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CHARACTERIZATION OF MIRROR MOUNT PROTOTYPES FOR RICH DETECTORS

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ABSTRACT

The requirement for a high precision mirror positioning inside RICH detectors (LHCb, COMPASS) assumes that every mirror is fixed on the mechanical support structure by means of a fine adjustable mount. This has to fulfil strict mechanical criteria. Otherwise the adjustment process could be time-consuming, difficult and in some cases even impossible. The situation is complicated by the fact that apart from the adjustment precision requirements, only a small amount of material (representing a low fraction of radiation length) can be used in the mount design. In this article, the results from our measurements on the mechanical characteristics of mount prototypes developed in the TA2 group, INFN and TU in Torino and TU in Prague are presented.

INTRODUCTION

The spherical mirror walls inside the RICH[1] detector vessel are constructed as a mosaic of smaller, hexagonal shape mirrors. Every mirror element has to precisely point to the common focal point. At present, the required positioning angular precision has been given a value of ~0.1 mrad for the LHCb RICH-2 [*1*] detector and of ~0.2 mrad for the COMPASS RICH-1 [*2*] detector. After the adjustment, the positions have to be conserved during a large fraction of the detector lifetime (the mirror mount long-term stability is discussed in [3]).

In order to reach the required mirror positions, every mirror segment is fixed on an adjustable mount with the possibility of two angular adjustments. The adjustments have to be fine, with sufficient range, without hysteresis and with minimum deviations from the adjusting direction (crosstalk). This means that clearances and frictions in the mechanism must be minimized. To make the adjustment as simple as possible, the adjustment characteristics should be linear. The mount together with its mechanical support has to attenuate mechanical vibrations transferred from engines, vacuum pumps and other sources. To check all these adjustment properties, we developed a measurement set-up. Its main properties are high precision and flexibility to allow minimum adaptations to measure very different types of mount.

ADJUSTMENT REQUIREMENTS

In general, a three-dimensional object in space has six degrees of freedom. These are three rotations and three translations. In our case, the position of the spherical mirror has to be

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[1] We shall restrict our considerations essentially to the LHCb RICH-2 and the COMPASS RICH-1 detectors.

adjusted through two rotations about axes perpendicular to the optical axis of the mirror (see Fig.1). This adjustment is critical, because a small angle deviation produces over a distance of several metres a big displacement of the reflected light. The other degrees of freedom are fixed with rough adjustments or their values are obtained by careful mechanical construction.

A mirror angular position change causes double deviation of the reflected light angle. Thus the required positioning angular precision of 0.1 mrad means a precision of ~0.8 mm at the photodetector plane for the LHCb RICH-2 detector. In fact, this precision is worse because two reflections are needed, the second one on the plane mirror[2]. The adjustment range depends on the precision of the basic support structure production.

ADJUSTMENT WORKING PRINCIPLES

As a consequence of the low weight and of the low fraction of radiation length requirement, it is not convenient to use a classical precision-mechanics approach. Nevertheless, basic principles stay valid. To generate a fine adjustment angular movement, the simplest way is to transform a linear movement of a screw into a rotation of another part around a pivot. Flexible pivots are very convenient because they exclude clearances. For the required precision, it is necessary to design a proper transmission, e.g. based on the principle of the lever or of the wedge. Another possibility is to use a long arm. All the mentioned principles of fine movement transmission are shown in Fig.2-4, which represent each a different mount prototype.

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[2] ($\sim \sqrt{0.8^2 + 0.4^2} = 0.9$ mm). All the values are supposed to be r.m.s. values.

The wedge (a) (Fig.2) is pushed by the screw (b) in the direction x. Another wedge (c) can move only in direction y. This movement causes a rotation da of the arm (d) around the joint (e). The joint can be replaced by a flexible element. Corresponding formulas for the movement transformation are:

$$dy = dx * \tan\beta \qquad (1)$$

$$d\alpha \cong \frac{dy}{L} \qquad (2)$$

If the wedge angle b has value $b \le j$, where j is given by j = arctan f (f is a coefficient of friction), then the system is self-locking. This would enable to have a unique adjustment per direction.

