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# A compact mirror manipulator in the SRRC beamline

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A compact mirror manipulator which has high stiffness and is easily adjustable has been developed for new beamlines at SRRC. It consists of a vertical stem to support the mirror and allows for six-axis precise positioning. The rotation adjustment is designed with a minimum of cross-coupling between adjustments. An independent support is fixed to the ground to reduce vibration from the chamber and the pump. Some performance test results in vacuum and in atmosphere, including vibration, repeatability, long-term drift *etc*., are described in this paper.

**Keywords: manipulators; mirrors; beamlines.**

## 1. Introduction

The mirror system plays an important role in the performance of a complete beamline. In addition to the performance of the mirror itself, the manipulator provides the mirror with adjustability and mechanical stability. Many mechanisms of mirror manipulation and support have been designed (*e.g.* the M-800 Hexapod-Micropositioning System of Physik Instrumente Gmbb, Waldbronn, Germany; see also Barraza *et al.*, 1995; Oversluizen *et al.*, 1991; Swain, 1990, 1992). These are mostly three-point kinematic mounting mechanisms and are rather complicated and expensive. At the Advanced Light Source, Swain (1990, 1992) has analysed the vibrational response of the mirror mounting system. There are few other reports of this kind of test.

At SRRC, a compact mirror manipulator has been developed to support mirrors up to 600 mm long on several beamlines under construction, including U5 and Dragon beamlines. It provides adjustments in $x$, $y$, $z$, pitch, roll and yaw directions for fine tuning of the mirror. To meet the requirements of users, the angular vibration of mirrors must be minimized to maintain the beam centring on the entrance slit at as little as 5 µm. In some cases, long-distance translation is necessary to switch the mirror to a different experiment branch. Therefore the manipulator has to be of a high stiffness while being easily adjustable.

## 2. Design considerations

The following engineering design concepts were adopted to meet the above-mentioned requirements: (i) adjustment in $x$, $y$, $z$, pitch, roll and yaw directions with little cross-coupling, (ii) stability of angular vibration below 1 arcsec, (iii) angular resolution less than 1 arcsec, (iv) all adjusting mechanisms to be outside the vacuum and (v) compact size accommodating medium flange-port size.

Basically, the manipulator consists of two parts. One is an $xyz$-stage with strong cross-roller bearings to provide the orthogonal translation movement, and is commercially available. The other is a tilting stage for adjustment of pitch, roll and yaw rotation, and is shown in Fig. 1. The height of the tilting stage is about 40 cm and the width is about 30 cm.

The tilting stage consists of a vertical adjusting stem ($a$) on which sits a pivot ball ($b$) to provide angular adjustment. Three micrometers ($c$) on the adjusting arm ($d$) are installed at suitable positions to eliminate cross-coupling for each angular adjustment. Three springs ($e$) opposed to the micrometers are used to provide the contact pressure between the micrometers and the adjusting arm. To obtain good anglular resolution, a differential-type micrometer with 0.5 µm resolution is adopted. The top plate ($f$) is a 100 CF blank flange to connect the mirror holder. The pivot ball is close to the top plate, the short distance giving high rigidity to the vertical stem. The bellows provide flexible vacuum shielding of the mechanism. Upon evacuation, the adjusting stem, together with the attached arm and the top plate, is lifted by the vacuum force (about 130 kg) and the pivot ball is pushed into connection with the upper ball support ($g$). The upper ball support, centre tube and base plate are fixed to the $xyz$-stage, making the ball a pivot for adjustment. Most parts of the tilting stage are outside the vacuum, with the exception of the top plate which connects the mirror holder. An independent stand fixed to the ground supports the mirror assembly to isolate the vibration from the chamber and the pump.

