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COMMISSIONING OF THE TRANSVERSE DEFLECTING CAVITY ON VELA AT DARESBURY LABORATORY

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Abstract

A 9-cell S-band transverse deflecting copper cavity (TDC) has been designed and built to provide a 5 MV transverse kick in order to perform longitudinal profile measurements of the electron bunch on the Versatile Electron Linear Accelerator (VELA) at Daresbury Laboratory. The cavity has been manufactured by industry and has been field flatness measured using a bead-pull system. The cavity has then been installed on to the VELA facility and commissioned for operation with the electron beam. This paper discusses the cold testing and the RF conditioning of the cavity.

INTRODUCTION

The Versatile Electron Linear Accelerator (VELA) [1] at Daresbury Laboratory is a facility which has been built for the investigation and development of novel and compact accelerator technology specifically aimed at medical, health, security, energy and industrial processing. For this purpose the facility consists of two separate user areas for scientific research.by industrial users. In addition VELA is to be used to study fundamental requirements for the next generation FEL as part of the development of the Compact Linear Accelerator for Research and Applications (CLARA) facility being built at Daresbury Laboratory [2].The VELA facility is designed to provide a 4 - 6 MeV electron beam with bunch charges between 10 - 250 pC, a short bunch length 0.1 – 3 ps) and low transverse emittance. The facility consists of an S-band photo-injector gun with a copper cathode which is driven by a Coherent Inc. UV laser providing a pseudo-Gaussian profile of 1 mm FWHM at the cathode. The beam is then transported to either of the user areas via a diagnostic line consisting of a transverse deflecting cavity (TDC), a wall current monitor, YAG screens, Faraday cup and slit/strip line beam position monitors (BPMs).

To accurately measure the longitudinal profile of the electron bunch an S-band 9-cell copper transverse deflecting cavity has been designed [3], built, characterised, installed (Fig.1) and commissioned. The cavity was manufactured by Research Instruments GmbH, Germany and was designed to provide a transverse kick of around 5 MV to the electron bunch which converts the longitudinal position into a transverse offset seen on a YAG screen enabling the bunch profile to be analysed [4]. The specifications of the TDC are shown in Table 1.

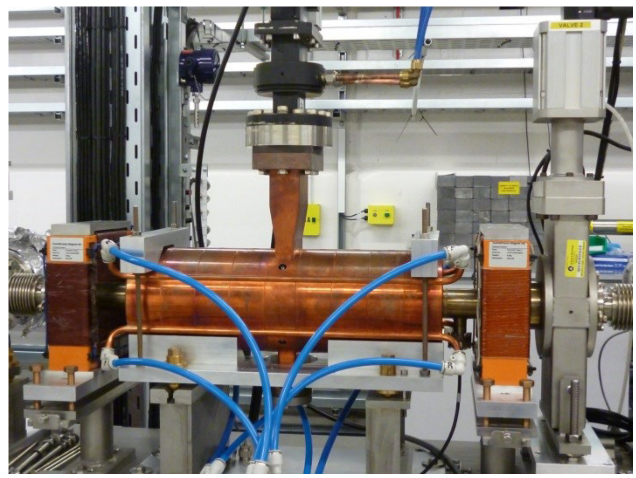

Figure 1: VELA Transverse Deflecting Cavity.

Table 1: VELA TDC Parameters

Parameter	Value	Units
Frequency	2998.5	MHz
Bunch energy	4-6	MeV
Time resolution	10	fs
Phase stability required	0.1	°
Operating mode	TM110-like	
Nearest mode separation	>5	MHz
Available RF power	5	MW
Pulse length	Up to 3	μs
Average RF power loss	<150	W
Input coupling	WR284	

CAVITY RF COLD TESTS

On delivery the frequency and field flatness of the cavity were measured. S-parameter measurements from the input coupler to the probe showed a room temperature operating mode frequency of 2999.1 MHz. This dictated an operating temperature of 55°C to achieve the required 2998.5 MHz. The water temperature will be reduced during RF operation to maintain the cavity frequency and to compensate for RF heating. An S21plot and the S11 Smith chart with the cavity at 55°C and under vacuum are shown in Figure 1. The bandwidth of the operating mode is 383 kHz and Q_0 is measured to be 13700.

The cavity has a vertical probe that couples to the operating mode, and a horizontal SOM coupler that couples to the orthogonal polarisation of the operating mode. The power in the cavity when in use is of the order

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of MW, so the probe was trimmed to give a coupling strength of -67.2 dB to give a reasonable power for the LLRF systems. This can also be seen in Figure 2. Measurement of the SOM coupler showed a coupling of less than -90 dB to the operating mode. It is otherwise much longer than the probe in order to couple strongly to transverse modes.

