OPTICAL CLOCK DISTRIBUTION SYSTEM AT THE ALICE ENERGY RECOVERY LINAC

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Abstract

We report here on the status of the optical clock distribution system installed on the ALICE energy recovery linac (ERL). The installed clock distribution is described as well as two fibre stabilisation control techniques based on the RF beat spectrum and optical nonlinearities respectively. These are both currently under development and a preliminary result for drift compensation using the RF system is presented. Also presented is the implementation of a beam arrival monitor on the optical link which has demonstrated that good sensitivity can be achieved using both low optical pulse power and the low bunch charges routinely operated on ALICE.

INTRODUCTION

Highly stable clock distribution across future light sources is important for the synchronisation of beam generation, manipulation and diagnostics with photon experiments. Optical fibre technology can be used to combat the stability challenges in distributing clock signals over long distances with coaxial cable. A stabilised optical clock distribution system based on the propagation of ultra-short optical pulses has previously been developed on the FLASH-FEL at DESY [1]. We report here on the progress made at the Daresbury Laboratory in implementing a similar link on the ALICE ERL. The system presented here is the first step in improving the timing and stability of ALICE. It will also provide a testbed on which to develop more novel techniques for the improved stabilisation of such systems on future accelerators.

OPTICAL TIMING SCHEMES

The layout of the optical timing scheme at Daresbury is shown in Fig. 1. A stretched-pulse erbium doped fibre ring laser from Toptica Photonics is used as an optical clock and is phase locked to the 81.25 MHz RF signal from the ALICE master oscillator. The laser incorporates an erbium doped fibre amplifier at its output to produce an output power of 250 mW, followed by free space dispersion compensation compressing the output pulses down to 65 fs. At the exit of the laser, a portion of the output pulses is tapped off via a polarising beam splitter to be maintained as a reference clock pulse, while the rest of the laser output is coupled into a 100 m long, dispersion compensated distribution fibre transporting it into the accelerator area. Half the optical power is extracted at the far end for use as the distributed clock and the rest is reflected back to meet the reference pulses. To maintain the forward and reverse propagation symmetry, no amplifiers are implemented in the link itself. At return, the reference and link pulses are recombined and detected to determine their relative timings.

We are simultaneously progressing two different techniques for monitoring the relative signal timing. The first uses the RF spectrum of the combined pulse trains, and the second is an optical method using a nonlinear crystal to detect pulse overlap. We intend to combine both methods to enable us to achieve both the fine resolution of the optics with the wider range provided by the RF technique.

RF Locking

With the RF locking technique, the reference and link pulses are recombined in the beamsplitter and detected with a fast photodiode to obtain its RF spectrum. It can be shown that for pulse trains which are nominally delayed by nearly half a period, a pair of adjacent harmonics can be chosen to monitor any relative movement of the trains from their nominal separation. The choice of harmonics is determined by the nominal separation chosen. Higher harmonics are required for separations approaching a half period, but also provide greater detection sensitivity. Although the relative power of the harmonics will increase or decrease depending on the deviation from nominal separation, the harmonics will increase or decrease *together* in the case of an amplitude fluctuation reducing the amplitude dependence of the timing signal. Further amplitude independence is achieved by normalizing the harmonics' power difference to their total power.

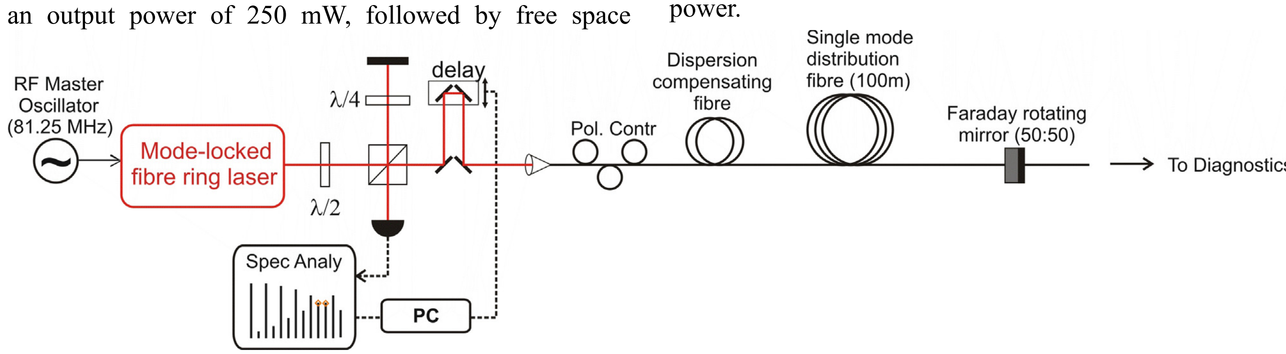

Figure1: Layout of the optical timing scheme.

