I.FAST

Innovation Fostering in Accelerator Science and Technology

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MILESTONE REPORT

Delivery of an electro-optic waveguide prototype for demonstration at RHUL test bench

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ABSTRACT

Task 10.7 aims to develop novel electric field sensors for use in high-bandwidth accelerator beam diagnostics. The technology chosen to achieve the fast response time required is based on fibre-coupled optical waveguides made from lithium niobate. Prototype waveguides were developed in collaboration with a UK industrial partner and delivered to Royal Holloway University of London (RHUL), where they were integrated into an optimized design of electromagnetic pick-up, suitable for subsequent beam tests at CERN. The integrated electro-optical pick-up was bench at RHUL tested using a 20 GHz vector network analyzer and a fast photodetector data acquisition system. The delivery of the hardware and demonstrated operation of the prototype in the laboratory fulfills the 'delivery of an electro-optic waveguide prototype for demonstration at RHUL test bench'.

For more information on I.FAST, its partners and contributors please see https://ifast-project.eu/

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Delivery Slip

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TABLE OF CONTENTS

1. Introduction

Task 10.7 aims to develop novel electric-field sensors, based on electro-optic waveguides to address new challenges in fast time response (<50 ps) beam instrumentation. Such sensors may find application as high-frequency diagnostics, e.g. for the High-Luminosity LHC that targets operational bandwidths of 6-10 GHz [1][2], or in any future accelerator bunch-by-bunch diagnostic where a rapid time response is required. Potential applications include the detection of crabbed-bunch rotation or as a higher bandwidth alternative to conventional head-tail instability monitors.

The operating principle of an Electro-Optical Beam Position Monitor (EO-BPM) is to replace the electromagnetic pick-up in a conventional BPM, with a birefringent crystal that responds rapidly when influenced by the transverse electric field of the relativistic particle bunch via the Pockels effect. The change in optical polarisation state can be recorded by fast photodetector. EO-BPMs were initially developed based on free-space crystals using bulky and complex optical beam delivery systems [3][4][5] with a performance that was enhanced using interferometric methods [6][7][8], although the sensitivity was still limited for the most challenging accelerator applications.

In this Task, a novel concept is explored that has enabled the development of new, high bandwidth (>10 GHz) electric-field detectors, based on exquisitely sensitive electro-optic waveguides made from birefringent lithium niobate. The key advantages are that the electro-optic waveguide are readily fibre-coupled, which enables a compact, Mach-Zehnder interferometric configuration of the pick-up, which improves the sensitivity well beyond that of state-of-the-art free-space crystals. The work has focused on the development of electro-optic waveguide design and electromagnetic optimisation of the mechanical layout with the integrated waveguide.

This report documents the milestone production and delivery of a prototype electro-optic waveguide sensor that was bench tested at RHUL, ahead of beam tests at the HiRadMat facility at CERN, which is documented in the annual task progress report.

2. Prototype production

Waveguides were integrated into an Electro-Optic Beam Position Monitor (EOBPM) based on a new electromagnetic and mechanical design developed at RHUL. Electromagnetic simulations of the pick-up were performed in CST to optimise the field strength at the waveguide and assess the time response. The goal was to reduce the size and complexity of the existing EO-BPM designs by using lithium niobate waveguides in place of crystals. The waveguides are readily fibre-coupled to form a Mach-Zehnder interferometer embedded in the pick-up(s), which enhances the sensitivity and eliminates the necessity for complex free space optics.

Customised waveguides for the new pick-up design were produced in collaboration with the UK photonics industry. The waveguides were optically inspected on reception in the 'superFab' nanofabrication cleanroom facility at RHUL, with an example waveguide shown in Figure 1, which reveals the microscopic (<10um) ridge waveguide structure that has be precisely cut into the lithium niobate surface. The waveguides were fibre-coupled and the optical transmission checked prior to assembly into the mechanical pickup.