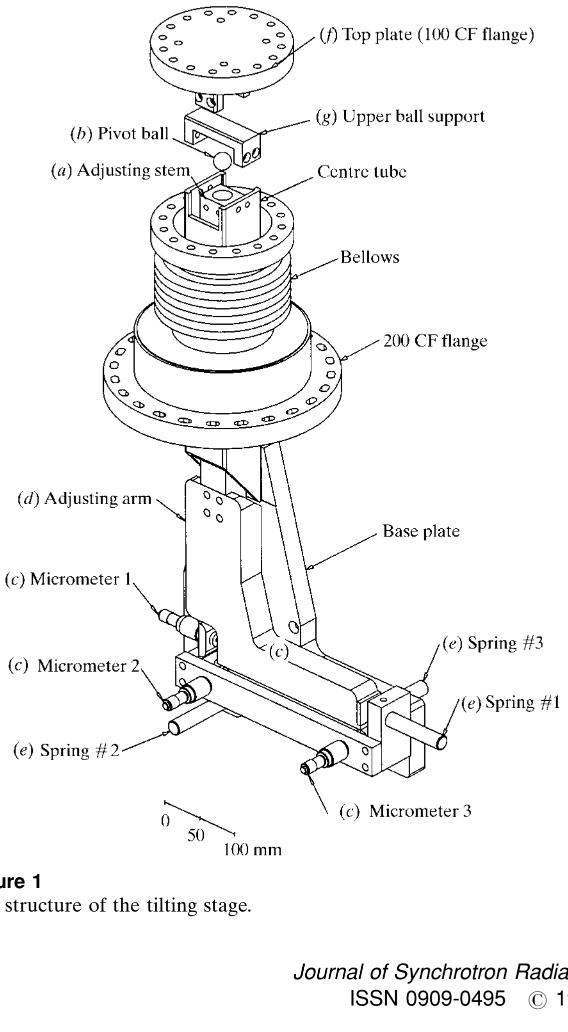

**Figure 1**
The structure of the tilting stage.

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## 3. Performance test results of the manipulator

### 3.1. *Angular vibration*

The angular vibration of the mirror manipulator was measured by an autocollimator installed on a stable steel support and a reflector fixed onto the manipulator under the vacuum chamber. The system was tested under a vacuum greater than $10^{-3}$ torr. The autocollimator and the vacuum chamber share the same support in order to eliminate relative motion. The *xyz*-stage of the manipulator was also fixed to the bottom plate of the support. In the laboratory, the vibration amplitude of the support is near the ground (below 100 nm). The measured vibration from the reflector can therefore be regarded as relative to the ground. As shown in Figs. 2(*a*) and 2(*b*), the angular vibration of the mirror manipulator in both the pitch and yaw directions is less than 0.05 arcsec (peak-to-peak) at a sampling rate of about 20 Hz.

### 3.2. *Pitch repeatability*

The pitch adjustment is essential for the vertical focusing mirror in the beamline. To test the repeatability, we attached three inductive axial probes with 0.1 μm resolution to monitor the position of the adjusting arm. We adjusted the pitch micrometer forward and backward twice and kept probe 1 (near the micrometer monitoring the attached arm position) in the same position in each step to observe the pitch repeatability. Two kinds of spring force of springs #2 and #3 were tested. The repeatabilities using 6 kg force and 10 kg force are below 0.75 arcsec and 1.5 arcsec, respectively. It can be observed that the larger force induces some repeatability deviation in the yaw direction due to minor shifting of the contact point between the probe and the adjusting arm.

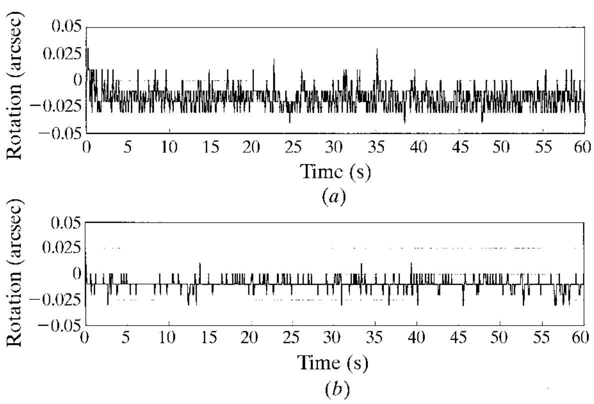

**Figure 2**
Angular vibration (*a*) in pitch direction, (*b*) in yaw direction.

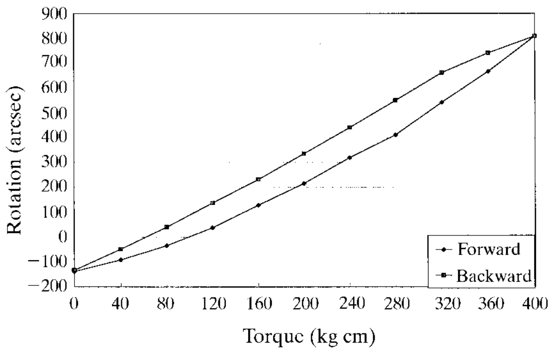

**Figure 3**
Rotating spring test rate of the bellows.

### 3.3. *Yaw repeatability*

In principle, yaw is determined by a force balance between springs #2 and #3, the micrometers, the adjusting arm and the intrinsic bellows torsional force. We found that the higher the spring force, the larger the adjustment range of the yaw. From the test results, the yaw adjustment range was about ±500 arcsec in the 10 kg spring force test. In the 20 kg force test, the yaw adjustment range was ±800 arcsec.