In our setup we have used a spectrum analyzer to measure the 39th and 40th harmonics of our 81.25 GHz signal from which we were able to obtain 4 ps/mV sensitivity and a 150 ps maximum range. The measured signal is then fed via a PC back to a delay stage to compensate for any measured drift in the link. This can be seen in Fig. 2 which shows the measured drift of the link with and without the stabilisation activated. Also shown is the delay stage movement required to maintain compensation of the stabilised link. Having verified the sensitivity achievable with the selected harmonics, further work using analogue filters is currently underway to increase the speed of the feedback and enable rapid jitter stabilisation.

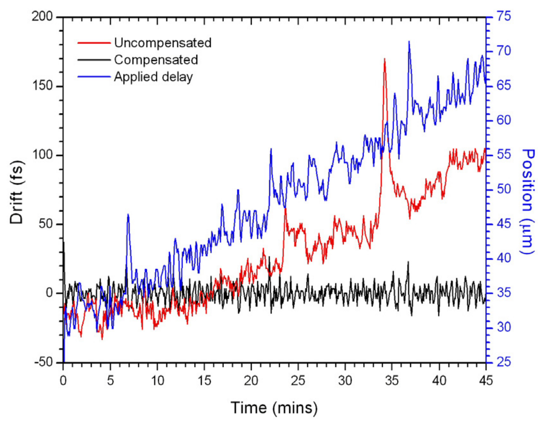

Figure 2: Measured drift of the optical link with and without the RF stabilisation scheme.

Optical cross correlator using a type-I PPLN

To obtain a higher detection sensitivity than is expected to be achievable with the RF scheme, we are also developing an optical cross correlation detector based on a type-I PPLN crystal. Fig. 3 shows the configuration of the proposed detection scheme. At the nominal locking position, the reference and link return pulses should have a small separation and be of orthogonal polarisations after recombination in the beam splitter cube. The combined pulses are then split using a non-polarising beam splitter such that both pulses will pass in the forwards and backwards directions through the nonlinear crystal. In the straight (lower) arm, the pulses pass through a half wave

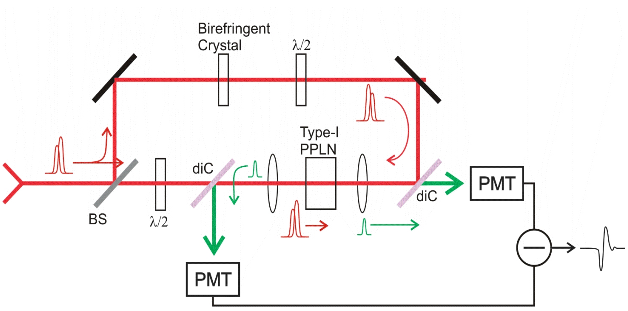

Figure 3: Configuration of the optical cross correlator based on a type-I PPLN. BS: nonpolarising beamsplitter, diC: dichroic mirror.

plate and are rotated by 45 degrees ensuring that half of each of the signals are aligned with the PPLN. Second harmonic generation (SHG) in the nonlinear crystal produces 780 nm light, which is enhanced when the pulses are overlapped, is extracted for detection with a dichroic mirror. In the upper arm, the pulses pass first through a birefringent crystal, delaying one pulse with respect to the other and effectively swapping their order. The pulses then pass through the PPLN in the backward direction with generated SHG signal also extracted via a dichroic mirror. Any change in the nominal separation of the pulses at input will create more overlap in one arm and less in the other and thus give an error signal from the difference of the two SHG powers.

While the scheme is slightly more complex than others proposed elsewhere [2], it allows the use of type-I PPLNs which are more readily available and have a greater conversion efficiency than type-II PPLNs.

