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MOTION CONTROL IMPROVEMENTS FOR THE KIRKPATRICK-BAEZ MIRROR SYSTEM FOR SIRIUS/LNLS EMA BEAMLINE*

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Abstract

The Kirkpatrick-Baez (KB) mirror system is composed of a vertical focusing mirror (VFM) and a horizontal focusing mirror. Both concave mirrors focus the X-ray beam by reflecting it at small grazing angles. The relocation of this system from UVX XDS beamline to Sirius EMA beamline facilitated a full revision of the motion control system, whose controller was migrated to Omron Delta Tau Power Brick LV. The beam focus is controlled by bending the mirrors through camshaft mechanisms coupled to low current Faulhaber motors. Although the amplifier is designed for higher currents, controller settings allowed the use of lower currents. Another improvement made is the ability to drive both bender motors in gantry mode and still control the lag between them. Each bender has a capacitive sensor to monitor the position of the center of the mirror, which is read by the analog input of the controller and made available by EPICS [1]. The VFM is supported by a tripod and a new kinematics was developed to reference the center of the mirror as the point of control. This paper presents the implementation of the new motion control KB system and its results at Sirius EMA beamline.

INTRODUCTION

The KB mirror system from XDS beamline at the previous accelerator UVX has been reconditioned for its operation at EMA beamline at Sirius. A full review of mechanisms and optics was done at the system since it was in operation for years at XDS. Some parts were adapted with new concepts brought from other Sirius devices, such as DCM and mirror systems [2,3]. The new parts give the system more repeatability since the backlash is reduced by the substitution of bushing-axis mechanism to parallel leaf spring translator. The mechanical enhancement favoured upgrades on the mirror bending control system.

A closed loop was developed using Power Brick controller for the mirror bending system. Since this controller has more features than the one used previously, the entire system, including its rough positioning by its supporting bench, has been redesigned. A kinematics inspired on mirror systems [4] was developed for a better user experience during commissioning, alignment, and operation because no hand calculation would be necessary to position the mirrors by commanding the actuators one by one.

The present paper is going to present further studies of driving low current stepper motors inspired on [5], the peripherical sensors that offer monitoring during operation and the details of kinematics implementation.

SYSTEM ARCHITECTURE

The KB system is composed of eleven motors with encoders, two piezos for fine pitch and two capacitive sensors. These are divided into two subsystems: VFM and HFM. Each subsystem is composed of a mirror with two motors responsible for driving the bending mechanism, with a capacitive sensor at the center of the mirror, and a base.

The HFM base is composed of one motor for each translation (Ux and Uy) and one for rotation around the X axis. The VFM base is more complex, composed of a tripod responsible for the required rotations (Rx and Ry) and translation on the Y axis.

All motors and encoders are controlled using a Power Brick LV. The capacitive sensors signals are read using the analog input in the same controller after being conditioned through the standard PI device. The piezos are controlled individually using PI servo controllers.

For the final users, all necessary commands are implemented in a graphic user interface (GUI) using process variables (PVs) made available by EPICS.

MIRROR BENDER

Driving Low Current Motors with High Current Amplifier

The Power Brick LV controller was adopted at Sirius for its ability to cover a range of motion control solutions. This controller is integrated with a 5 / 15 A amplifier [6]. The mirror bender motors used in the KB System are 250 mA and although the manufacturer does supply controllers with low current drivers, we opted to adapt the 5 / 15 A amplifier due to cost and time constrains. It has a bending system with two stepper motors AM2224 series model 0250 [7] coupled to a camshaft that pushes the mirror to bend and sets its focus.

Rising the inductance was the first setup to match the motor and controller specifications. To delay the current rising time, different values of inductors were placed in series with a low current test motor and the amplifier circuit could properly control the current on the motor coils.

Adding new components to the motor phases would change the motor properties, increase system cost, and decrease robustness. A detailed analysis led to the conclusion of limiting 48 V amplifier output PWM duty cycle. Since the current rise on the PWM on time and fall on the PWM off time [8], limiting the on-time voltage we chop the maximum reached current.

