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Time-Resolution and Timing Correction at the Femtosecond X-ray Experiments Instrument of the European XFEL

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Hard X-ray free-electron lasers (XFELs) have been a powerful tool for investigating ultrafast dynamics for more than ten years, with ever-improving capabilities in measuring on faster and faster timescales. The unique combination of Angstrom wavelengths and sub-100 fs pulse durations has proven especially important for probing the interplay between electronic and structural dynamics in a broad variety of samples. To observe such subtle and complicated processes, an ultrafast optical pump pulse is often used to initiate the dynamics, with femtosecond laser sources covering the UV to visible spectral range commonly being used, followed by an X-ray probe pulse. European XFEL can provide high intensity X-ray pulses with around 109 to 1012 photons/pulse (bandwidth dependent), high repetition rates from 100 kHz up to 4.5 MHz femtosecond X-ray pulse with 10 trains per second1. These X-ray pulse durations are generally around 50 fs (FWHM) but can be made substantially shorter, to the few fs regime, with different accelerator configurations. The facility pump-probe laser system is also capable of dynamically matching the X-ray pattern, with two default operation modes of 50 and 15 fs (FWHM) 800 nm pulses ranging from hundreds of uJs to mJ level (repetition rate dependent)2. These excellent characteristics make EuXFEL an attractive facility to perform ultrafast femtosecond time resolution research. However, the femtosecond time delay between the X-ray and optical laser pulses needs to be monitored as precisely as possible to get a relatively more accurate value from which to improve the time resolution. This relative timing stability can be affected by both slow (drift) and fast (jitter) components that can originate from a number of sources. One standard approach to address this issue is to measure on a shot-to-shot basis the relative timing difference between the laser and X-rays. Once the pulse-resolved timing jitter has been measured, the pump-probe time delays of each pulse can then be corrected, removing this contribution from the measurement3.
In this talk, we will present the Femtosecond X-ray Experiments (FXE) instrument4,5, which is focused on measuring ultrafast dynamics in the condensed phase using a broad variety of hard X-ray spectroscopy and scattering techniques. We will present the results of several measurements on solution-phase metal-centered molecular complexes6 where the time resolution of the instrument is explored, and the contributions of the various sources of timing instability are identified and measured. The results will focus on the deployment of the pulse arrival monitor (PAM) laser-X-ray timing diagnostic7, with an explanation as to how it is integrated into the parallel measurement capabilities of the instrument, and how the complementary beam arrival monitor (BAM) accelerator diagnostic information can be used as a complementary timing diagnostic. The photochemical dynamics reported include the X-ray emission spectrum and X-ray scattering, measured in parallel with both BAM and PAM diagnostics, providing an improvement in the timing resolution. The presentation will conclude with a summary of the important elements for achieving good time resolution at the FXE instrument, and an overview of the experimental conditions for achieving this.

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6. Lima, F. A. et al. Experimental capabilities for liquid jet samples at sub-MHz rates at the FXE Instrument at European XFEL. J. Synchrotron Radiat. 30, (2023).
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I plan to submit also conference proceedings

No

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