ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPRO052

BEAM PHYSICS COMMISSIONING OF VELA AT DARESBURY LABORATORY

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Abstract

A user facility VELA (Versatile Electron Linear Accelerator) based on an RF photoinjector has been commissioned at Daresbury Laboratory in April 2013, providing beam to first users in September 2013. Machine study runs in 2013-2014 have concentrated on characterisation of main beam parameters like bunch charge, its momentum, beam emittance and dependence of these parameters on the launching RF phase. Major efforts have been also concentrated on investigation of the dark current from the gun and its dependence on the RF amplitude. Significant time has been dedicated to investigation of relative stability of LLRF and drive laser having significant impact on the overall machine stability. We present here the results of these studies.

VELA COMMISISONING

The goal of VELA commissioning is essentially dual. Firstly, to benchmark experimentally measured beam parameters and compare them with the design specifications and secondly, to characterise and refine the dedicated beam diagnostics suite [1] to be used as a test bench for a future RF gun for the CLARA project [2]. These two goals also enable to provide beam delivery effectively to VELA beam users. The parameters of interest for both academic and industrial beam users are the maximum achievable momentum (energy), minimum and maximum bunch charge (beam current) and associated parameters such as momentum spread, bunch length, beam emittance (brightness). The shot-to-shot and long term stability of the beam as well as minimisation of dark current from the gun is important for any user.

The general layout of the VELA diagnostic line is shown in Fig. 1. Starting from the gun, the beam line comprises a fast Wall Current Monitor (WCM), six diagnostic stations equipped with YAG screens and high resolution digital cameras for beam observation. Area of dedicated beam diagnostics suite includes a dispersive beam line to YAG-04 and a straight on beam line up to YAG-06. Stations at YAG-01 and YAG-02 have movable vertical and horizontal slits for emittance measurements. In addition the YAG-01 station is equipped with two collimators with diameters of 6.3 mm and 10 mm which can be inserted into the beam line during normal operation for suppression of the gun dark current. Longitudinal parameters of the beam are measured with dispersive section comprising a dipole magnet, large aperture diagnostic station at YAG-04 and two quadrupole magnets QUAD-05 and QUAD-06 for adjustment of the dispersion and focusing of the beam. Three high resolution beam position monitors (BPM) allow for precise measurements of the position of the deflected by the dipole magnet DIP-01 and non-deflected beams. In addition, the beam charge can be measured with a Faraday Cup (FC) installed at the end of the dispersive beam line. A place between YAG-02 and YAG-03 is reserved for installation of a Transverse Deflecting Cavity [3] in near future. Four quadrupole magnets installed just after YAG-01 allow effective beam transport as well as emittance measurements on downstream YAGs.

In this paper we describe methods of characterisation of some beam parameters and present current status of the beam commissioning and results.

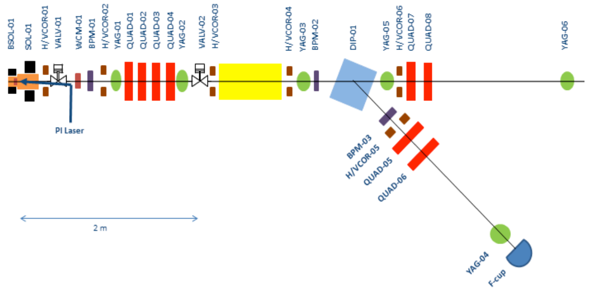

Figure 1: General layout of the VELA diagnostic line.

BEAM MOMENTUM CHARACTERISATION

For measurement of the beam momentum and its dependence on RF power and relative phase of the laser pulse arrival, the dispersion section shown in Fig. 1 was used. By varying the RF power and phase and by positioning the beam at the BPM-03 centre with the dipole current allows for measurements of the average beam momentum with a precision of less than 0.7%. The typical dependence of the momentum on the RF phase is shown in Fig. 2. At the RF power of 6.5 MW measured at the gun RF window the maximum measured momentum of 4.9 MeV/c is essentially lower than calculated with the RF and particle tracking and simulation codes 5.7 MeV/c. It can be explained by excessive power losses in the RF network which are being investigated. Additional information on measurement of maximum achievable momentum can be found in [4].

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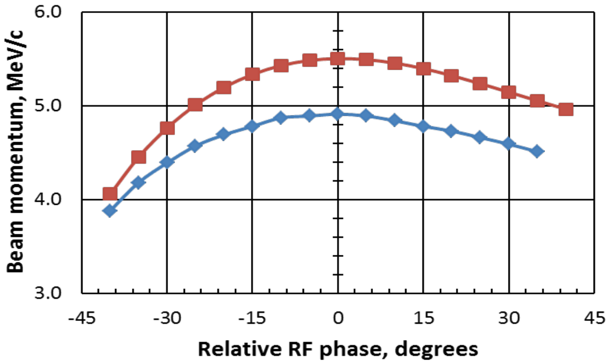

Figure 2: Dependence of the beam momentum on relative RF phase at an RF power of 6.5 MW simulated (red) and experimental.