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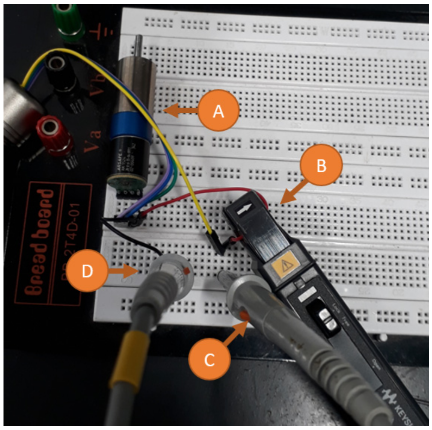

Figure 1: Proof of concept of current limiting by PWM scale factor.

Figure 1 shows the experimental setup for the validation of the duty cycle limiter concept. The phase A of ARSAPE AM1524 stepper motor A was submitted to a current bias of 100 mA from Power Brick. The current probe B was measuring the current passing on phase A coil and two voltage probes C and D were disposed to measure the voltage across the coil.

Starting from 95% of the full value of PwmSf, the percentual of the scale factor was reduced to zero and current measurements were performed at each scale factor value. The mean value of each measurement was calculated and plotted into the Fig. 2.

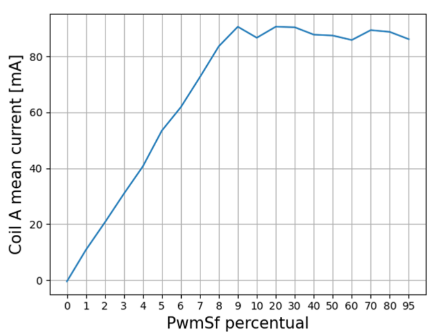

Figure 2: Percentual of full value of PwmSf versus Mean value of current at phase A submitted to a constant bias from the controller.

The test proved the current limitation, although the controller was trying to keep the current at 100 mA, it was not possible since PwmSf was limiting its output. This solution was chosen by its simple design. To ensure that the motor will not be damaged, phases fuses were displaced on final implementation.

Gantry Mode

To synchronize the bender motors movements, we created both the forward Eq. (1) and inverse (which is trivial from forward since the equation system is linear) native kinematic scripts implementing the following equations:

$$\begin{cases} X = 0.5(m_5 + m_6) \\ Y = 0.5(m_5 - m_6) \end{cases} \tag{1}$$

Where Y is the desynchronization angle and m_i are the motor positions. The X value is the bending parameter and can be interpreted as the bisector between the motor axes. Values set to the X parameter should move both motors in a synchronized manner, keeping the Y lag angle constant between them.

Capacitive Sensor Analog Input

There is a capacitive sensor behind each mirror to monitor the distance of the center of the mirror to infer the bending radius. An optical characterization of the mirror system was done using a Fizeau interferometer, which aims to find the relation between the mirror bending radius and the position read from the capacitive sensor.

This setup allows us to close the loop between bending motors and the capacitive sensor. Since the capacitive sensor does a direct measurement of the bending radius (in opposite to the bending motors encoders, which are coupled to the motor axis and perform an indirect measurement of the mirror bending radius) the control system would be more accurate on its setpoints. Closing this outer loop was not done yet due to the beamline deadlines but this is the next step on improving KB's positioning system.

VFM KINEMATICS

The VFM is supported by a tripod, a parallel robot with three degrees of freedom: Rx, Rz and Y, in Sirius reference frame. There is a linear stage coupled to the tripod that allows movements along the X axis. Those movements are required for the sake of simplicity on positioning the mirror on the correct place. The kinematics feature circumvents the need for iterative operation, improving time and user experience on the positioning of the mirror. Figure 3 shows the graphic user interface used with kinematics.

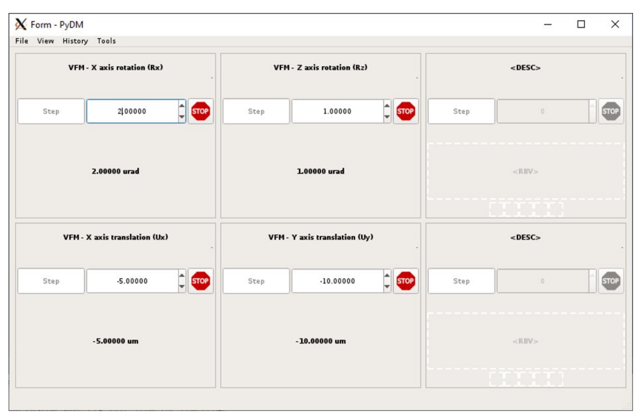

Figure 3: Test user interface for KB operation.

