REPORT ON THE REDESIGN OF THE FIBRE LINK STABILISATION UNITS AT FLASH

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Abstract

Recently, the fibre link stabilisation unit of the optical synchronisation system at FLASH has been subject to several design changes involving some major issues. Enhancements of the optical design have led to improvements in the efficiency of the free space optics and a new motorised optical delay line allows for a more than twice as long adjustment range. The amplitude noise, encountered previously at the remote station of the links, could be further decreased by a new beam splitting configuration. In this paper we report on the changes of the opto-mechanical design and we present first results from the recently commissioned links.

INTRODUCTION

All key components of the laser-based optical synchronisation system at FLASH (Free electron Laser in Hamburg) have evolved during the past few years from bread-board designs used in proof-of-principle measurements to more sophisticated and mechanically stable engineered versions. [1]. The optical reference, i.e. the Master Laser Oscillator (MLO), is a SESAM-based laser delivering a pulse train of ultra-short soliton pulses at a repetition rate of 216 MHz with a centre wavelength of 1559 nm, so that standard telecommunication components can be used [2]. The distribution of those reference laser pulses to the individual remote locations is accomplished by actively length-stabilised fibre links. Currently seven links of different design stages are installed and in operation. Figure 1 gives an overview of the synchronisation system infrastructure at FLASH. The newest opto-mechanical design is applied for two of those links: one to the EO-laser laboratory and the other connects to the pump-probe laser (PP-Laser) over a distance of about 500 m single-mode fibre, which is the longest link in operation. The current opto-mechanical design has been initially tested with the PP-laser link showing promising results. A strong suppression of the amplitude noise of laser pulses passing through the link has been measured [2]. In the near future, it is planned to exchange the existing link set-ups with an updated version of the opto-mechanics to result in a uniform system.

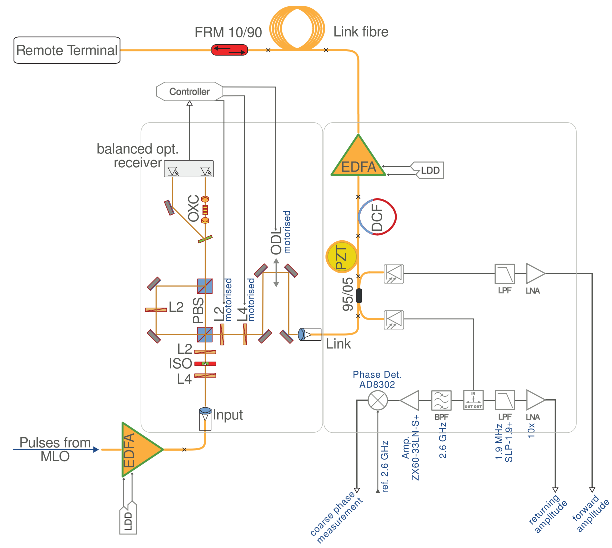

Figure 2: Schematic of the current optics and fibre layout of Link Version 3.0.

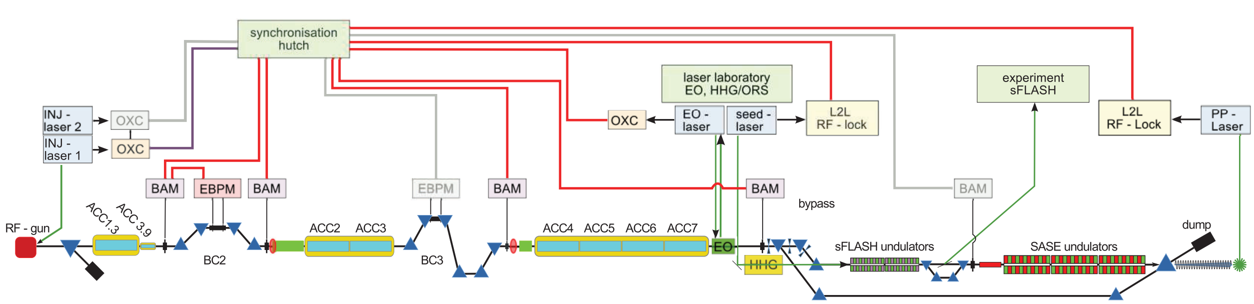

Figure 1: Infrastructure of the laser-based synchronisation system at FLASH. In red all of the seven currently operational fibre links are highlighted.