BUNCH CHARGE MEASUREMENTS

The charge of the electron bunches delivered by the photocathode gun is measured with the WCM installed right after the gun. Fig. 3 shows dependence of the bunch charge, as measured with WCM, on RF phase. The results of beam commissioning clearly indicate that the charge delivered by the photocathode gun meets the machine specification of 250 pC (see [4] for details). During beam commissioning a temporary was installed in Beam Area I. There is one Integrated Current Transformer in halfway through the beam line.

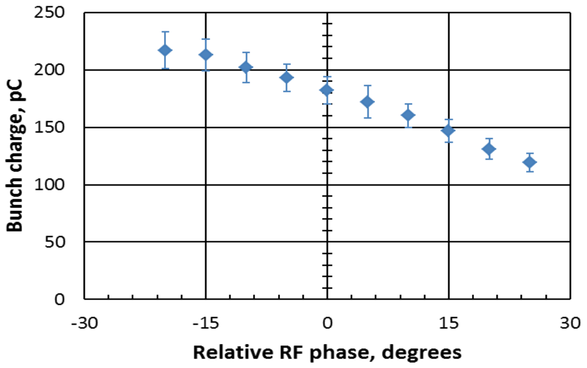

Figure 3: Typical dependence of the bunch charge on the relative launching phase.

DARK CURRENT MEASUREMENTS

Dark current, generated in the gun during a 3 µs RF pulse arises due to the field emission from the photocathode and irises and has significant negative impact on the overall accelerator performance. Since dark current transport through the beam line differs compared to the main beam due to its different energy, it can interfere with precise measurements of the beam and cause unnecessary radiation levels in the accelerator hall.

In S-band guns the phase range, where dark current generated, significantly differs from the crest phase where the main beam is launched. As a result, the majority of the dark current has lower energy than that of main beam pulse. Proper selection of the field in the gun focusing solenoid allows the dark current to reach WCM and be measured with good precision. It has appeared as well that field of the bucking coil, compensating the field of the main solenoid in the photocathode plane significantly influences the dark current propagation. In Fig. 4 the dependence of the dark charge, obtained by integration of the dark current over RF pulse, is shown as a function of main solenoid current at different currents in the bucking coil. As may be seen at a current gun field of 65 MV/m integrated dark charge is quite high and can reach 1.2 nC so special precaution should be taken to prevent its propagation down the beam line.

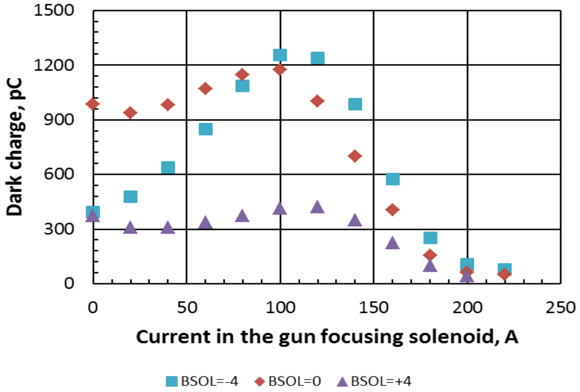

Figure 4: Dark current integrated over 3 µs RF pulse as measured with WCM as a function of the focusing solenoid current at different currents of bucking coil.

During normal operation, focusing solenoid is set to higher value to allow the main beam to propagate into the beam line. At that strong focusing the dark current is defocused in the plane of YAG-01. The YAG-01 collimator stops majority of the dark current whilst the majority of the beam is transported without losses.

PRELIMINARY RESULTS OF BEAM EMITTANCE CHARACTERISATION

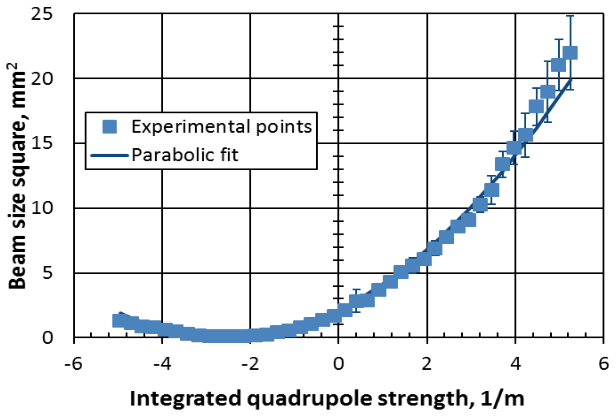

Figure 5: Dependence of the beam size square on the integrated QUAD-03 strength.

Projected and slice normalised transverse emittances are some of the key beam parameters dictating design of the facility for investigation of novel FEL and acceleration methods. The preliminary emittance measurements have been carried out by scan of quadrupole magnet QUAD-03 in the range from 0 to 1 T/m and monitoring the beam images on YAG-02. At every quadrupole settings 10 images have been taken. A subsequent analysis of the beam image has been performed by 2-D Gaussian approximation of beam intensity distribution characterising horizontal and vertical beam sizes. The results of parabolic fit are presented in Fig. 5. Calculated from the fit vertical emittance is 2.2 mm·mrad that is significantly higher than 1.3 mm·mrad obtained with beam dynamics simulation. It may be explained by the influence of space charge at low beam momentum and jitter of the injector.

