PROTOTYPE REFINEMENT OF THE VELA TRANSVERSE DEFLECTING CAVITY DESIGN

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Abstract

The Versatile Electron Linear Accelerator (VELA) at Daresbury Laboratory will deliver low energy (5/6 MeV) short bunches (~40 fs) to a number of industrial experimental stations and for scientific research. In order to measure the longitudinal profile of the bunch an S-band transverse deflecting cavity will be inserted into the beamline to deflect the bunch onto a YAG screen. A transverse kick of around 5 MV is required therefore a 9 cell design has been chosen. As part of the design iteration a three-cell prototype has been built. Frequency measurements have been performed on the prototype cavity as well as using a Coordinate Measuring Machine to confirm that the dimensions are to the required design tolerances. Subsequently, further modelling has been performed to improve and refine the design of the 9-cell cavity, to ensure that the frequency of the final design is within the tuning range of the water thermal control system and that the field flatness requirement can be obtained.

INTRODUCTION

The Versatile Electron Linear Accelerator (VELA) at Daresbury [1] is a source of low energy (5/6 MeV), short (down to 40 fs RMS), low emittance bunches. In order to accurately measure the longitudinal bunch profile, a transverse deflecting cavity will be utilised to streak the bunch onto a YAG screen converting longitudinal position into transverse offset at the screen hence allowing bunch profile measurement [2].

Table 1: Parameter List for the VELA Transverse Deflecting Cavity Design

Operating Frequency	2.9985	GHz
Bunch energy	5-6	MeV
Time resolution	10	fs
Phase stability required	0.1	deg
Operating mode	TM110-like	
Nearest mode separation	>5	MHz
Available RF power	5*	MW
Pulse length	3	µs
Repetition rate	10	Hz
Average RF power loss	<150	W

* 6MW klystron power, assume 5MW due to losses in transmission line.

The deflecting cavity has been designed around the requirement to use an existing 2998.5 MHz, 6 MW klystron as the RF source and its length is limited to 720 mm due to space requirements of the VELA facility. The system is designed to have a 10 fs resolution of a 6.0 MeV beam at emittances of up to 1 mm mrad requiring a deflecting voltage of 5.0 MV, hence the requirement for a high shunt impedance design. Additionally, the competing constraint of short time from conception to delivery of the cavity has required conventional technology to be used. Taking these requirements into account, a standard standing wave cavity configuration has been chosen, similar to cavities developed at Tsinghau University [2] and SPARC [3].

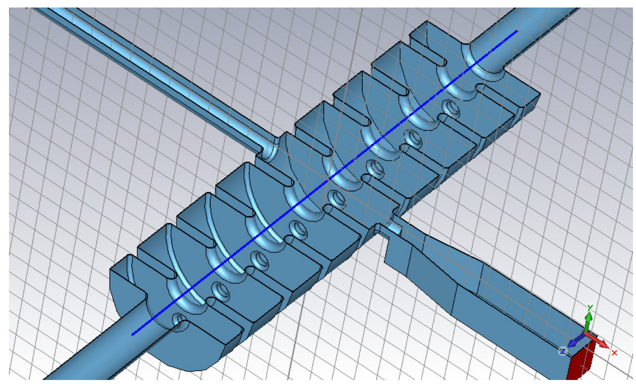

Figure 1: View of the final cavity design, showing the input coupler and dummy waveguide.

As reported in [4], a nine-cell TM110-like mode cavity was designed. A central coupler prevents the excitation of the even-numbered modes of the dipole pass-band, therefore the nearest excitable mode is the 7p/9 mode, 6.5 MHz away from the p-mode. A dummy port is used for cavity evacuation as well as balancing out the field to ensure its symmetry is maintained.
A three cell prototype of the cavity was built in order to verify the design.

3-CELL PROTOTYPE MEASUREMENTS

Braze quality

A visual inspection of the braze joints using a mirror (and subsequently when the cavity was cut open) showed no apparent flaw. As the prototype cavity was not specified to be vacuum tight the integrity could not be verified.

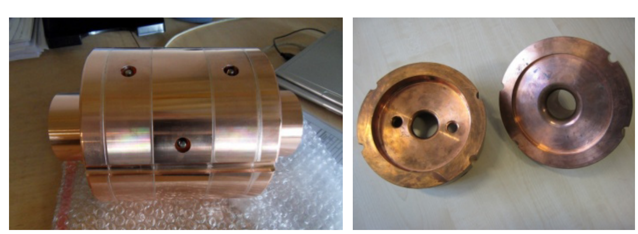

Figure 2: Prototype 3-cell cavity and sections.

