IN-SITU MEASUREMENT OF BEAM-INDUCED FIELDS IN THE S-BAND ACCELERATING STRUCTURES OF THE DIAMOND LIGHT SOURCE LINAC

C. Christou
Diamond Light Source, Oxfordshire, UK

Abstract

Higher order modes induced by beam in the accelerating structures of the Diamond Light Source pre-injector linac have been directly measured using directional couplers in the high-power waveguide network. These modes are compared with an electromagnetic simulation of the structures and the use of the higher order modes for alignment of the beam to the structure is investigated.

DETECTION OF INDUCED FIELDS

Much work has been done on the analysis of wake fields using dedicated test accelerators, particularly at the ASSET facility in SLAC [1, 2] and the SBTF at DESY [3]. Extension of the method to a low-energy device in a user facility with minimal disturbance to the installed hardware offers scope for cost-effective physics studies and diagnostic development. In the work presented here, wake fields and structure higher order modes are studied in the Diamond Light Source pre-injector linac. This device uses two 5.2 m DESY linac II-type accelerating structures to generate a 100 MeV electron beam suitable for injection into the booster synchrotron [4]: the layout of the linac is shown in Figure 1. The structures are normal-conducting constant gradient designs, operating in the $2\pi/3$ mode at 3 GHz. Each structure is independently powered by a TH2100 klystron amplifier which provides a 5 µs pulse of around 20 MW five times per second in normal operation.

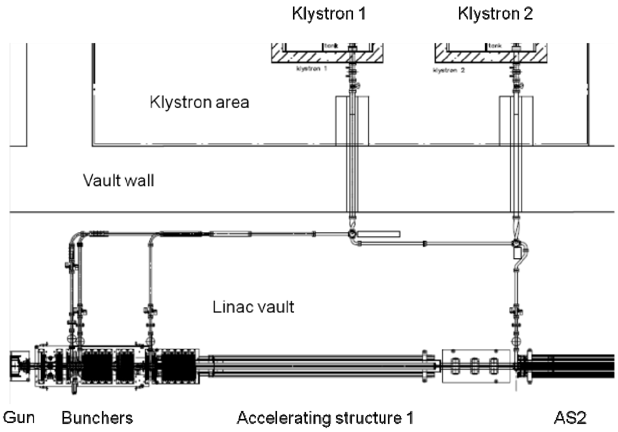

Figure 1: The Diamond linac

Directional couplers, manufactured by Spinner, are mounted in the waveguide network at the exits of the klystrons and at the windows of the accelerating structures. These couplers measure forward and reverse power and monitor operation and protect the klystrons. If either one of the klystrons is left unpowered, the beam can drift through the accelerating structure and the directional coupler can be used as a monitor of the beam-induced wake fields in the structure.

Signals were discernible on an Agilent DS091304A 13 GHz-bandwidth oscilloscope for beam drifting through bunchers and through both accelerating structures in single-bunch mode and in multibunch mode. The most intense signals were obtained for high charge (1 nC) single bunches drifting through the second accelerating structure at 47 MeV (corresponding to the standard operating gradient of the first accelerating structure) with good temporal bunching; Figure 2 shows an oscilloscope trace recorded for these parameters.

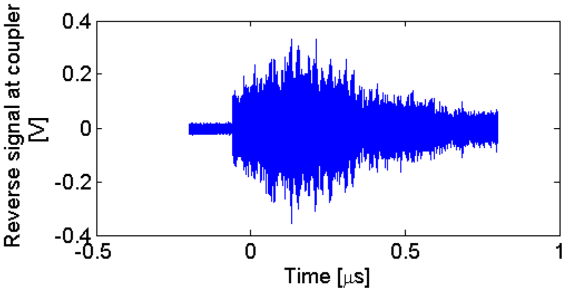

Figure 2: Passage of single bunch detected at the directional coupler in the non-powered RF line

There is rich spectral content to this induced signal, as can be seen in Figure 3. Two measurements are shown in this figure, recorded with and without beam in the structure, establishing that the most intense peaks in the spectrum are the third and fourth harmonics of the 3 GHz RF power fed to the first accelerating structure. The fundamental 3 GHz signal is not transmitted from structure to structure.

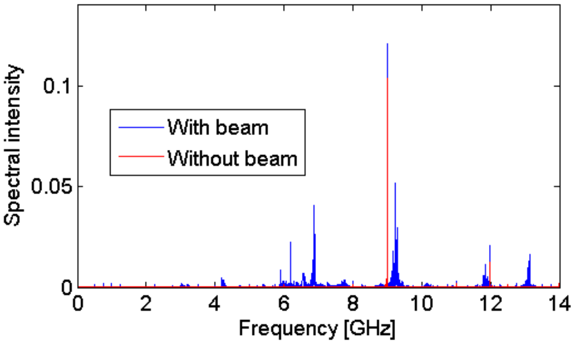

Figure 3: Frequency content of induced pulse

The wake can also be differentiated from the RF noise by making a small change to either the master oscillator frequency or the cavity temperature and observing that the RF signals shift only with frequency and the wake signals shift with only temperature, as shown in Figure 4.