SYNCHRONISATION AND STABILITY

Investigations have begun into the factors limiting the phase stability of the VELA accelerator. Recent experiments have demonstrated that the long-term stability is currently limited by the phase-lock between the 2.998 GHz oscillator reference delivered to the gun RF system and the output of the amplified Ti:Sapphire photoinjector laser (Coherent Legend HE).

Drift measurements were performed on a shot-to-shot basis at 10 Hz, using a fast oscilloscope (LeCroy WaveMaster 806Zi-A; 40 GS/s, 16 GHz bandwidth) to simultaneously monitor the 2.998 GHz and laser amplifier output (fast photodiode pick-off, 300 ps rise time). The relative time delay is plotted in Fig. 6A. A near-linear temporal drift of 4.0±0.4 ps is recorded, corresponding to a 4.3±0.4 ps relative phase drift of the 2.998 GHz. Taking into account the calculated resolution of the measurement (2.0 ps), the rms jitter is found to be 1.3 ps.

To monitor the phase stability of the accelerator during standard operation, the cresting phase of the gun RF was monitored at regular intervals over a 4 hour period; these results are shown in Fig. 6B. The linear phase drift of 4.3±0.5 ps recorded is in direct correspondence with the phase drift of the 2.998 GHz reference and laser amplifier.

Long term measurements of beam position on BPM-02 and BPM-03 also show a correlation between gun cooling water temperature and the related RF phase change. Better temperature control and read back of the thermocouples will be available in future to be included in the stability investigations.

CONCLUSION

The results of the last commissioning period have shown that beam momentum of up to 4.9 MeV/c, measured with the magnet spectrometers, is lower than the value of 5.7 MeV/c predicted by RF model of the gun and beam dynamics simulation at a measured RF power of 6.5 MW. It may be explained by excessive power loss in the RF network. The designed bunch charge of 250 pC is achievable though depends on the RF phase in a predictable way, as explained by the Schottky effect. Dark charge, generated within 3 μs RF pulse is as high as 1.2 nC, but may be reduced significantly with selected collimation scheme. Beam emittance, measured with quadrupole scan is at a level of 2.2 mm·mrad and is higher than predicted by theoretical model 1.3 mm·mrad. During commissioning significant drift of the relative RF phase in the gun has been observed. Detailed investigation has shown that similar drift is observed between 2.998 GHz master oscillator and the laser pulse. Further investigation is required to discover the origin of these drifts.

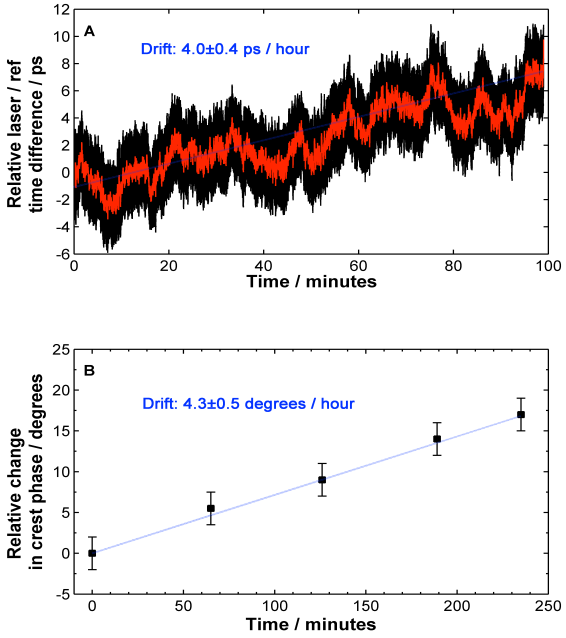

Figure 6: A) Drift measurement comparing the relative time delay between the 2.998 GHz RF reference and fast-photodiode output of the amplified Ti:Sapphire photoinjector laser. The 1 s average (red) and corresponding ±1σ level (black) are presented. B) Drift measurement of the VELA gun cresting phase.

ACKNOWLEDGEMENTS

The authors would like to acknowledge help from VELA team during beam commissioning and characterisation runs.

REFERENCES

[1] B.L. Militsyn et al., "Photoinjector of EBTF/CLARA facility at Daresbury", Proc. of LINAC2012, Tel-Aviv, Israel, 2012
[2] J.A. Clarke et al., "CLARA conceptual design report", *JINST* **9** T05001, 2014
[3] J.W. McKenzie et al., "Design of the production and measurement of ultra-short electron bunches from an S-band RF photoinjector", Proc. of IPAC2012, New Orleans, USA, 2102
[4] P.A. McIntosh et al., "VELA: A New Accelerator Technology Development Platform for Industry", Proc. IPAC'14, Dresden, Germany, WEPME083.