Tuning range

The prototype cavity was designed with tuning pegs of the same design as those proposed for the final cavity. A verification of the tuning range was carried out with a particular attention taken to verify the braze fillet was not so great as to hinder tuning. The initial achievable tuning range was in the order of 200 kHz. One concern that was noted was that the copper work hardens very quickly and it was difficult if not impossible to pull the tuning pin back to its original position. The final achievable tuning range was 77 kHz after work-hardening. Additionally during the tuning process, it was found that pulling hard on the tuning pins caused the braze on a number of pins to fail. Thus, it is planned on the final cavity to only tap the pins in, and adjust the overall frequency using water temperature changes.

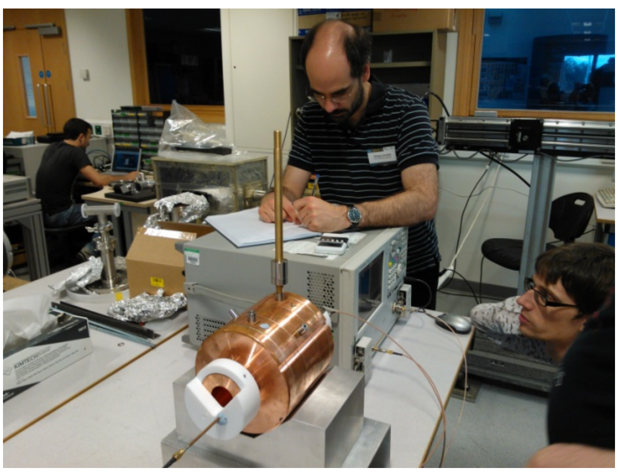

Figure 3: Prototype cavity tuning range evaluation.

Cavity frequency measurements

The cavity frequency was found to be slightly below what was expected from the cavity design (as built, based on the drawings provided). Multiple measurements were taken using different network analysers, by different operators and indeed independently by the manufacturer, Research Instruments [5]. All of those measurements, when scaled to account for the change in permittivity from air to vacuum and dimensions from temperature, came to 2.9845 GHz, which was a difference of ~2.6MHz in cavity frequency with respect to the simulated frequencies (2.9871 GHz). This was of concern due to the fact that the estimated available tuning range is approximately ±1.5 MHz (limited by the practical water cooling temperatures).

Cavity dimension measurements

One possible explanation for the discrepancy in the frequency was that the cavity dimensions might not match the drawings – to verify this, the cavity was cut open and extensively measured on a Coordinate Measuring Machine (CMM). All measured dimensions were found to be within the 20 μm tolerance. The frequency deviation could therefore not be explained by dimensional errors.

MODELLING INVESTIGATIONS

The cavity was initially designed primarily using the eigenmode solver from CST 2012 [6]. The default FPBA hexahedral mesh was used and a mesh convergence study was performed. The model was checked using the frequency domain solver, but also using a hexahedral mesh.

Since the CMM measurements of the cavity, and the frequency measurements carried out using different network analysers, by different people and at different places all showed a frequency error, an extensive study of the modelling was carried out. The prototype cavity was modelled exactly as built, and studies were also performed on a simple pillbox cavity for which there exists an analytical solution. Results from CST and COMSOL [7] were compared to the measured data as well as to the analytical pillbox solution.

It was found that the hexahedral mesh did not allow us to solve to the required frequency accuracy, irrespective of the mesh density used. The results tended to converge to several MHz higher than the actual frequency (Figure 4). A tetrahedral (hence finite element) mesh with a curvature of second order or better in CST Microwave Studio or COMSOL did however match the measured frequency, as well as matching the frequency from the analytically solved pillbox. The error in frequency was therefore due to the modelling options used and highlighted that finite-element solvers should be used in multi-cell cavities when an accurate frequency is required.

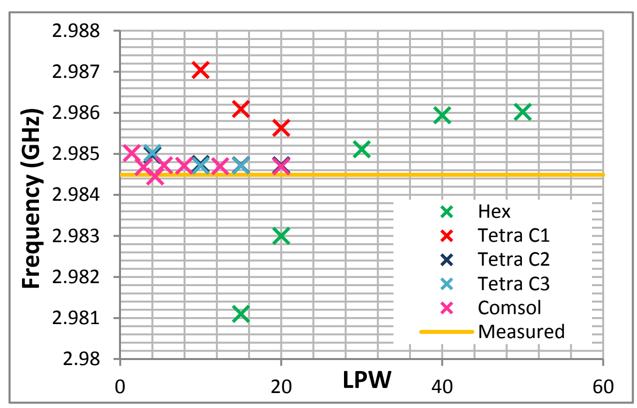

Figure 4: Frequency comparison between hexahedral and tetrahedral meshes, at different orders of curvature.

