MECHANICAL DESIGN OF THE MID SPLIT-AND-DELAY LINE AT THE EUROPEAN XFEL

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Abstract

A new split-and-delay line (SDL) is under development for the Materials Imaging and Dynamics (MID) end station at the European XFEL.[1] The device utilises Bragg reflection to provide pairs of X-ray pulses with an energy of (5 … 10) keV and a continuously tunable time delay of (-10 … 800) ps – thus allowing zero-crossing of the time delay. The mechanical concept features separate positioning stages for each optical element. Those are based on a serial combination of coarse motion axes and a fine alignment 6 DoF Cartesian parallel kinematics[2]. That allows to meet the contradictory demands of a fast long-range travel of up to 1000 mm and in the same time a precise alignment with a resolution in the nanometre range. Multiple laser interferometers monitor the position of the optical elements and allow an active control of their alignment. All optical elements and mechanics will be installed inside an UHV chamber, including the interferometer and about 100 stepper motors.

With this paper we present the mechanical design for the SDL. It will additionally show the design of a prototype of a positioning stage which allows extensive testing of the implemented concepts and techniques.

INTRODUCTION

The intention behind the presented project is the provision of pairs of X-ray pulses with picosecond delay times at the MID end station at the European XFEL. This is to be achieved by a SDL system, which splits the XFEL beam into two branches and merges both after delaying one branch with respect to the other branch. Osaka et al. proofed such a split and delay concept to work with an in-air system for hard X-rays and a delay times up to 220 ps [3]. Earlier, Rosecker er al. developped a SDL working at fixed energy and in air [4].

The SDL under development allows for a window-less integration into the MID beamline and thus places all mechanics into an UHV environment. The SDL is designed to work with an energy in the range of (5 … 10) keV and to achieve a continuously tunable delay time of (-10 … 800) ps. This range also covers the zero crossing of the delay time. The mechanics for the positioning of the optical elements feature a precision in the range of single nanometer and tens of nanoradians, while in the same time allows long-range travel of up to 1000 mm. Full adjustability and an efficient operation will be possible due to the motorisation of most of the controllable dimensions of freedom (DoF) and multiple monitoring and measurement systems.

GENERAL CONCEPT

Bragg reflections of silicon crystals in 220-orientation is utilized to generate the intended beam paths. This, in contrary to grazing incidence mirror optics, is working at high reflection angles, which allow a much shorter and space saving design.

The general concept of the SDL is shown in Fig. 1. It features an upper and a lower branch, in which the incoming beam is divided to by a beam splitter. Both parts of the beam are brought back together at the end of the system by a merger crystal. The two crystals in the upper branch are adjustable in position and angle in order to realise different path length and therefore different delays, and different working energies. The lower branch features two channel cuts, creating a fixed delay to allow also small negative overall delay times.

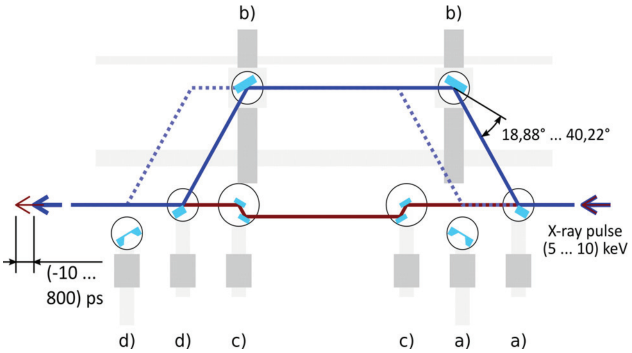

Figure 1: Conceptual view of the SDL indicating the mechanical concept. a) beam splitters; b) upper branch crystals; c) channel cuts; d) beam merger.

Two different splitter and merger stages are foreseen, either using extremely thin crystals and an intensity splitting of the X-ray beam, or the edge of a thick crystal, to split the beam geometrically. The unused version can be translated out of the X-ray beam. Moving all optical elements out of the beam allows the beam to pass through the system without any reflection, i.e. when the SDL is not required for an experiment.

In order to have a most versatile control and evaluation of the system, various measuring and monitoring systems will be integrated. This includes:

- a visible feedback laser, guided parallel to the FEL beam on dedicated mirrors, monitored by nano cameras
- Two 3-axis laser interferometers with sub-nanometre resolution, monitoring the upper branch crystals

- optical encoders with nanometre resolution to track the coarse motions
- beam intensity diodes next to each optical element
- beam position monitors in the upper and lower branch

The mechanics will be installed in an UHV chamber in order to minimize disturbances. This allows for windowless operation, as any window in the coherent X-ray beam would lead to parasitic scattering. To allow for a sufficient controlling of the system, the majority of the controllable DoF are motorized. Due to the vast options of adjustment and the thereby large number of DoF to be controlled, the system features an overall amount of more than 100 in-vacuum stepper motors.