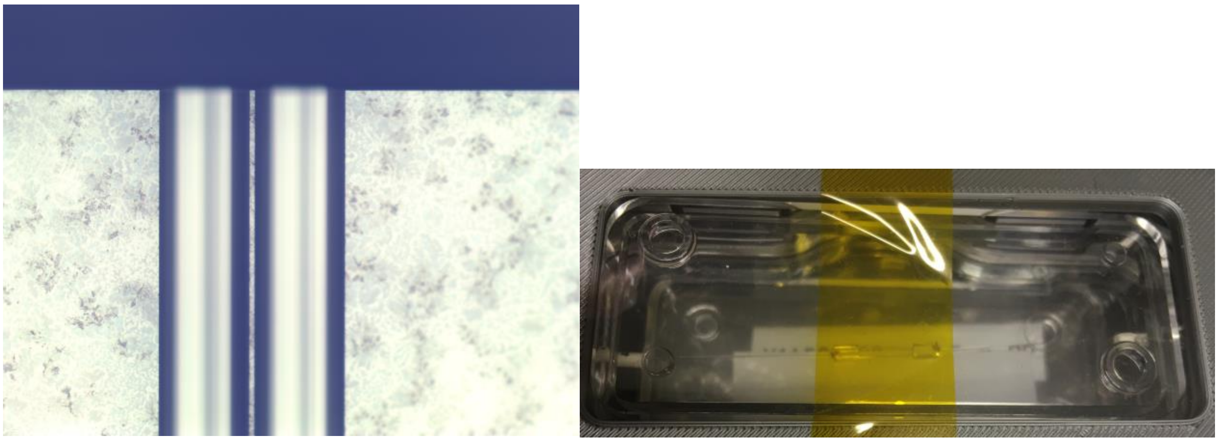

Figure 1 Optical inspection of waveguide in RHUL clean room

A precise assembly of custom components was designed at RHUL, and the waveguides were incorporated into the EO beam pick-up, as shown in Figure 2.

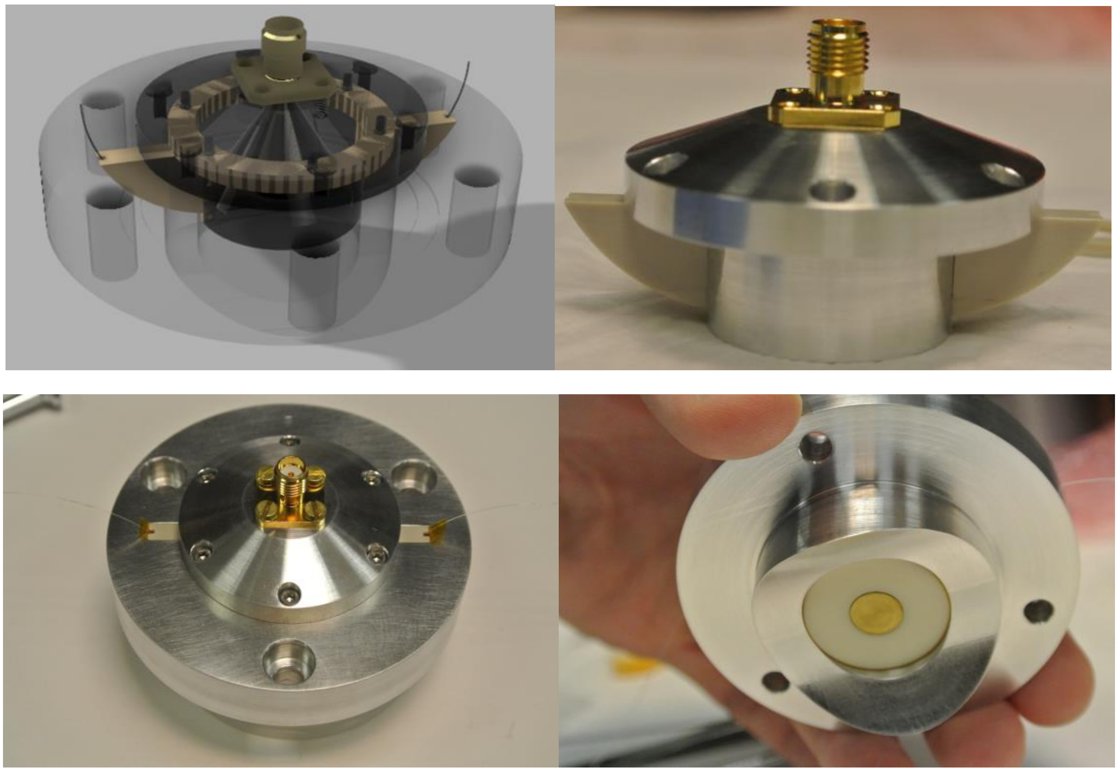

Figure 2: Compact fibre-coupled waveguide pick-up design and assembly, © RHUL

3. EO-BPM prototype on VNA bench test

Two opposing pick-ups were placed in a cylindrical coaxial line setup that enabled a fast electromagnetic signal to be sent to the pick-up mimicking the beam input. A fibre-coupled, narrow linewidth, continuous wave laser illuminated both pick-ups and the optical response was recorded as the signal was modified. The light was conveyed via a splitter tree based on commercial bi-conic fused tapered couplers that were installed in the fibre management system, shown in Figure 3. Additive manufacturing was used to rapidly print the required complex shape required to safely route and protect the optical fibres.

