TUNING OF THE INJECTOR SYSTEM TO MATCH POSSIBLE LATTICE UPGRADES AT DIAMOND LIGHT SOURCE

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Abstract

Studies of novel lattice upgrades for Diamond Light Source to achieve an increase in the number of insertion devices and/or a lower natural emittance are underway [1]. Such upgrades if carried out progressively would result in successive reductions in storage ring circumference. To maintain synchronous injection then requires the injector system to operate at various frequencies to match these changes. This paper describes the tests carried out with beam, to prove that the injector system of linac and full energy booster can be tuned over an extended frequency range.

EFFECTS OF THE LATTICE UPGRADE

Modification of the DBA lattice at Diamond Light Source to a Double DBA (DDBA) lattice is under consideration [1]. This would allow the introduction of an insertion device between two DBA achromats in any modified DDBA cell, and also bring about a reduction in storage ring emittance. The present design envisages a change in length, δl of a modified cell, leading to a new RF frequency f_{RF} for N modified cells, given by

$$f_{RF} = \frac{c}{C + N\delta l}$$

where c is the speed of light and h is the harmonic number, presently 936 corresponding to the circumference C of 561.6 m. Figure 1 shows the notional implementation of the DDBA lattice across all 24 cells of Diamond, with δl = -25 mm. In order to minimise the excursion from the present operating frequency, the harmonic number is reduced by one after the modification of twelve cells, leading to a restoration of the original operating frequency after the completion of all 24 cells.

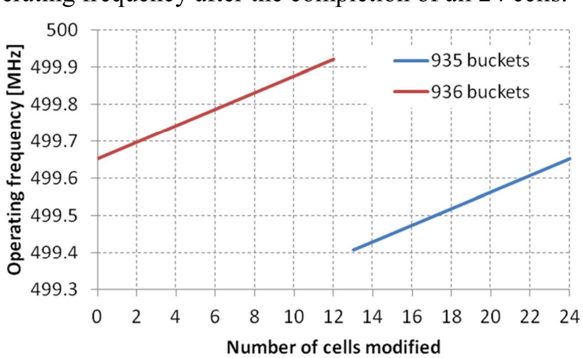

Figure 1: Frequency change required for multiple cell implementation of the DDBA lattice.

The work presented in this paper is an analysis of the practicability of operating the Diamond injection system at frequencies different from the design value. The frequency ranges of individual RF components are investigated, and full-energy beam is demonstrated for extreme values of machine frequency.

HIGH POWER AMPLIFIERS

The Diamond Light Source injector consists of a 100 MeV Linac and a 3 GeV full-energy booster synchrotron [2]. The S-band linac operates at the sixth harmonic of the common master oscillator frequency and is powered by two RF stations, each including a pulsed Thales TH 2100 klystron. The booster cavity is driven by a Thales TH 793 IOT amplifier cycled in power from injection to extraction at the master oscillator frequency in the UHF. The fundamental parameters of the amplifiers, including -1 dB bandwidth are presented in Table 1; clearly the amplifier tubes are not a limiting factor in off-frequency operation.

Table 1: High Power Amplifier Tubes used in the Injector

Tube	Power	Frequency	Bandwidth
TH 2100	37 MW	2998.5 MHz	10 MHz
TH 793	60 kW	500 MHz	6.5 MHz

LINAC FREQUENCY TUNING

There is no active frequency tuning on the linac and so a change in operating frequency results in a degradation of performance, as shown in Fig. 2.

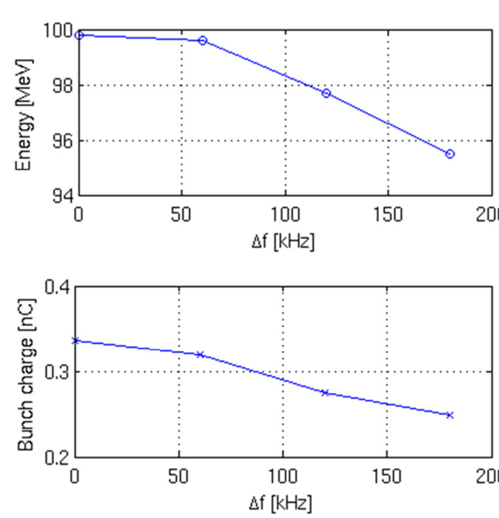

Figure 2: Effect of frequency change on linac performance.

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Linac charge and energy decrease over a few hundred kilohertz in the S-band, although there is scope to recover much of this degradation by increasing the voltage on the modulator pulse forming network and by retuning the RF phasing of the bunching and accelerating structures. Eventually, however, a harder limit is reached when the RF begins to couple to a different accelerating mode in the linac structure. The Diamond linac is a constant gradient structure with tapering cell dimensions and is designed to operate in the TM010 mode with a phase advance of 2π/3. The accelerating mode is illustrated over six cells in the CST Microwave Studio simulation shown in the upper part of Fig. 3. The points on the lower part of this figure show the dispersion diagram calculated for the first, middle and last cell of the linac.