The stage above the tripod must be modelled together to obtain a single set of equations that describes the relationship between user positions and motor positions. This was done by transforming the parallel tripod robot into a serial robot with three joints, each one responsible for the three degree-of-freedom. Applying Taylor expansion on the tripod inverse kinematics (the angles are very small) turns the system easily inversible with a solver from the Python

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SymPy library solver [9]. The operation resulted on the forward approximated equations and those positions could be translated to the robot joints. The full model was obtained by adding the linear stage into this serial version of tripod. Figure 4 shows the joint scheme derived from the system showed in Fig. 5.

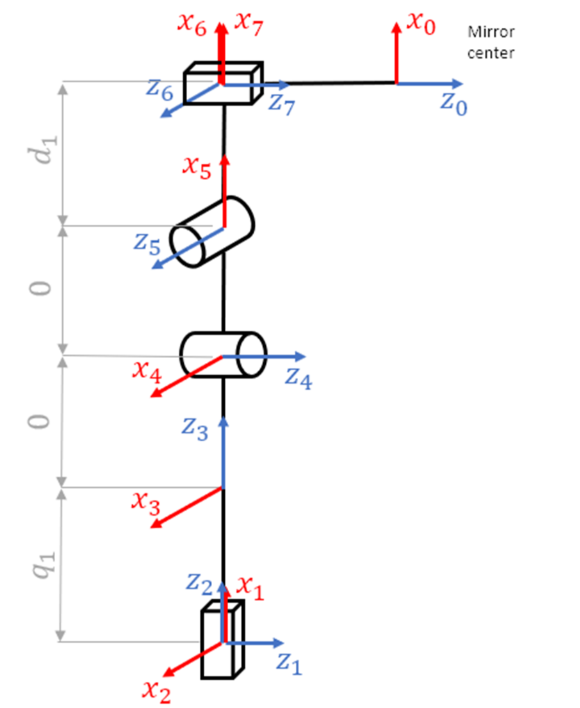

Figure 4: Kinematics joint scheme for geometric modelling.

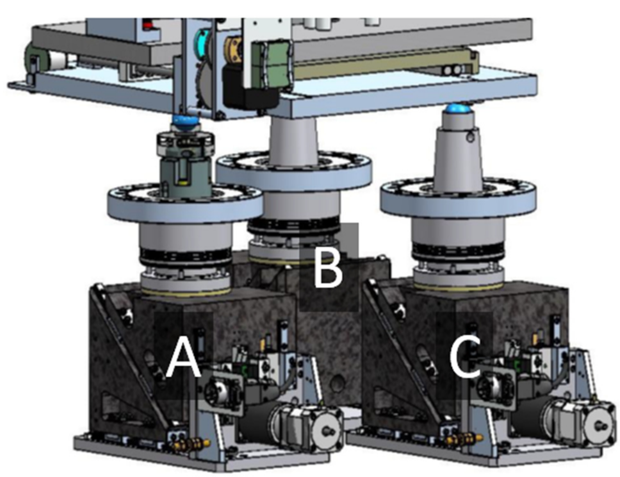

Figure 5: Tripod draw from system specification [10].

The KB solution uses the forward kinematics, which could be found by applying the basic transformation matrices on the robot joint scheme. The inverse kinematics is fundamental to command the motors with a setpoint input on Rx, Rz, Y and X axes and was found from the forward kinematics equations. The Power Brick embedded algorithm uses the Newton method [11] to solve the forward kinematics for the motors using as input the four user axes.

CONCLUSION

The EMA beamline KB system has been conditioned, it was successfully migrated to the new standard controller used at Sirius, the Omron Delta Tau Power Brick LV.

The studies and methodologies used on this work made possible and reliable to control low current motors with high current amplifier.

It was also possible to receive the capacitive sensors analog signals in the controller. This allows the simplification of the architecture and facilitates future improvements in closing the outer loop with this extra feedback.

The new kinematics used for the base of VFM improved usability and its equations were fixed, considering the reference frame transformation instead of simple geometric relations, as used before, which infer more accuracy to the motion.

To enhance the bending system and incorporate more accuracy on its movements, further work is going to set up a closed loop control using the capacitive sensor as feedback. This approach would measure the real bending radius instead of indirect measurements from the motors encoders.

At the time of this publication, the system has been commissioned and it is fully functional with the new improvements implemented.

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