Figure 3 Additive manufacture of the support for the fibre management system and installation on the coaxial line with EO pick-up

The interferometric signals were detected by an array of fast (>10GHz) photodetectors, which were bandwidth limited by the filter/amplifier chain to <3GHz, and the data were recorded using a vector network analyser to validate the frequency-response of each electro-optic pick-up. A series of VNA tests were systematically performed for each interferometer in the system. The electro-optical response was also checked by applying a 1 GHz sinusoidal signal from a Rohde&Schwarz signal generator and the response observed on a 23GHz DPO72304DX digital oscilloscope in the time domain.

The completed prototype EO-BPM assembly is shown in Figure 4, prior to shipping to CERN for beam tests at the HiRadMat facility. The beam tests were successful in demonstrating single shot observation of the passing proton bunches, and further details on the results will be presented in an invited talk at IBIC September 2022.

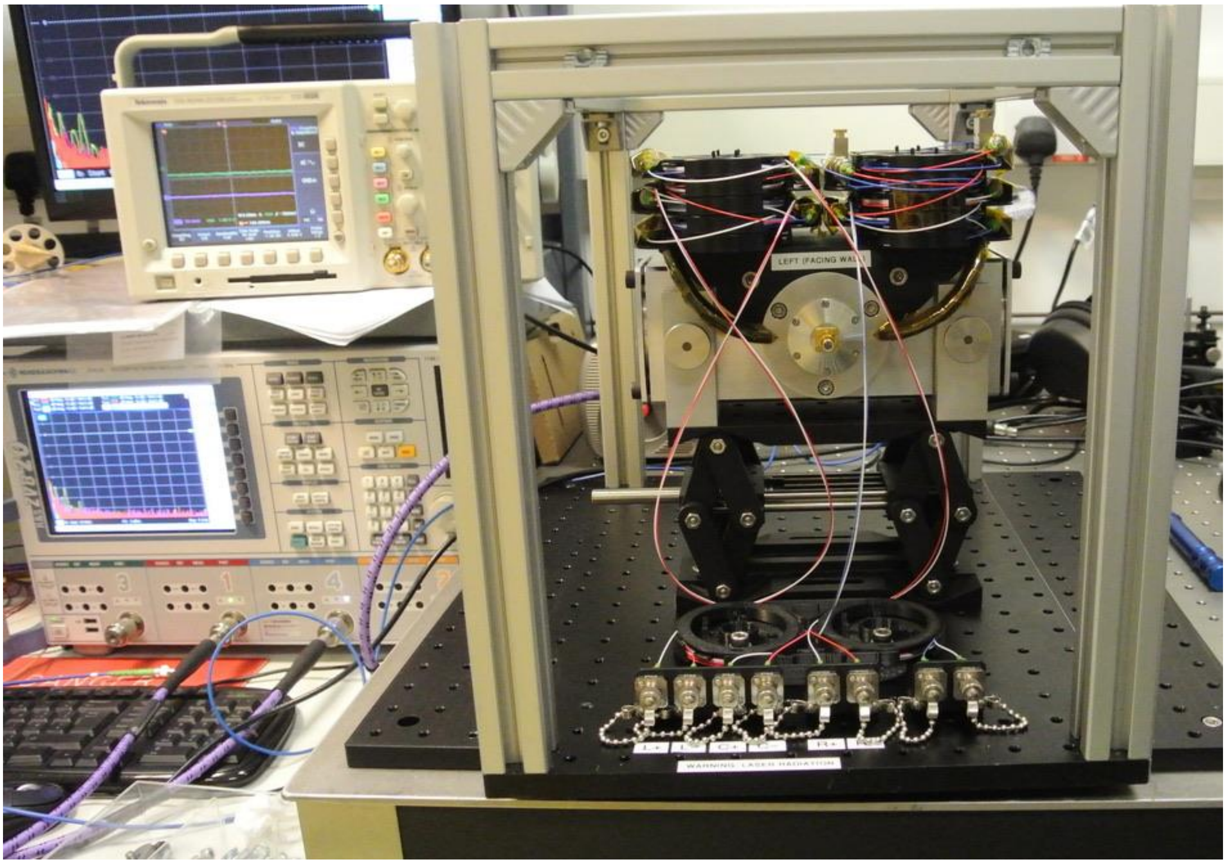

Figure 4 The prototype waveguide EO-BPM delivered for bench test with a vector network analyser.

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