CUSTOM OPTOMECHANICS FOR THE OPTICAL SYNCHRONIZATION SYSTEM AT THE EUROPEAN XFEL

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Abstract

Free-electron-lasers like the upcoming European XFEL demand highly reliable optical synchronization in the range of a few femtoseconds. The well-known optical synchronization system at FLASH had to be re-engineered to meet XFEL requirements comprising demands like ten times larger lengths and raised numbers of optically synchronized instruments. These requirements directly convert to optomechanical precision and have yielded in a specialized design accounting for economical manufacturing technologies. These efforts resulted in reduced spatial dimensions, improved optical repeatability, maintainability and even reduced production costs. To account for thermal influences the heart of the optical synchronization system is based on an optical table made out of SuperInvar. To fully exploit its excellent thermal expansion coefficient, mechanical details need to be taken into account. This work presents the design and its realization of the re-engineered optomechanical parts of the optical synchronization system, comprising mounting techniques, link stabilization units and optical delay lines for high drift suppression.

INTRODUCTION

Laser based synchronization systems based on stabilized short pulse master laser oscillators (MLOs), deliver pulse trains with femtosecond accuracy. These MLOs are usually phase-locked to a master oscillator (MO), being the master timing for the complete accelerator. After its generation, the light is split in a free-space distribution (FSD) into several channels, each serving one link-stabilization-unit (LSU). The LSU itself splits the light into a reference and a working channel. The working channel comprises the actuators for its stabilization, like a piezo-based fibre-stretcher for fast changes and an optical-delay-line for slow long-term drift compensation, plus a spool of matched dispersion compensating fibre and an optical amplifier. The path of the working light is called link, at the link-end a fraction of the working light is reflected back to the LSU. The remaining light is delivered as low noise, time stable reference to synchronize end-stations like bunch-arrival-time monitors (BAMs) [1], laser-to-RF (L2RF) [2] stations and laser-to-laser (L2L) [3] synchronization modules. The reflected fraction moves back to the LSU and gets compared to the initial reference using an optical cross-correlator (OXC) based on a PPKTP-crystal. This signal is used to stabilize the fibre-link. A simplified LSU structure is shown in Figure 1.

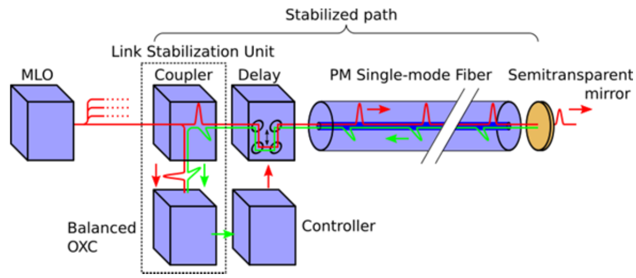

Figure 1: Simplified link stabilization scheme.

LESSON LEARNED

In the beginning and a long time on, the FSD and the MLO were mounted on a massive Invar-plate, which itself was mounted loose on top of a standard optical table, made of stainless steel. The light was coupled into fibre-collimators and led into the LSUs. For temperature variations inside the synchronization laboratory, the FSD only slightly influenced the absolute timing while the fibre from FSD to LSU added an uncorrelated fibre drift, which cannot be corrected. This is temperature coefficients of the used materials [4]. In Table 1 the thermal expansion coefficients of the used materials are calculated to timing errors.

Table 1: Temperature and Humidity Influence of Various Materials [4]

Material	Temperature fs/K/m	Rel. humidity fs/%RH/m
Aluminium	≈77	-
Steel	33	-
SMF28e	40	2.5
Furukawa PSOF	3.2	0.4
Air (at 1550nm)	3	0.03
SuperInvar	<1	-

FREE-SPACE DISTRIBUTION

To eliminate the most obvious sources of errors, the new optical table is made from SuperInvar and the FSD is mounted directly to the table. Further on, the light paths to the individual LSUs are kept identical in length at 2.6m and the coupling to the LSUs is completely in free-space. In this arrangement one single lens system optimizes the beam parameters for all LSUs simultaneously.