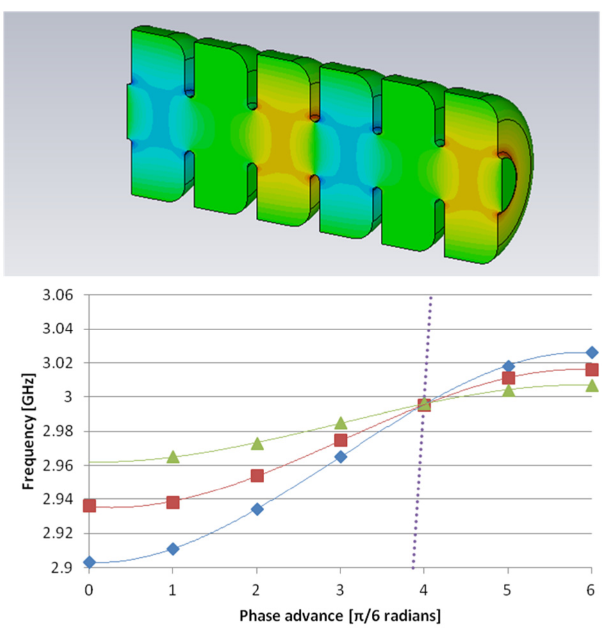

Figure 3: Dispersion curves of first (blue), middle (red) and last (green) cell of Diamond linac accelerating structure.

The dispersion relation for a periodic array of coupled resonators may be written as

$$f = \frac{f_{\pi/2}}{\sqrt{1+\eta\cos(\phi)}}$$

where the resonant frequency, f, is a function of the phase advance, φ, cell-to-cell coupling, η and $f_{\pi/2}$, the resonant frequency at phase advance π/2. Dispersion curves are fitted to the calculated points in Fig. 3, yielding the coupling values for the modelled cells and mode spacing for one cell difference from the 2π/3 phase advance in each case. These results are summarised in Table 2.

Table 2: Linac Cell Properties

Cell position	Coupling	Mode spacing
First	4.15%	1.1 MHz
Middle	2.75%	0.7 MHz
Last	1.50%	0.4 MHz

Mode frequencies were measured directly by two methods: firstly, by a measurement of reflected signal from a low power klystron pulse powered by a swept-frequency local oscillator, and secondly with a vector network analyser mounted on a linac switch configured to see into the second of the two accelerating structures. Both measurements gave equivalent results, shown in Fig. 4 for the VNA case.

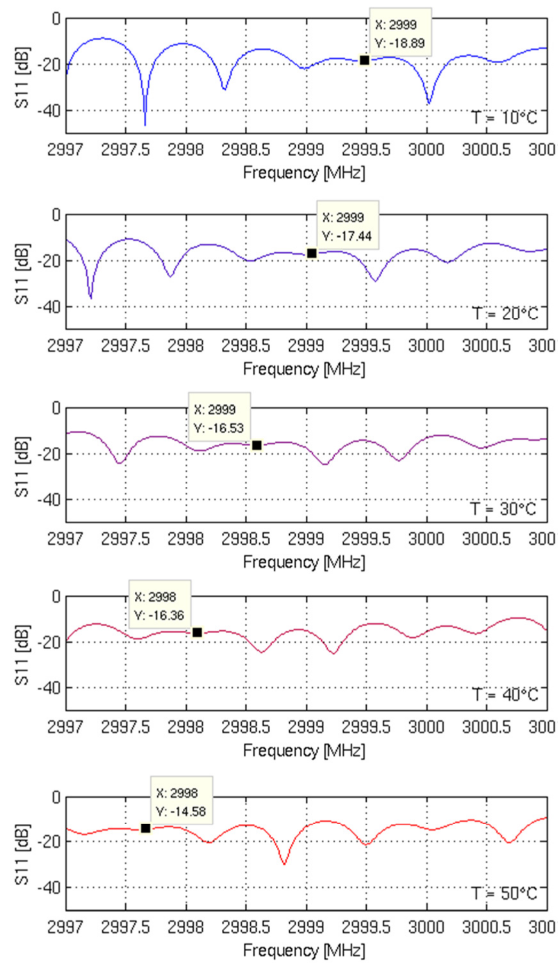

Figure 4: Temperature scan of linac TM010 modes.

The temperature of the local water cooling circuit was changed in order to shift the frequency of the 2π/3 mode, which is indicated in each case. Figure 4 shows that the accelerating mode can be moved across several mode resonances by temperature control, enabling precise control of operating frequency necessary for off-frequency operation of the master oscillator. Measured mode spacing is consistent with the values calculated in Table 2, with the different cell-to-cell mode spacing apparent as a broadening of individual resonances in the figure.