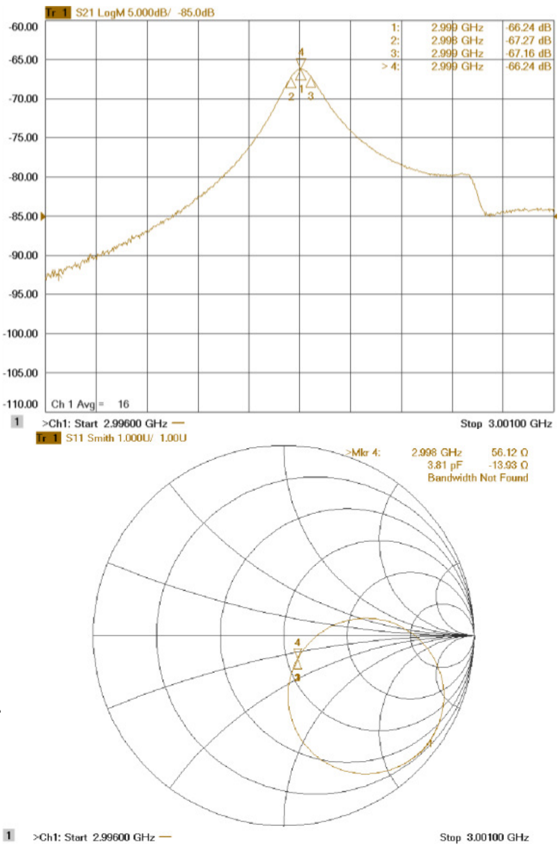

Figure 2: The S21 and S11 Smith chart for the cavity under vacuum and at operating temperature.

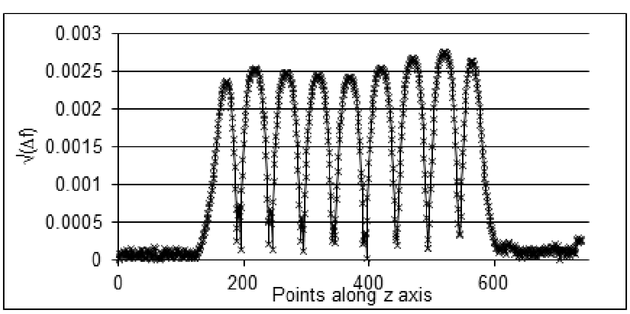

Figure 3: The square root of the frequency change in the cavity from a perturbing bead pulled along the z axis.

Bead-pull measurements were performed on the cavity as shown in Figure 3, and it can be seen from the measured axial H field that the field flatness of the cavity is 85%. If the cavity were limited by the peak field this would result in a 10% reduction in transverse voltage, however for VELA the cavity is limited by the klystron, so this field flatness is adequate.

THE RF SYSTEM

The RF power to the TDC is provided by a 6 MW TH2056 klystron operating at 2998.5 MHZ, and is driven by an in-house built high voltage pulse modulator in combination with a 15:1 oil-filled pulse transformer (Fig.4), which is located on the roof of the VELA facility. The modulator has a 10-stage pulse forming network (PFN) which is charged to a maximum of 21 kV by a Lambda 152 A capacitor charging power supply. The specified repetition rate is 10 Hz. The main switch is an e2V CX1154 thyratron which applies half the PFN voltage (up to 10.5 kV) to the pulse transformer primary with a primary current of 1800 A. Pulse length is approximately 3 µs. The secondary voltage and current is then 156 kV at 120 A as required by the klystron. The high voltage section of the modulator is interlocked with mechanical key switches to prevent entry unless the circuit is earthed. Control equipment plus power supplies for the klystron focus coils and cathode heater are located within the modulator.

The RF power is provided to the cavity via WR284 waveguide with forward and reverse power monitoring after the klystron and before the RF cavity window.

Figure 4: TDC klystron modulator.

TDC COMMISSIONING

Prior to the complete installation of the RF system the klystron modulator was separately commissioned with the klystron output fed into an RF water load via a circulator and powered to a peak RF power of 5 MW with an RF pulse width of 3 µs and at a pulse repetition rate of 10 Hz.