BEAM ARRIVAL MONITOR

The short optical pulses delivered to the accelerator site have been used to implement a beam arrival monitor (BAM). The layout of the BAM is shown in Fig. 4. The short optical pulses emerging from the 50:50 Faraday rotating mirror in the link are passed through a Mach-Zehnder modulator (MZM). The modulator contains an electro-optical crystal which is driven with the RF signal from an electrical pickup on the accelerator beampipe and converts it into an amplitude modulation of the signal.

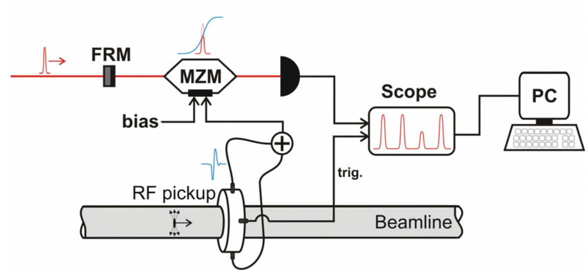

Figure 4: Concept of the beam arrival monitor.

Installation on ALICE

The electrical pickup used on the ALICE accelerator is a ¼ wavelength stripline pickup originally installed for use as a beam position monitor, and exhibits an S-curve characteristic with zero-crossing located at the centroid of the measured electron bunch. By synchronising the signal pulses with the nominal S-curve zero crossing, the beam arrival monitor would be able to convert any time shifts of the curve into an amplitude modulation on the signal. The use of ultrashort pulses here thus enables the sampling to be delta-function like and provide the highest time resolution. At the modulator output, the pulses are detected with a low bandwidth photodetector and read off an oscilloscope which acts as an ADC. The relative attenuation of the synchronized signal pulses can then be normalised to the unmodulated pulses to measure the time delay of the electron bunches with respect to the optical clock.

To characterise and calibrate the electrical pickup we used for the BAM, the delay between the optical clock and the electron bunches was scanned across a 500 ps range in 1.2 ps steps. This is shown in Fig. 5. The flattening that can be observed on the trough and the peak indicate that the full V_π of the MZM is being utilised. Although further flattening would reduce the range of the measurement, it would increase the slope which determines the sensitivity of the BAM in the region around the zero crossing. This slope (and flattening) is determined by the bandwidth of the pickup, the V_π of the modulator and the charge of the electron bunch. For our MZM with V_π of 6.7 V, we were able to maximise the sensitivity of the modulator by operating it at a bias of 3.3 V. Thus for 7 mW distributed optical pulses and a bunch charge of 40 pC, we were still able to obtain a sensitivity of 26 ps/dB on the BAM. The noise observable in Fig. 5 is due to the 5 GS/s sampling rate of the scope used for data acquisition.

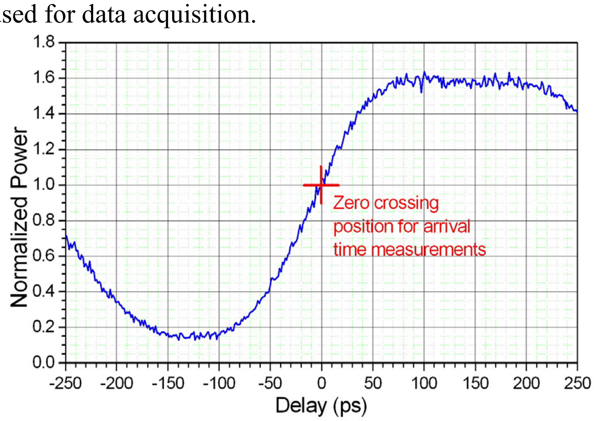

Figure 5: Beam arrival monitor characterisation showing 26 ps/dB sensitivity when operating at 40 pC bunch charge.

CONCLUSIONS

We are implementing an actively stabilised clock distribution system on ALICE for use with a beam arrival monitor. The system will be used to improve ALICE stability as well as being a testbed for the development of novel timing and synchronisation techniques.

Our initial measurements compensating the drift in the link are promising and have enabled us to anticipate the sensitivity of the RF technique. In the near future we plan to progress both the described techniques by implementing analogue filters on the RF feedback and resolving noise on the SHG. We expect these improvements to bring us to achieving an active link.

REFERENCES

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[2] J. Kim, J. Chen, Z. Zhang, F. N. C. Wong and F. X. K¨artner, *Long-term femtosecond timing link stabilization using a single-crystal balanced cross correlator,* Optics Lett.,32(9): 1044-1046 (2007).