The lever can be of inverting (Fig. 3a) or of non-inverting (Fig. 3b) type. The lever (a) is pushed by the screw (b) and turns around the support (c). The arm (d) then turns about the pivot (e). Parts (a), (c), (d) and (e) can be connected or replaced by flexible elements, called flexible joints. The first order- and second order- levers differ only by the sense of the resulting movement. Here are the corresponding formulas:

$$dy = dx * \frac{b}{a} \qquad (3)$$

$$d\alpha \cong \frac{dy}{L} \qquad (4)$$

For the long arm option (Fig. 4) the principle is simple. The long arm (a) is turned by the screw (b) around the joint (c). To get the transmission fine enough, the arm has to be long. Also, in order to ensure the required precision, the arm has to be rigid. This solution is acceptable if we have sufficient space in the design. da is given by

$$d\alpha \cong \frac{dx}{L} \qquad (5)$$

In the following, three prototypes from CERN, INFN and Univ. of Torino, and Tech. Univ. of Prague are described. They are based on the principles shown above and are the most representative between several prototypes we have tested.

PROTOTYPE DESIGNS

Mirror mount prototype A was designed in the EP/TA2 group at CERN for the LHCb RICH-2 detector. The requirement of robust, stable mirror mounts, with a favourable material budget, resulted in a decision to use Polycarbonate (PC) as material for the basic components of the adjustable mount. The mechanical properties of PC together with measurement of the long-term stability of the prototype are discussed in [3].

The working principle of prototype A (Fig. 5) is as follows: the adjustment of the mirror tilts is enabled by a flexible membrane (a). The whole holder structure (b) is made of one piece of PC, eliminating therefore clearances in the mechanism. It is mounted in a machined hole to a structure (c), which will support all the mirrors and the mirror mountings. A wedge (d) is pressed by a screw (e) into the PC structure, consequently pushing the central part of the holder (f) out of the axis position. The flexible membrane deforms elastically, therefore providing the reaction forces necessary to hold the mirror (g) in place. The latter rotates about the centre of the flexible membrane together with the central part of the holder. The angular tilt a is given by the formula: $a = y / L$, where y is the displacement due to the wedge and L is the length of the PC support. If the screw thread gives for a turn (360°) a displacement x_g to the wedge, then (see Eqs 1 and 2)

$$d\alpha = \frac{x_\gamma \, tg\beta}{L} \, d\gamma \qquad \text{(xx)}$$

In Table 1 we show the average da/dg for all tested prototypes, together with their r.m.s. values and the respective crosstalk r.m.s.

To achieve fine tuning in a, we need to decrease the numerator or/and increase the denominator. However, considerations of increase in X_0 fraction and material stiffness and stability define a range in the possible values for screw thread, wedge angle and holder length. Moreover, it is desirable to have a self-locking system to ensure a complete blocking of the mount, which defines an upper bound for the b angle. Therefore, a compromise was found and at present a full turn of the screw means $x_g = 0.7$ mm, $b = \ldots°$ and $L = 40$ mm. The same principle is applied for horizontal and vertical tilts and the average fraction of X_0 represented by the mount is ~ 5%.

The second mount prototype (prototype B, Fig. 6) was developed in INFN and Univ. of Torino for the first RICH detector of the COMPASS experiment. The principle of the long arm discussed in the previous section was used. Two perpendicular arms (a) turn independently around a ball joint (b). The movement is initiated by two screws (c). The design is light, made mostly of aluminum. In comparison with the PC prototype, it is somewhat less robust, as for example in case of induced vibrations from environmental background.

The prototype from the Technical University in Prague (prototype C, Fig. 7) adjusts mirror position by means of three levers of the first order. They are placed on the mount base under angle 120°. If one of the levers is adjusted, the mirror turns around the axis that connects the two other levers. The lever (a) is connected by flexible joints (b) with the other parts of the mount. The angle of the lever is controlled by the screw (c). Beside the required angular adjustment, it is possible to equip the mount by an adjustment (flexible structure (d)) in a plane perpendicular to the optical axis of the mirror.