Frequency of the accelerating mode as a function of temperature is shown in Fig. 5. Very roughly, a shift of 1 MHz in operating frequency in the S-band can be brought about by a local temperature change of 20°C, allowing the frequency range of 0.5 MHz in the UHF shown in Fig. 1 to be achieved by water temperature control alone.

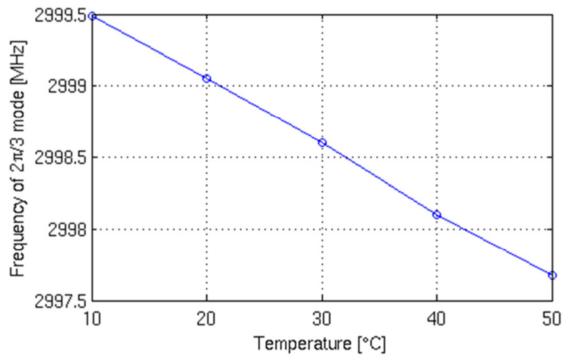

Figure 5: Temperature dependence of accelerating mode.

BOOSTER CAVITY FREQUENCY TUNING

The Diamond booster cavity is a five-cell normal conducting structure with frequency tuners mounted on cells 2 and 4 in order to maintain the required resonant frequency and field balance [3]. The large travel available on the tuner mechanism enables operation over a broad frequency range, shown in Fig. 6.Three data sets are shown for the two tuners, corresponding to power loading at injection, the ramped operating cycle and an extended CW test at a power level equivalent to normal operation. Extrapolation of these plots shows that the booster cavity can easily cover the range shown in Fig. 1. Again, a local water circuit is available for further frequency tuning if necessary.

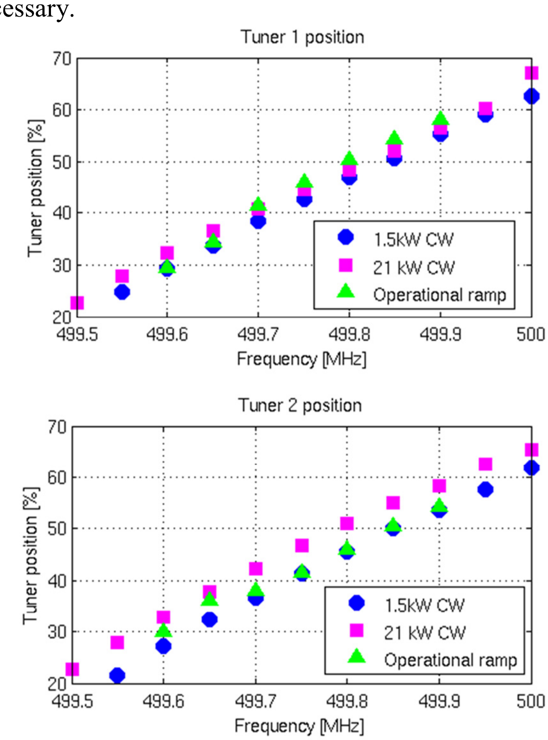

Figure 6: Booster frequency scan.

PROOF-OF-PRINCIPLE DEMONSTRATION

The left side of Fig. 7 shows the current in the diamond booster measured with a DCCT for the whole of the 100 MeV to 3 GeV ramp. On the right side, the signal from a stripline BPM in the booster to storage ring transfer line is presented, showing 3 GeV beam suitable for injection into the storage ring. Plots are shown at two different master oscillator frequencies, corresponding to linac temperatures 10°C above and 10°C below the normal operating temperature. This clearly demonstrates the ability of the injection system to operate at frequencies different to the design value.

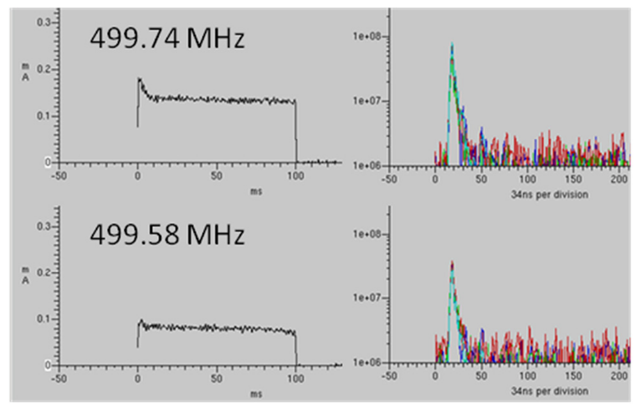

Figure 7: Beam in the booster and BTS transfer line at extreme frequencies.

SUMMARY

Temperature-tuning of the Diamond Light Source pre-injector linac has been demonstrated and quantified, and has been shown to be sufficient to cover the range of frequencies expected to be encountered by the implementation of a complete change of storage ring lattice to the DDBA design. High-power amplifiers and the booster RF cavity are able to cover the required range with no further modifications.

Operation of the injection system as a whole has been demonstrated at non-standard frequencies and as such present no obstacle to the introduction of the first cells of the DDBA lattice in the Diamond storage ring.

REFERENCES

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