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The length-stabilising fibre links consist of three major sections: the free-space opto-mechanics in the so-called link box, a single-mode fibre assembly and electronics for read-out and control. The change in link fibre length is precisely measured by use of a balanced Optical Cross-Correlation (OXC). For this purpose, amplified pulses coming directly from the MLO are split depending on their state of polarisation into reference and link pulses. The latter travel along the link, are partly reflected at the remote location by use of a Faraday Rotating Mirror (FRM) and then travel in opposite direction back to the link-box where they are cross-correlated with new pulses from the MLO, for details refer to [3, 5]. To find the temporal overlap and to actively stabilise the link length a motorised linear stage is used for coarse and slow delay adjustments and a fibre stretching piezo-electric transducer (PZT) for fast and small adjustments, compare Fig. 2.

CURRENT OPTO-MECHANICAL DESIGN

Figure 3 shows a technical design drawing of a link box with the current opto-mechanics. The box is separated in three compartments: the free-space optics on the upper layer, the fibre optics in the middle layer and RF-components of the read-out electronics in the lower layer. The fibre assembly includes devices for pulse amplification, monitoring, in-fibre first order dispersion control and fibre length control. All of those fibre-coupled components are well-arranged at the bottom side of the thick aluminium plate which supports the free-space optics. The electronics, which include fibre-coupled photo-diodes, low-noise amplifier, band-pass filter, RF phase detector and a DC voltage divider, is mounted on the base-plate of the link box, (schematics in Fig. 2). It is planned to comprise all of those electrical components into one integrated circuit board for efficient space utilisation and for being cheaper than the individual components.

MAJOR DESIGN CHANGES

In the following, the substantial changes compared to all earlier link designs are shortly mentioned. All of which have enormously improved the ease of assembly and alignment of the optics as well as the fibre and cabling management.

Optical Delay Line

The motorised delay line, which is used in the fibre link setup for the coarse tuning of the temporal overlap has been mounted at a wrong position of the optical path in the previous link configurations [4]. Because of this, the laser pulses traversed the delay line only in forward direction, but not in the backward direction. All timing changes have been overcompensated considering the timing at the link ending. Thus, the adjustment of the delay line for compensating the timing drifts of the fibre link round trip time solely affected

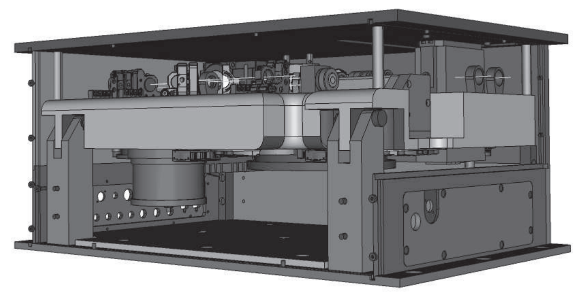


Figure 3: Design drawing of the Link-box version 3.0. Sideview.

