Welding of stainless steel flanges must be made after the final brazing operation made on the RF structure.

After parts of the cavity body and the central stem are fabricated, preliminary tuning operation can take place as a part of the QC procedure. The goal of this stage is to ensure that after brazing the parts are in the right relative position and the expected frequency after brazing is within acceptable range. If found necessary, specific assembly fixtures must be designed (and fabricated) to assist during brazing and tuning.

Water cooling circuit for the cavity body will be brazed using low-temperature (tin-based) alloys after the final brazing of the RF structure is made and corresponding QC step finds results of this operation satisfactory. All primary water inlet and outlet connections shall be the Male American National Standard Pipe Tapered Thread (also known as MNPT) as defined by the ANSI/ASME B1.20.1 Standard for Pipe Threads.

6. Baking

As the in-situ baking provision dictates using only CF-type flanges, it also requires making sure all the sub-assemblies can tolerate the backing temperature. Linear motors in the tuners are rated to work at 120 °C. If a higher baking temperature is needed, the motors must be removed or protected by other means. All water cooling circuit must be disconnected and water removed from the cooling channels. This requires using connectors that can be relatively easy disconnected. Baking temperature is also limited by a softening temperature of brazing alloys used for brazing movable RF contact on the tuners' plunger (40Sn60Pb alloy was used to assemble the plunger in MB-458624; T_{soft} = 183°C). Brazing alloy to assembly a cooling circuit on the stem shell must have similar or higher softening temperature.

7. Lifting and transportation

The assembled cavity must be equipped with a provision for safe lifting and transportation. This includes using eye-bolts attached to the top (stem) flange and a transport fixture that prevents the drift tube from displacement due to vibration during transportation.

8. Fiducialization

The RF structure of the cavity must be equipped with alignment fiducials that must be references to the axis of the beam channel. The type and location of the fiducials must be agreed with the alignment group and with technical personnel responsible for the cavity installation in the MEBT beam line.

9. Dimensioning and tolerancing

All attempts must be made to use standard nomenclature of material used to build the cavity. To simplify quality control, where it seems possible, theoretical dimensions (shown in the drawings in millimeters) must be rounded to a nearest value conforming to the XXX.X0 pattern.

The goal of the tolerancing process is to ensure that after fabrication the cavity can be tuned to the nominal frequency using only HINS tuners. Sensitivities of the cavity frequency to different modes of the cavity geometry distortion can be found in [2] or requested from the RF design team if additional information is needed.

A deviation from any nominal dimension will be counted as acceptable if it does not result in a necessity to move **one of the tuners** to change the frequency by more than ~50 kHz. Based on this criterion and taking into account the sensitivity data, for the length of the Stem, an acceptable dimensional tolerance is ±0.15 mm, which results in the requirement for the accuracy of the height of the Central Block and the Stem Cylinder of ±0.1 mm.

The inner diameter of the cylinders in the cavity body can also be machined with the ±0.1 mm accuracy.

10. Q/C at the design stage

As the cavity's frequency is very sensitive to any changes of its shape, a QC process will include design activity. This means generation of independent RF model using reverse engineering approach and verification of main RF and mechanical properties of the cavity by modeling.

11. Q/C and Acceptance Procedure during fabrication

Due to high sensitivity of the cavity frequency to relative position of elements inside the cavity in the beam line area, measures must be taken at the design stage to simplify reaching the desired accuracy by using special fixtures and measurement devices.

Cavity design must establish steps where cavity quality is inspected during fabrication. The scope of the inspection must include meaningful control of dimensions (including relative position of parts in the cavity), surface finish, brazing quality, leak test when appropriate, and, if found necessary, measurement of the cavity frequency and quality factor.

References

1. Bunching Cavity for PXIE MEBT. Functional Requirements Specification. PX document #1071-v1. FNAL, July 16, 2012

2. M. Chen, J. Coghill, I. Gonin, T. Khabibuolline, G. Romanov, I. Terechkine, “PXIE MEBT Bunching Cavity: Design Proposal”, FNAL TD note TD-12-019, Dec. 2012.

3. I. Terechkine, T. Wokas, “Testing Central Stem Cooling Concept of the PXIE MEBT Bunching Cavity”, FNAL TD note TD-12-015, Oct. 2012.