MECHANICAL DESIGN

Figure 2 shows a general view of the SDL with the vacuum chamber containing an optical bench. This bench acts as the supporting structure for the precision mechanics and other components. The chamber sits on a granite block to obtain a high stiffness and eigenfrequencies. For installation and maintenance purposes, one half of the cylindrical shell can get tilted up – providing a wide access to the inner mechanics. In the closed state the chamber features a very high stability due to its cylindrical shape.

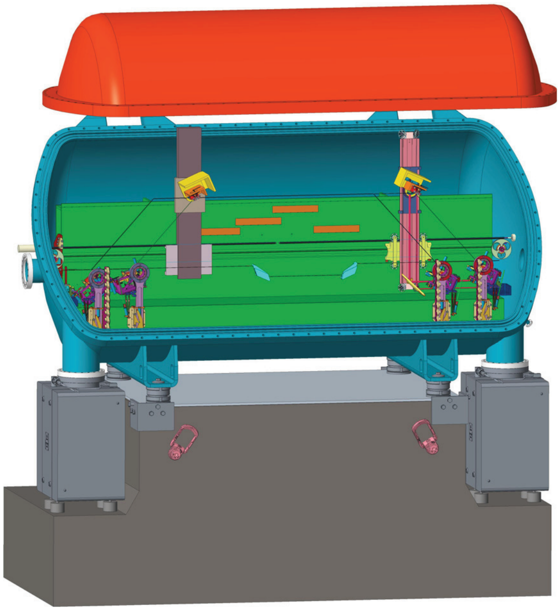

Figure 2: General view of the SDL in its current state of design.

The optical bench is designed for high stiffness. It provides a stable support structure for the installation of the mechanics as well as monitor and measurement systems, as shown in Fig. 3. Decoubling the bench by a minimal amount of connections to the chamber in positions where the chamber rests on the granite, the effects of mechanical or thermal disturbances from the environment onto the precision mechanics are minimised.

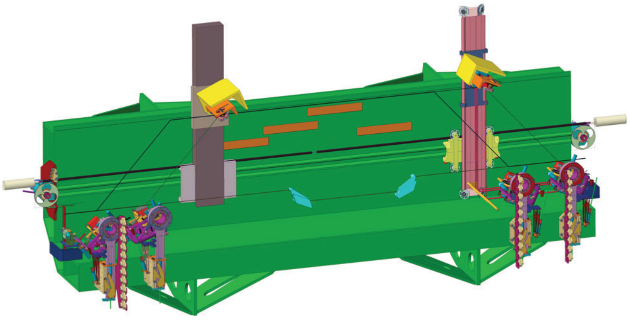

Figure 3: The optical bench as support structure for the precision mechanics and further components.

The system features separate positioning stages mounted to the optical bench for all optical elements. The mechanics of those have to meet two contradictory demands: They must provide a fast long-range travel – in some cases of up to 1000 mm – in order to allow for a positioning according to desired energy, time delay or splitting/merging option. In the same time they must allow a precise alignment with a resolution in the range of single nanometre and tens of nanoradians, in order to select a precise time delay in the order of a few femto-seconds and an overlap of the two split micron sized X-ray beams at the sample position 8m downstream of the SDL. This is achieved by a serial combination of coarse motion axes with a fine alignment stage. Figure 4 shows one beam splitter assembly.

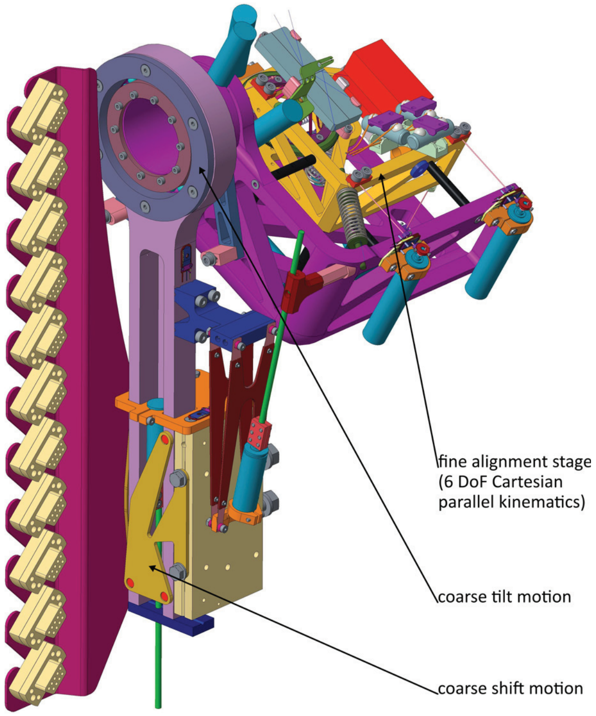

Figure 4: Positioning stage for the beam splitter.

The fine alignment stage is implemented as a 6 DoF Cartesian parallel kinematics. It features a platform supported by a structure of six stainless steel cables. These cables are adjustable in length and preloaded by springs. As these cables are orientated parallel to the

Cartesian coordinates, the need for complex coordinate transformations is avoided and a simple control scheme can be applied. All cables are coiled on a gear shaft, which is driven by a small stepper motor, thereby allowing for a change in length of each cable. The gear ratio is 154.368. This gives a resolution for their length of about 2,5 nm per full step. Due to the Cartesian orientation of the legs, this is also the linear resolution for the fine alignment stage. The rotary resolution depends on the lever arm, created by the distances between the cables. For the generic design of the fine alignment stage, the three rotary resolutions are about 36 nrad per full step.