The spring force of springs #2 and #3 was set to 20 kg and the yaw was adjusted forward and backward twice using micrometer 3, while keeping probe 3 (near micrometer 3) at the same reading. The repeatability was found to be about 25 arcsec. We also observed that a 1–2 μm displacement of probe 2 (near micrometer 2) was equivalent to 5–10 arcsec deviation in the yaw repeatability. There seemed to be a further factor influencing yaw repeatability. Setting spring forces of springs #2 and #3 to 10 kg, we tested repeatability in the yaw direction three times by adjusting micrometer 3 and returning probes 2 and 3 to the same position by adjusting micrometers 2 and 3. In the second and third pass, yaw repeatability was as low as 2 arcsec, but in the first pass, repeatability was as high as 10 arcsec.

We suggest the following explanation. Fig. 3 shows the torsional properties of the bellows and shows a hysteresis loop. At a torque of 200 kg cm, equivalent to a 10 kg force, the angle lag is as high as 100 arcsec. In a smaller adjustment range the hysteresis lag is smaller but still exists, as shown in Fig. 4. The instability of the bellows may be a plausible factor in the poor yaw repeatability. Some homogenizing process for the bellows may be necessary prior to assembly.

### 3.4. *Long-term drift*

The long-term angle drift is important to users and is related to the stiffness, thermal deformation and creep phenomena of the *xyz*-stage and tilting stage. The test was performed on the optical table in atmosphere. A strong Acme lead screw and cross roller bearings are adopted in the *xyz*-stage. From a preliminary test, the *xyz*-stage has excellent stability over 10 h in a 0.1 K temperature-variation environment. The drift of the manipulator *versus* temperature change is shown in Fig. 5. The change in angle is reversible upon returning to the original temperature. A 0.5 K temperature variation induces about 0.1 arcsec change. A plastic sheet shielding is a simple way to keep the temperature stable.

### 3.5. *Lifetime test of the bellows*

To investigate the safety of the bellows used in the yaw adjustment, a lifetime test of the bellows was performed. The bellows were driven by a stepping motor with a yaw range

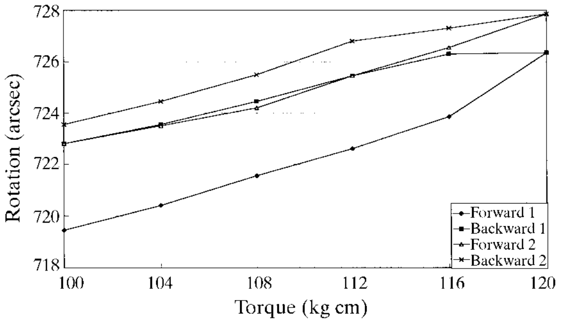

**Figure 4**
Rotating spring test rate of the bellows at a smaller torque.

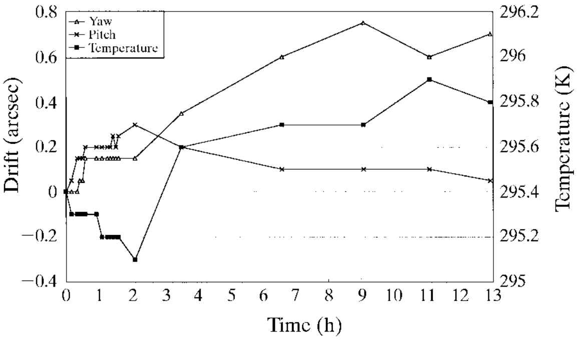

**Figure 5**
Long-term drift test of the manipulator.

±500 arcsec forward and backward 1000 times with a period of about 10 s. After the test, the leak rate was near the background of the leak detector (~$1 \times 10^{-10}$ atm $cm^3$ $s^{-1}$).

## 4. Discussion

The repeatability and stability of the pitch and yaw are governed by the force balance arising from the vacuum, spring and, particularly, the bellows. In the pitch direction, the rotational spring rate of the bellows is low, so the repeatability and stability are good. In the yaw direction, the torsional spring rate of the bellows is high and some hysteresis seems to occur. Therefore, generally, the yaw repeatability is worse than the repeatability in the pitch direction. In addition, temperature change has some influence on the long-term drift. Adopting a high heat-capacity material or a low thermal-expansion material may be a reasonable approach.

## 5. Summary

This type of manipulator basically meets the requirements of the beamline, and has been installed in the U5 beamline at SRRC. In the normal case, it can maintain 0.02 arcsec stability and 0.2 arcsec drift over a 10 h period. Repeatability in the pitch direction can be kept below 1 arcsec if the precision probe is monitored.

Since the torsional properties of the bellows restrict the yaw direction adjustability, greater spring force has to be exerted on the system to maintain a large range of yaw adjustability. The experimental data show that good repeatability is hard to maintain when a larger range of yaw adjustability is necessary. Further studies and improvements have to be made in the near future.

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