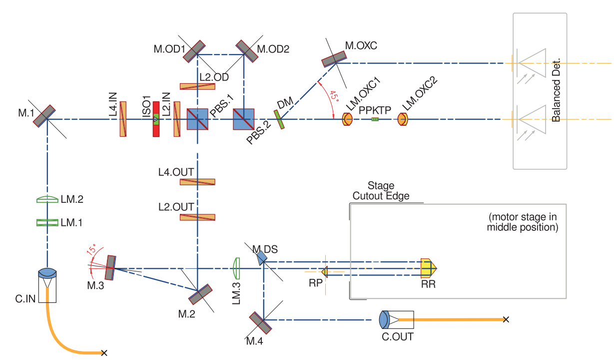


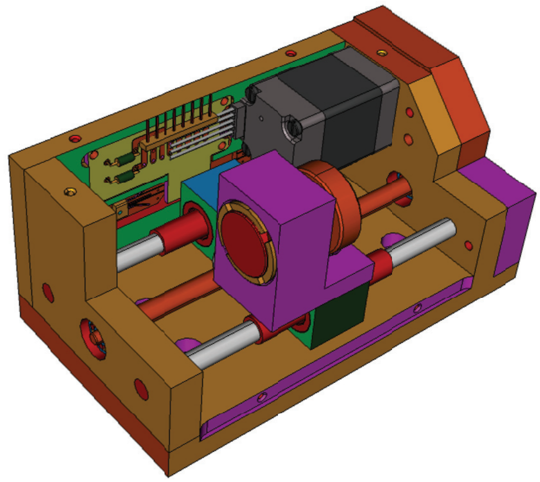
Figure 4: Layout of Fibre-Link Vers. 3.0.

the pulses in forward direction, which could clearly be observed at the bunch arrival time monitors (BAM) connected to four of the seven link endings. The design fault does not compromise the link functionality, as long as the excess timing shift of the link pulses is compensated with an additional motor stage behind the FRM, as it is realised in the BAMs. This design error has now been fixed.

Motorised Delay Stage

In the older versions of the fibre link box a plane mirror was mounted on the delay stage. In this configuration it rendered very difficult to achieve an incoupling to the link collimator with high efficiency over the whole delay range, due to imperfections of the mechanics of the motor stage. The incoupling efficiency dropped by up to 30 % at each end of the delay line, compared to the maximum efficiency in the centre of the 42 mm total delay span.

In order to improve the position dependent incoupling efficiency and to maximise the covered delay range, the simple plane mirror was exchanged with a folded beam path using a solid glass retroreflector (RR) in combination



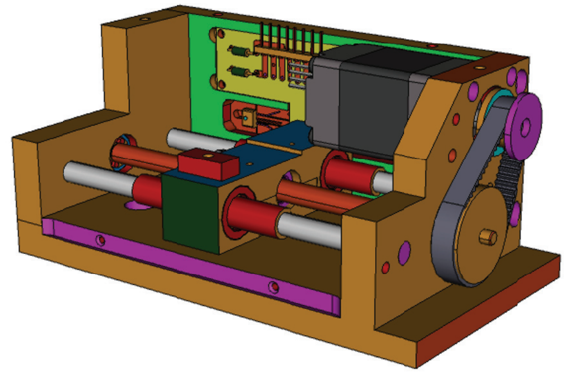


Figure 5: Design of the new motor stage manufactured in-house. Mounted onto it is the solid glass retroreflector within a customised holder.

with a right angle prism (RP) in front of the delay line. The right angle prism guides the laser light a second time into the retroreflector, such that it is spatially separated from the incident light and can be guided directly to the link collimator (C.OUT – for a schematic of the free-space optics see Fig. 4 and for a detailed 3D view of the beam path through the prism configuration see Fig. 6). Compared to the old configuration, with just two passes in the forward direction, the light traverses the delay line now four times in the forward link path and again four times in the returning path, which is a valuable extension of the optical delay span by a factor of 2.

The mechanical design of the motorised stage was gradually changed after a few iterations from a single dove-tail guiding to a combination of a high-precision spindle, two ball bearing cages on guiding rods and a geared belt drive, see Fig. 5. The travel range of the newest motor stage version was extended from 42 mm by a few millimeters by mounting the hall end sensors further apart from each other. In order to compensate even bigger delays, more space was additionally allocated in the mechanical design to have the ability to incorporate a longer delay line later, if this becomes necessary for long-haul links, for example at the European XFEL.