To preserve the thermal properties of the SuperInvar table and keep away induced stress by mechanically attached devices; the mounting techniques had to be improved. Single posts with a diameter of 24mm and attached mounting adapters for mirror mounts and beam splitters are kept directly using grub screws. Other devic-

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es like lasers or LSU baseplates are mounted using a kinematic fix-point connection. Figure 2 shows the simplified method.

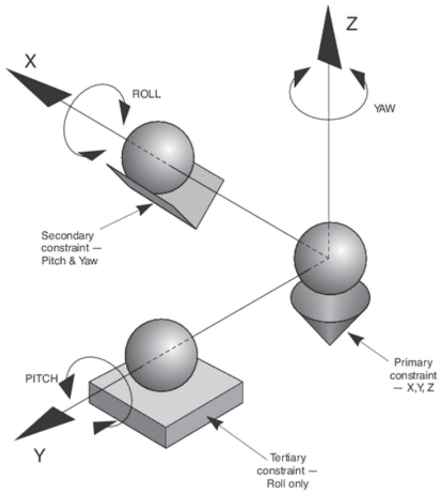

Figure 2: Simplified kinematic connection theory ©@ Newport Corp. [5].

The finalized parts for the kinematic mounting are shown in figure 3. The V-groove, cone and flattop supports are made from tungsten carbide and provided by Newport Corporation. The pads are glued into simple M6 threaded hexagonal stainless steel adapters, which are screwed directly to the table. To complete the supports, special fine-threaded screws with spherical ends guaranty individual alignment of each device.

Figure 3: Kinematic mounting supports for larger devices.

The spherical ending screws are mounted via a M8 threaded hex adapter from brass. This adapter has to be put to every device to be mounted. In addition polyamide screws set through the devices can help to balance or mechanically stabilize it. Using this mounting technique, thermally influenced devices don't apply stress to the optical table.

For easier alignment of the FSD and longer beam paths, MNI-H half inch mirror mounts from Radiant Dyes where chosen. They feature fine threaded screws with a pitch of 150µm/turn and 4 springs [6].

The FSD beam splitters consist each of a half-wave-plate in a THORLABS RSP/M rotation mount and a 10mm x 10mm polarizing beam cube. Mirror mount and beam splitter combo are each mounted on special post-adapters, shown in Figure 4. The adapters are developed in a way that the laser beam is ideally always guided above a line of threaded holes in the table surface.

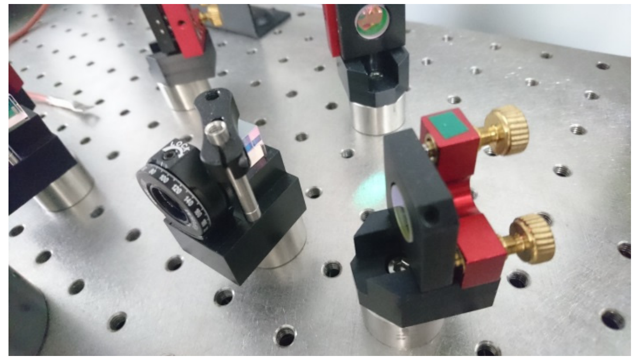

Figure 4: Mirror mount and beam splitter in the FSD of the XFEL synchronization laboratory.

LINK STABILIZATION UNITS

Former LSUs consisted of an optical free-space splitter, optical delay line (ODL) and OXC on an integrated baseplate plus the Erbium doped fibre amplifier (EDFA), the piezo fibre stretcher, the DCF spool and some diagnostics in an integrated large box. The only parts required directly on the SuperInvar table are the splitter for working and reference light, plus the OXC, which compares both signals. The ODL, diagnostics and fibre parts could be centralized. This was especially required because the new developed ODL for longer links, like the XFEL ones, has to be much larger to cover all potential timing drifts.