A special driving system was developed for the long translations of the upper branch crystals. These translations are driven by a combination of a conventional lead screw for the horizontal translation and a cable system for the vertical translation. A conceptual layout of this is presented in Fig. 5. This implementation allows to have two motors dedicated to individual motions, while in the same time the motors can be installed in a fixed position within the system. This allows for a better cooling scheme and minimizes the thermal impact on crucial mechanical elements.

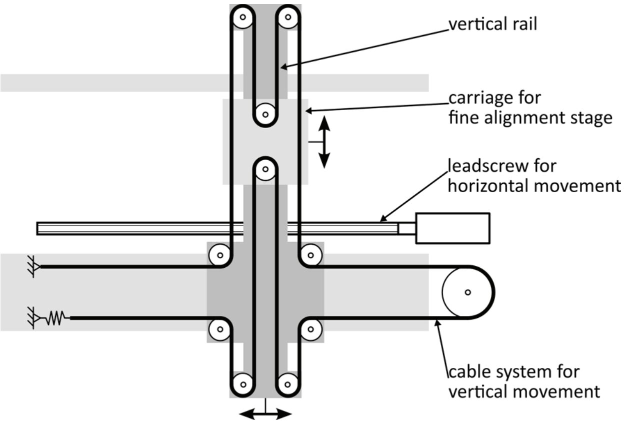

Figure 5: Concept for the driving of the coarse translations of the upper branch positioning stages.

PROTOTYPE

A prototype of a beam splitter positioning stage has been designed and build. Figure 6 shows a photograph of this device. This prototype allows to investigate the capabilities of the mechanical design. First tests of the prototype and the laser interferometer have been conducted in air. It was shown that the mechanics works as intended. However, due to the heavy influence of the air onto the interferometer system, quantitative statements on the achieved accuracy can not be made so far. In order to investigate the capabilities and limits of both components, the test set-up will be transferred into a vacuum environment for further test.

In addition, a thermal camera was used to investigate the thermal behaviour. The camera monitored the area around the lead screw and nut for the vertical shift, while this axis was driven three times over a height of 30 mm (see Fig. 6). On a qualitative level, the results show very clearly the induction of head due to the friction between the nut and the lead screw. This occurs mainly during upwards movements due to the higher force and therefore higher friction in this direction. Accordingly, the temperature degreases while moving downwards. As the relevant temperature differences are in a very small range of less than 1 K, a further optimisation and calibration of the set-up is necessary to allow for quantitative results.

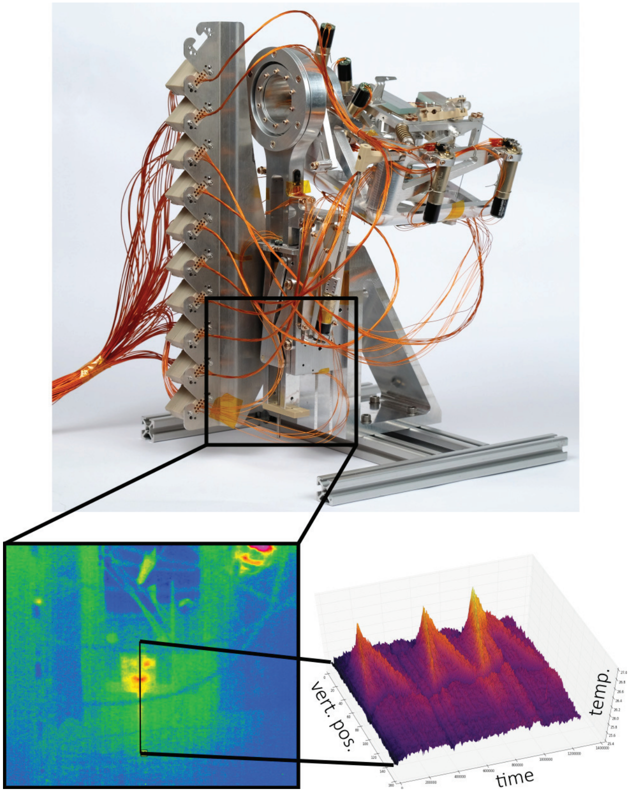

Figure 6: Photograph of the assembled and wired prototype and the results of the thermal investigation.

CONCLUSION

We developed a concept and a corresponding mechanical design for the MID Split-and-Delay line. Advanced mechanical solution were found for crucial points such as the mechanics for the coarse and fine movements. Considering the mechanical design together with the exceptional feedback, control and monitoring systems, that are applied, we are convinced that the system will be able to provide pairs of X-ray pulses with the intended properties.

A prototype of a positioning stage as one of the key mechanical elements was build and is under investigation using a dedicated laser interferometer. First results are promising and will be followed by further investigations with an improved set-up under vacuum conditions.

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