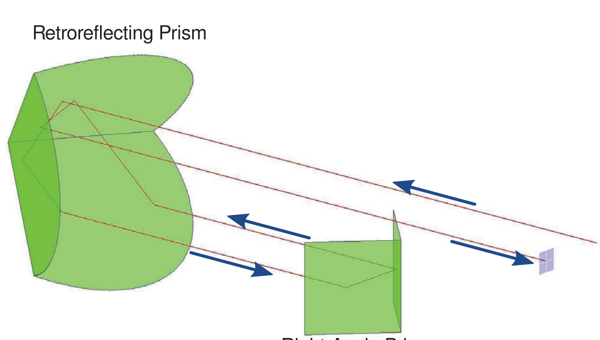


Figure 6: Arrangement of optical elements for the mechanical delay line

Furthermore, the new optics configuration with retroreflector and right angle prism is insensitive to some imperfections of the mechanical delay stage, like pitch and yaw. Because of their special arrangement, they compensate imperfections of the delay stage in almost every degree of freedom. A beam which is reflected by a retroreflector is always parallel to the incident beam, while being transversely offset. The reflection is widely insensitive to angle deviations of the retroreflector. By mounting its corner as close as possible to the spindle of the motorised stage the transversal effect of angle deviations of the delay stage on the retroreflector is also minimized. Transversal positioning errors of the stage still have to be taken into account because they influence the position of the reflected beam on the entrance surface of the retroreflector. In horizontal direction this influence has no effect, because the right angle prism compensates for it. Only deviations in the vertical direction are not compensated in this setup. Nevertheless the stage itself is quite stable in this particular direction. A sketch of this arrangement with retroreflector, right angle prism and the optical path through this configuration can be found in Figure 6.

Figure 7 shows two measurements of the incoupling efficiency into the link collimator (C.OUT in Fig. 4) as a function of the motor stage position. The efficiency is measured as ratio of in-fibre optical power and free-space optical power in front of C.OUT. The maximum incoupling efficiency achieved with the new configuration is more than 95 % with optimised optics using matched lenses. Both measurements were performed with the new motor stage, in one case using a plane mirror and in other case the folded beam path. In the latter case, the stability and performance is increased enormously. Note that for the plane mirror the change in optical pathlength is only twice the motor stage position offset, but with retroreflector and prism the optical path length changes are 4 times larger than the motor stage displacement. An optimum incoupling efficiency over a large range of the total delay span affords to reduce the total optical power required for each link box, thus a lower gain of the EDFA between MLO and link will become sufficient.

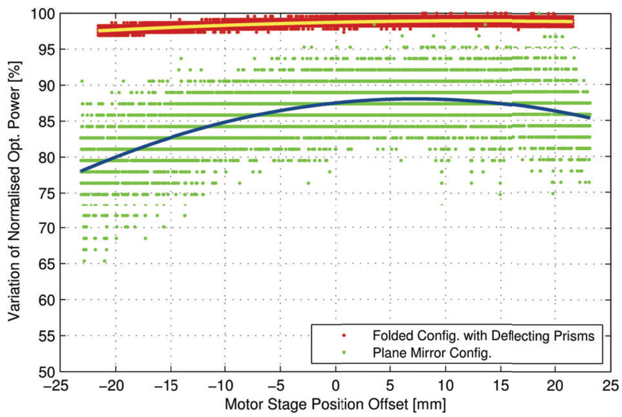


Figure 7: Incoupling efficiency of the new folded configuration compared to the old plane mirror configuration. For a better comparision, the incoupling efficiency is plotted against the offset in motor position not against the optical path length change.

Free-Space Optics

With an imaging system of three lenses the control of the Gaussian beam diameter along the free-space optics paths and the incoupling efficiency is optimised. The configuration is shown in Fig. 4: a telescope near C.IN with a bi-concave and a plano-convex lens in combination with another plano-convex lens shortly before the optical delay line. Furthermore, the ease of alignment for spatial overlap of reference and link pulse in the OXC is improved by this 'Two-Cube'- configuration where the returning pulses are guided through a two mirror detour between both Polarising Beam Splitters (PBS). With both mirrors not only angular errors but also position errors can be corrected for optimising the second-harmonic generation in the OXC setup. Another two-mirror configuration with an acute angle of 15° simplifies the alignment of the optical delay line.

SUMMARY

An extensive redesign of the fibre-link optomechanics had been carried out. Improvements have been achieved in optimising the assembly, alignment and operation of the links. Some performance issues are left, concerning additional contributions to amplitude noise, deformation of the laser pulse width and polarisation dependencies. Measurements and simulations are still in progress to minimise those unwanted effects in the near future.

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