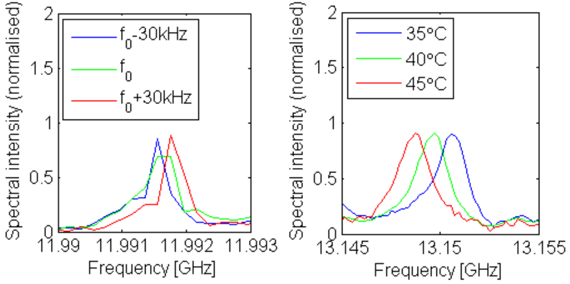

Figure 4: Effects of RF frequency and structure temperature change. The fourth harmonic of the RF frequency changes with frequency (left) and the wake-induced signal changes with cavity temperature (right).

STIMULATION OF HIGHER ORDER MODES

The trajectory of the beam in the accelerating structures can be controlled by steerer magnets located upstream of both structures. Scanning the current of the final vertical steerer before the second accelerating structure and recording the spectrum at each current gives the plot shown in Figure 5.

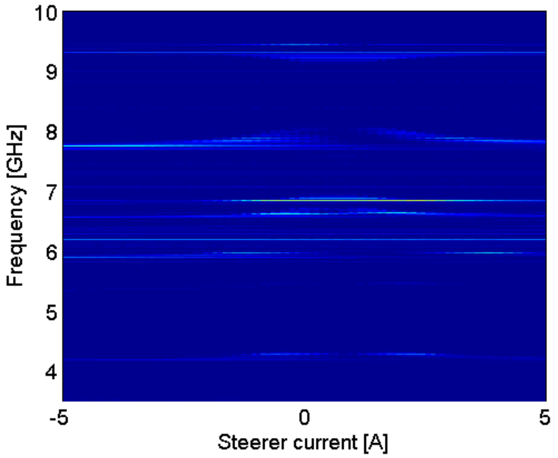

Figure 5: Frequency spectra explored by scanning steerer

Several points are immediately apparent from this plot, firstly that the frequency spectrum consists of bands rather than lines, and that these bands shift in frequency as the steer is applied. This effect arises from the constant-gradient design of the structure, requiring a tapering of cell dimensions along the structure to compensate for the loss in RF power as the pulse propagates along the structure: although the fundamental accelerating mode remains constant along the structure, the higher order modes are free to drift. Secondly, the monopole and multipole modes are easily distinguished, as the higher order azimuthal modes have a null on axis and so are absent from the spectrum when the beam is well aligned, with steerer current of approximately 1 A in this case, and grow as the beam leaves the axis.

The most intense modes are given in Table 1: this gives the lower and upper frequency limits of each band, and identifies each mode as a monopole or multipole mode.

Table 1: Classification of intense modes

Mode type	From [GHz]	To [GHz]
Multipole	4.19	4.35
Multipole	5.38	5.50
Multipole	5.90	5.98
Multipole	6.57	6.72
Monopole	6.78	6.92
Multipole	7.69	8.05
Monopole	9.13	9.32
Multipole	9.43	6.46
Monopole	11.78	11.98
Monopole	13.04	13.13

IDENTIFICATION OF MODES

Categorisation of all wake field modes is numerically intensive as the observed signal arises from a system of 156 coupled oscillating cells, each of different dimension, with TM, TE, TEM and hybrid modes all possible. To reduce the complexity of the calculation, CST Microwave Studio was used to model cells at the entrance, middle and exit of the linac; in each case studying resonant modes of the single cell, and coupling in structures of two, three and six cells of the same type. Dispersion curves in each case were then calculated by interpolating between the calculated modes for each cell type, and the behaviour of the cells was assumed to vary smoothly along the structure.

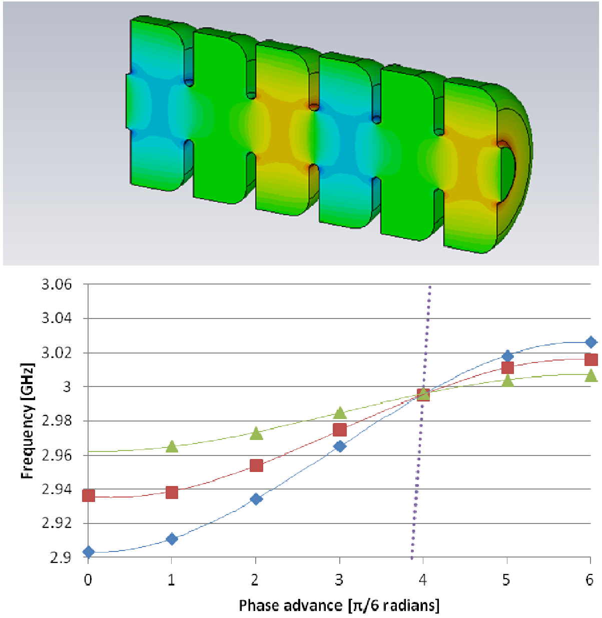

Figure 6: Simulation of accelerating mode

The validity of this approach is demonstrated in Figure 6, in which the TM01 accelerating mode is calculated for the three cells at the beginning (blue), middle (red) and

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end (green) of the structure, and is shown to intersect with the $v = c$ light line (dotted), representing the relativistic electron bunch, at a phase advance of 4π over the 6 cells of the model, that is $2\pi/3$ radians per cell, near 3 GHz.

