The Fastjack – A robust, UHV compatible and high performance linear actuator

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Abstract

With the development of the ESRF Double Crystal Monochromator (DCM) [1], there was a need for a robust, UHV compatible, nanometer level accuracy and centimeters range

linear actuator. Therefore, a custom designed actuator, called the "Fastjack" has been developed. In this paper, the specifications and associated design choices of the Fastjack are presented. Then, the testing procedure is described and the obtained performances are analyzed. Finally, improvements are proposed to overcome the identified performance limitations.

In terms of working conditions, the robustness of the Fastjack is a major concern as it will included in critical instruments, usually in UHV conditions and for which a maintenance is complex. Therefore, it should be able to perform 10 million cycles and be able to function in degraded mode without any position sensor feedback (i.e. in open-loop).

Regarding mechanical characteristics, it should have a high axial stiffness (> 10 N/µm) and be able to support large payloads (up to 10 kg). In terms of positioning capability, the linear stroke should be more than 30mm, the accuracy better than 5µm in open-loop (i.e. degraded mode) and better than 5nm in closed-loop mode.

The Fastjack is composed of a stepper motor (200 steps/turn) whose rotor is fixed to satellite roller screw (1mm pitch). A ball bearing guide is used to linearly guide the motion over a stroke of 30mm. A flexible joint is added in between the ball bearing guide and the piezoelectric actuator to allow for small angles between the fixed and mobile parts (useful for parallel architecture such as a tripod used for the DCM). A piezoelectric actuator with a stroke of 15µm is added for correction of position errors. The flexible membrane is used to pre-load on the piezoelectric actuator.

There are three main "working mode" for the Fastjack that are explained bellow. In "mode A", the Stepper motor is working in open-loop. This is the fallback mode in case the piezoelectric actuator is not working or if there is no feedback sensor signal available. This working mode is only here as a backup mode as the availability of the actuator is very important.
In "mode B", the repeatable errors of the Fastjack are calibrated using an external sensor. The stepper motor is then operated in open loop with a calibration table included in the motor driver.
"Mode C" works with an external sensor, typically an interferometer measuring the linear motion of the Fastjack. The piezoelectric actuator is operated in closed loop to compensate the position errors in real time. This is the normal working mode of the Fastjack.

In order to characterize the performances of the Fastjack, a test bench as been developed (see Figure 1). The Fastjack is supporting a payload (a 5kg granite) vertically guided with an air bearing. The motion of the payload is measured using an interferometer. A Speedgoat machine is used for the real-time feedback control of the piezoelectric actuator. A DAC and a voltage amplifier are used to drive the piezoelectric actuator. The IcePAP [2] is used for the control of the Stepper Motor. Finally, everything is orchestrated from BLISS [3].

The position errors in Mode A (i.e. open loop control of the stepper motor) are measured and analyzed.
These errors are shown in Figure 2 and can be separated into three main categories. First, the lead screw pitch errors (Figure 2a) which have a period equal to the pitch of the lead screw (i.e. 1mm) with an amplitude of approximately 1µm. Looking at smaller periods (Figure 2b), we see errors with an amplitude of 300nm that repeats every 20µm which is corresponding to a 1/50 of a turn. These are called micro-stepping errors. Finally, in Figure 3c, even smaller errors in the order of 50 nm with a period of 0.4µm can be seen. These errors are repeated every 5µm (1/200 of a turn, a full step).
Even tough the lead screw pitch errors have the highest amplitudes, when scanning with the Fastjack, the vibrations associated will be at low frequency and therefore will be the easiest to compensate using feedback control.

The performances in mode C is very dependent on the velocity of the motion. This is due to the fact that the frequency of the position errors of the Fastjack (Figure 2) are linearly proportional to the velocity. For instance, consider a scan with a velocity of 0.1mm/s. The frequency of the lead screw pitch errors will be equal to 0.1 Hz, while the micro-stepping errors will have a frequency of 10Hz and the torque ripple errors a frequency of 250Hz. Therefore, at this velocity, the lead screw pitch errors and the micro-stepping errors can be reduced using the feedback controller but not the torque ripple errors that are at too high frequency (i.e. outside the controller bandwidth).

Possible improvements in terms of positioning accuracy at high velocity are the use of active damping technique using an additional force sensor, or adding a rotational encoder to the stepper motor or even changing of the motor technology. We are currently implementing these solutions for validation tests.