The cavity frequency of the π-mode was set to 2998.5 MHz by adjusting the water temperature of the cavity to 55 ºC, with the water temperature controller capable of maintaining the stability of the temperature to ±0.5 °C. Conditioning of the cavity then commenced with a baseline vacuum pressure of 4.9×10^{-9} mbar and with the RF pulse width set to 1 µs and a repetition rate of 1 Hz. The RF power was then gradually increased to the cavity, whilst monitoring the vacuum level. The pulse width was then gradually stepped up; 1.5, 2.0 and 2.5 µs, and each

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time the RF power was gradually ramped up. As part of the conditioning process the water cavity temperature was adjusted and optimised for minimum RF reflected power. The optimum cavity temperature remained at 55 °C. During the conditioning only a few vacuum spikes were noted so the repetition rate was then increased to the full required 10 Hz. Further conditioning was then performed achieving 3.8 MW into the cavity with a pulse width of 2.5 µs. The RF power appeared to be limited by larger than anticipated RF power losses in the waveguide. Over the conditioning period the cavity vacuum pressure improved to $1.2x10^{-9}$ mbar.

Following the conditioning of the TDC, a beam of approximately 200 pC with a small vertical size was steered on to the centre of a YAG screen without RF power to the TDC. The timing between the gun RF and the TDC RF was optimised and with RF power applied to the TDC, an immediate effect to the beam was observed. Keeping the RF amplitude constant the beam position moved vertically whilst the RF phase was adjusted by 20°, and with a constant RF phase the beam size was observed to increase vertically, whilst roughly remaining in the same position, as the RF amplitude set point was increased as shown in Fig. 5.

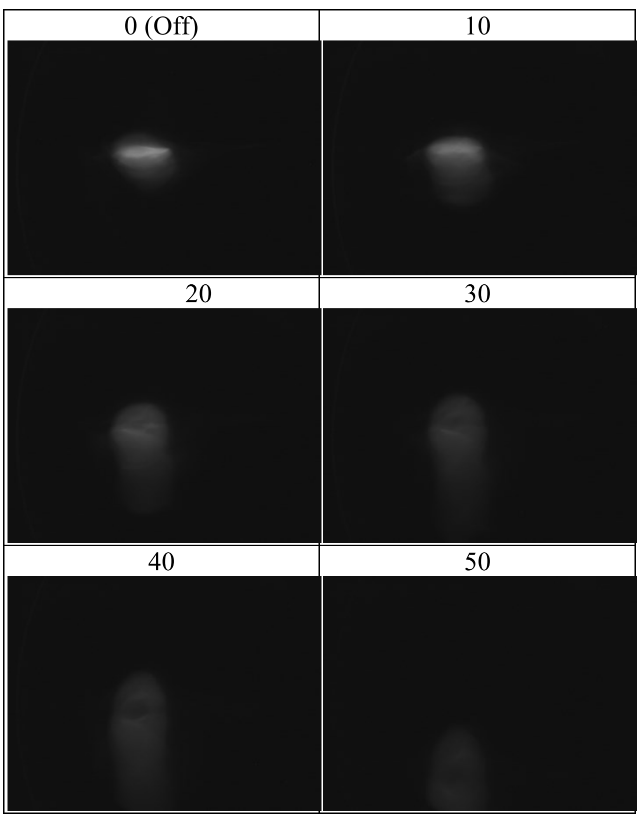

Figure 5: VELA beam with measured on a YAG screen after the TDC with a constant RF phase and increasing RF amplitude (Amplitude set point 0 – 50).

FUTURE PLANS

It is planned to perform further longitudinal profiling of the VELA electron bunch and to further characterise the TDC. Additionally it is planned to use the cavity to aid the characterisation of the electron beam from a high repetition rate gun [5] to be used on CLARA which is to be located next VELA. To improve the transverse voltage cavity tuning will be performed utilising an equivalent circuit model to interpret the bead-pull measurements. Cell frequency adjustment will be performed through the means of tuning studs.

SUMMARY

Cold test characterisation of the VELA TDC has been performed and the cavity has been successfully conditioned to 3.8 MW at a repetition rate of 10 Hz and with a pulse width of 2.5 µs with only a small number of vacuum events during the whole conditioning period.

An electron beam has been successfully transported through the TDC on VELA. Adjusting the RF phase on the TDC with constant RF amplitude moved the beam vertically as seen on a YAG screen after the TDC and increasing the RF gradient for a constant RF phase produced an increased vertical size of the electron bunch as anticipated.

Further longitudinal beam profiling of the electron bunch on VELA and characterisation of the TDC is to be performed.

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