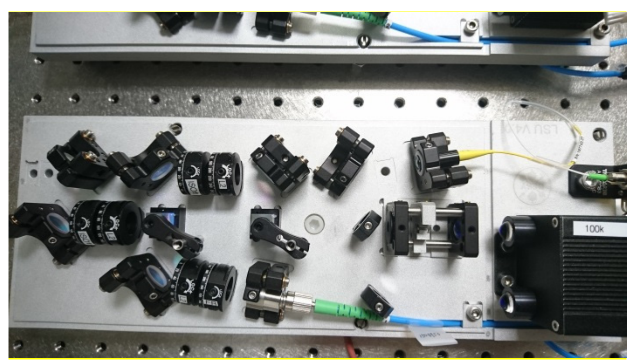

Figure 5: New developed LSU-baseplate.

The in-coupling of the working-light is done by a THORLABS triplet collimator to a standard polarization maintaining fibre. Here, it's led to a fibre rack under the optical table, where all the fibre actuators and parts are stored in separate crates. The path is guided to a second standard optical table made of stainless steel. On this table all in-loop ODLs are stored, see Figure 6. As they are within the feedback loop, their thermal behaviour is automatically compensated by the controller.

The LSU baseplate is mounted to the SuperInvar table using the kinematic mounting procedure plus a polyamide holding screw in the centre. To prevent timing drifts introduced by thermal expansion of the baseplate, the fixed mounting point, where the spherical screw meets the conical post, is calculated in a way, that timing errors cancel each other out. This way standard aluminium ma-

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terial can be used for the LSUs, while the excellent thermal properties of the SuperInvar table underneath are still significant.

OPTICAL DELAY LINE

Optical delay lines are required for all aforementioned end-station types and for the links themselves. Consequently one design should cover all needs. A required timing shift of 4ns had to fit on a small footprint. Therefor the optical path is driven vertically and folded six times. This number is a compromise between optical losses and maximum delay. For the links, such an ODL is used with fibre collimators for slow drift compensation. To shift the timing of the pulse train for individual end stations these ODLs are used free space between the FSD and LSU. In this application thermal expansion effects have to be avoided. Hence, these spindles are produced out of Invar36, which is comparable to the before mentioned SuperInvar.

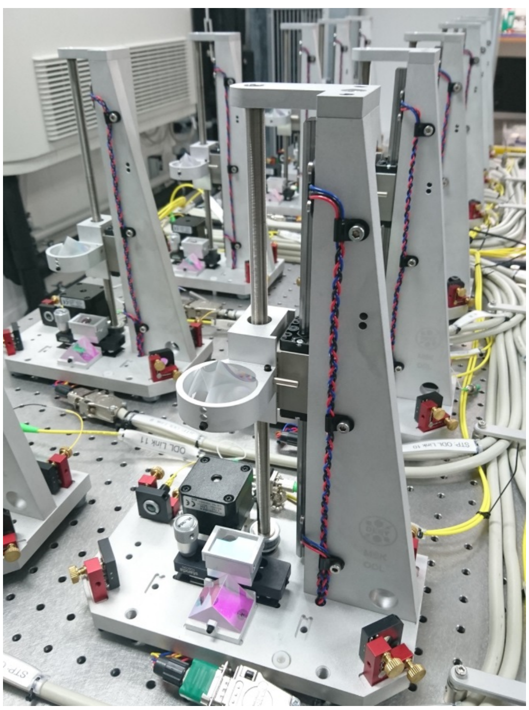

Figure 6: Optical delay lines on secondary steel table.

CONCLUSION

The large scale installation of the optical synchronization for the European XFEL necessitated major redevelopment of existing optomechanics. The resulting designs are more compact and allow for more links, stabilized on a moderately sized optical table. This is especially important as size contributes to timing drifts.

Furthermore, all designs are compatible to the metric optical tables (25mm grid) and to each other. This allows for many combinations of the optomechanics and highly flexible usability.

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