Figures

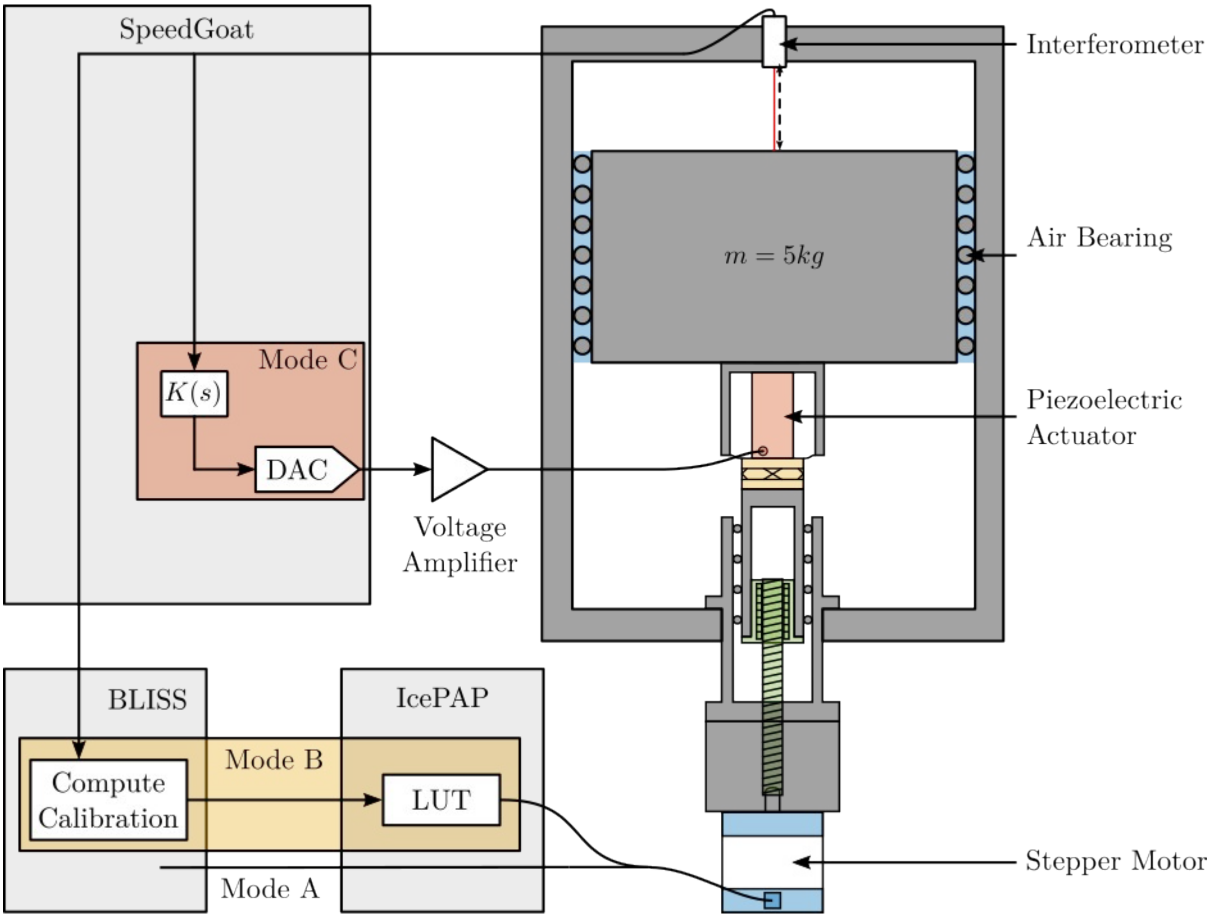

Figure 1 – Schematic of the Fastjack test bench and associated working modes.

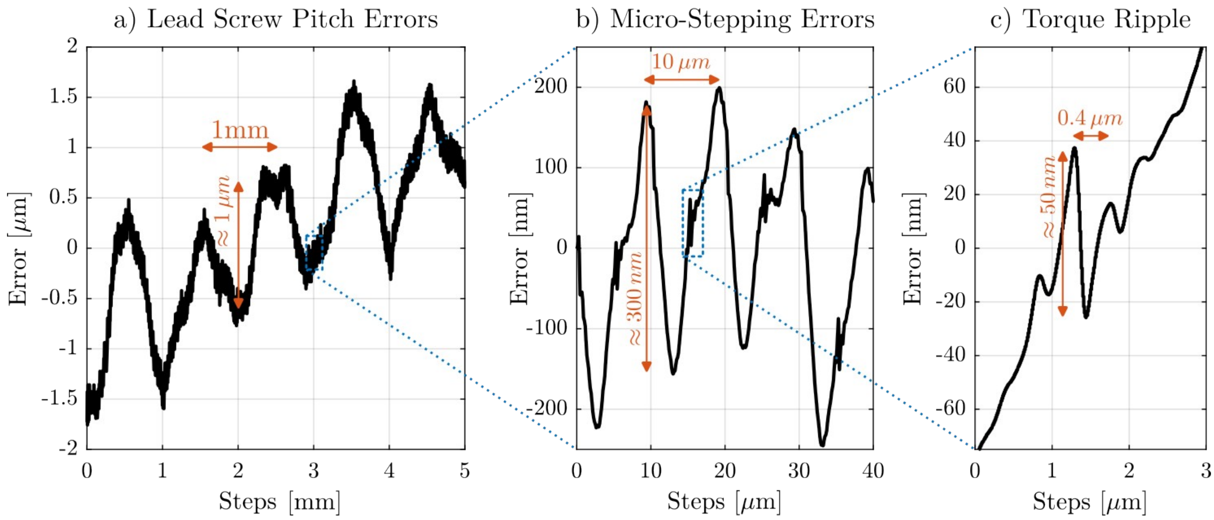

Figure 2 – Open Loop Errors of the Fastjack

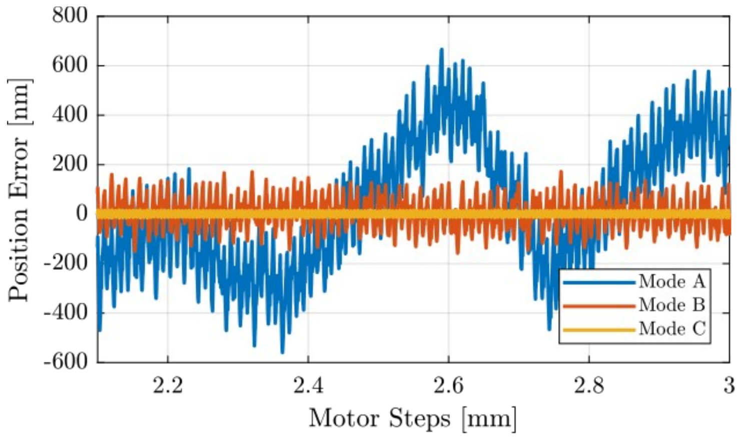

Figure 3 – Position erors of the Fastjack in mode A, mode B and mode C

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