The first intense mode observed is a TM11-like mode shown at the top of Figure 7. This is a dipole mode, and so the spectrum shows a null for well steered beam. The dispersion curve intersects the light line from 4.15 GHz to 4.42 GHz, with the modes up to 4.35 GHz exiting via the first cell, and modes above that trapped and invisible. Agreement with the observed spectrum is good.

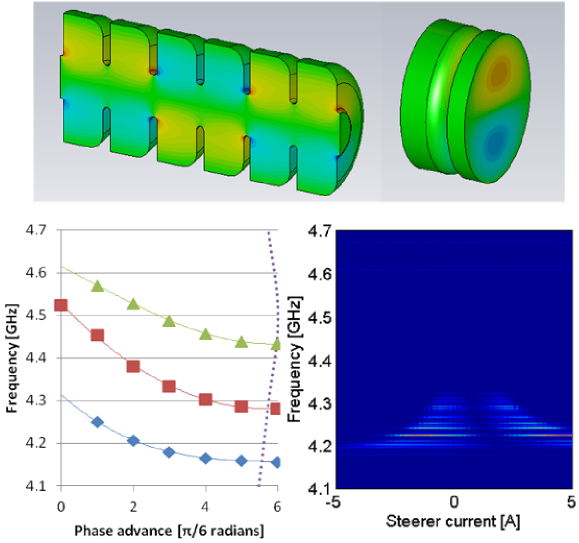

Figure 7: Simulation, dispersion curve and measurement of TM11-like mode

This approach was repeated for all modes up to the second monopole TM02 mode near 7 GHz. Results are shown in Figure 8; agreement with the model is good.

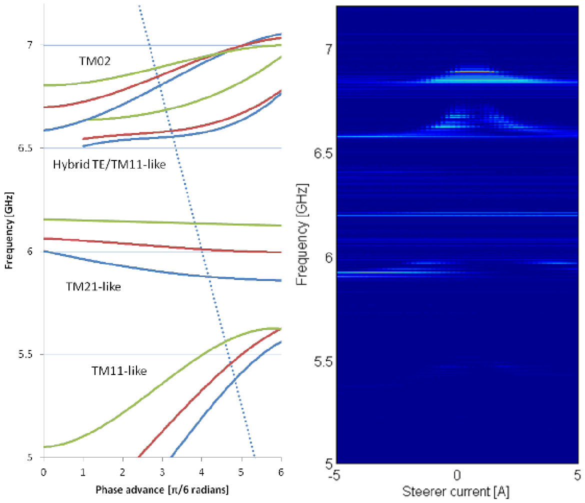

Figure 8: Scaling of dipole mode intensity in the buncher

The most intense spectral features can be clearly identified; although categorisation is difficult because of mode hybridisation and the degeneration of the simple pillbox modes in the shaped cell (for example the branches of the TM11-like mode at 4.3 and 5.5 GHz).

INDUCED FIELDS AS A DIAGNOSTIC

The trajectory-dependence of the dipole mode intensities allow the accelerating structures to be used as cavity BPMs. The absence of dipole modes in a well aligned beam is clear, leading to the possibility of an automatic multi-steerer alignment routine for the linac. A simple proof-of-principle experiment was carried out in which two steerers were scanned at the entrance to the second structure, and the ratio of the total integrated intensities of the hybrid dipole mode and monopole mode between 6.5 and 7.0 GeV was used as a measure of beam alignment. This ratio is plotted in Figure 9. The optimal position is clear, even without the ability to discriminate between horizontal and vertical position.

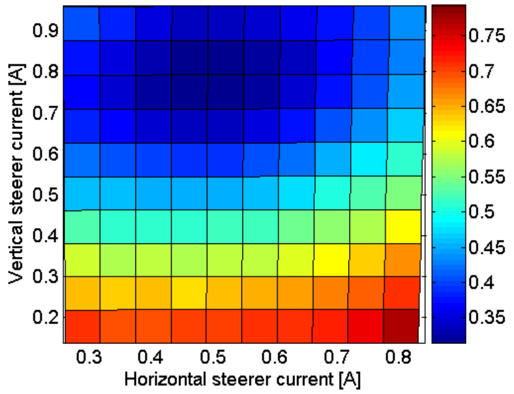

Figure 9: Optimisation of beam steer through the accelerating structure. The colour indicates the ratio of dipole to monopole intensity.

CONCLUSIONS

The directional couplers installed on the Diamond linac have been used to measure higher order modes in the structures, and CST Microwave Studio models have been used to unambiguously identify the spectral content. This simple measurement offers the opportunity to study accelerating structures in situ, and to optimise linac performance by using the accelerating structures as cavity BPMs. Use of the structures as both accelerators and position monitors offers a potential reduction in accelerator complexity and total length in future linacs.

ACKNOWLEDGEMENTS

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