CAVITY RE-OPTIMISATION

Cavity tuning

The cavity will be tuned using small tuning pins placed on each cell in order to achieve field flatness. The tuning range of these pins is however not sufficient to allow for the overall frequency tuning of the cavity. This will be achieved by controlling the cooling water temperature to ±0.1˚C. In order to give a good operational margin on the tuning, a default water temperature of 35 ˚C will be targeted. The frequency response of the cavity is 50.5 kHz/˚C.

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The drawings were scaled allowing for a 21 ˚C workshop temperature, meaning all significant dimensions (cavity radii, coupling hole positions, iris radii) were scaled by a factor of 0.99767 to keep the frequency as close to the target 2.9985 GHz as possible while at 35 ˚C.

Coupler retuning

The changes in frequency meant that the coupler design needed to be verified. However, changing the coupler also affected the field flatness of the cavity. Due to the inextricably linked affect the coupler had on the field flatness, the coupler was initially remodelled based on a two-cell solution that was then extended to the full nine-cells to reduce simulation time. The Q_e was set to be 17000 to match the calculated Q_0.

Field flatness retuning

The final operation that needed performing was to verify the flatness of the cavity fields. While the tuning pins will be available to adjust the cell frequencies, it is preferable to not need to use them at all.

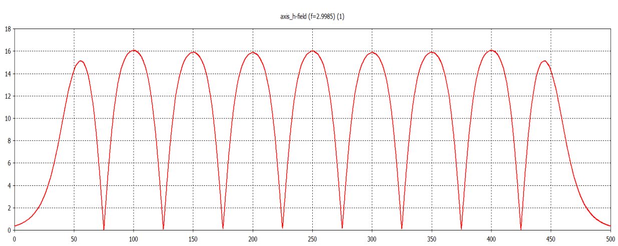

Figure 5: Simulated field flatness of the magnetic field in the final 9-cell cavity.

The dimensions required to achieve overall field flatness were calculated and are given in the table below.

Table 2: Final Optimised Cell Dimensions of the Transverse Deflecting Cavity (at 21˚C)

	Diameter	Unit
General cell	116.62	mm
Mid-cell	114.69	mm
End-cell	115.84	mm

The final cell dimensions having been calculated, the external Q was verified and the final design drawn up. A careful review process was undertaken to ensure that there were no errors in transcription between the CST dimensions and the CAD model. One verification method was modelling the cavity from the CAD model itself. Another was to perform a Boolean subtraction of the CAD model from the CST model to spot any differences. Both verification tests were passed and the drawings were sent for manufacture.

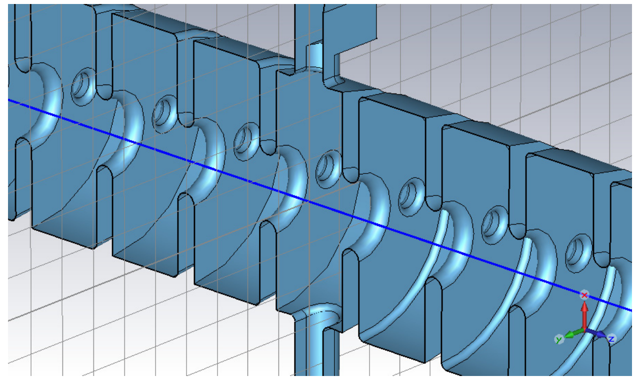

Figure 6: Cut-plane view of the cell-shapes and coupler design.

CONCLUSION

A 3-cell prototype cavity has been measured and issues were discovered when comparing these results to the modelled design. An extensive program of work was undertaken to identify the source of the errors. This was discovered to be due to issues with the simulation method used. An improved simulation procedure was defined and the 9-cell transverse deflecting cavity has been re-modelled and optimised to meet the specified design targets.

The final cavity is expected to be received from manufacture in the coming weeks. It will be cold-tested and flatness-tuned using a bead-pull system.

Installation of the cavity on VELA is planned during the August shut-down.

ACKNOWLEDGMENTS

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