EXPERIMENTAL SET-UP

We developed and prepared a set-up for the evaluation of adjustment characteristics of mirror mounts. Its scheme is shown in Fig. 8. A beam, produced by He-Ne laser source (a), is expanded and spatially filtered to extract the TEM_{00} mode (b). A spherical mirror with 5 m focal length (c) then gently focuses the obtained diffraction-limited beam on a CCD (h). The spot size and intensity on the CCD can be changed by means of a diaphragm (d). Half way between the spherical mirror and the CCD, a small plane mirror (g) fixed on the mount prototype (e) is placed. The prototype is loaded with a weight (i) that simulates the weight of the corresponding RICH mirror. Tilts, produced by the prototype adjustment, are measured by detection of beam-spot position on the CCD. For a detailed description of the set-up see ref.[..] .

The measurement is manual, the data processing partially automatic (beam-spot center of gravity finding). The tilt of the prototype is adjusted in regular steps (e.g. 45° of the adjustment screw turns). After every step, the CCD image of the beam-spot is acquired. Every few steps, the CCD position is changed in dependence on the corresponding step length on the CCD active area. The program first finds the rough location of the spot, then calculates its center of gravity. The spot consists of hundreds of pixels and the precision on spot position is 3 μrad or better. We measured the resulting tilt in the adjustment direction, as well as the parasitic tilt in the orthogonal direction (crosstalk). Both results are given in angular units.

MEASUREMENT RESULTS

We measured several prototypes of mirror mounts for the LHCb RICH-2 and COMPASS RICH-1 detectors. The measurement procedure is as following: in precise steps, the corresponding screw adjusts the loaded-mount tilt and for every step a CCD-image is acquired and stored. If possible, the whole range is measured. Then, the adjustment sense is reversed and the measurement continues back to the starting position[3]. The same procedure is applied for all two or three adjustment directions. Finally, from the processed data, we get the wanted information about precision, range, linearity, hysteresis and crosstalk.

Fig. 9 shows results taken on prototype A. Two cases were measured: the prototype equipped with aluminium wedges (results in Fig. 9a) and the same prototype with plastic[4] wedges (Fig.

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[3] It is not possible for the adjustment based on the wedge principle.

[4] Polyacetal (POM)

9b). The adjustment range is 3 mrad, which should be sufficient for carefully machined mounting holes in the supporting structure. Tilt change of 0.1 mrad corresponds to a screw turn of 36°, which enables a sufficiently precise adjustment. The relationship tilt-screw turn is nearly linear[5]. The r.m.s. crosstalk was lower than 0.01 mrad for plastic wedges and less than 0.015 mrad for aluminium wedges. From the results, it comes out that plastic wedges are more convenient, because of a smaller friction coefficient for the combination PC-POM than for PC-aluminium. As it was said before, the wedge principle excludes the possibility of an adjustment in reverse sense. Consequently, if the obtained tilt passes beyond the set-point value, it is necessary to restart the adjustment procedure.

Results from prototype B are shown in Fig. 10. The total adjustment range is wider than 12 mrad. A tilt of 0.1 mrad corresponds to a screw turn of 15°[6]. This value is well acceptable for the precision requirement of 0.2 mrad needed in the COMPASS RICH-1 detector. The adjustment characteristic is linear in the whole measured range. The r.m.s. value of crosstalk was better than 0.01 mrad. Adjustment characteristics are acceptable. Due to its design and material used, this prototype seems to be vibration sensitive and will need special care in order to damp vibrations.

Prototype C measurement results are presented in Fig. 11a,b. The measurement was done over the whole adjustment range which is 9 to 12 mrad for the three main directions. A tilt of 0.1 mrad is caused by a 36° screw turn[7]. The adjustment characteristics are linear and without hysteresis. The measured crosstalk was relatively large, its r.m.s. value being 0.04 mrad. However, the curve is smooth, as shown in Fig. 11b, which means that a precise adjustment of

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[5] The screw used had a pitch of 0.7 mm, that means a displacement of the wedge of 0.0875 mm for 45° turn.

[6] The screw used had a pitch of 0.5 mm.

[7] The screw used had a pitch of 1.25 mm.

the mirror tilt is still achievable. The prototype is vibration insensitive and was equipped with an interface mount–mirror, which was designed to minimize deformations at the thin-mirror rear surface caused by stresses from reaction forces and gravity. A lighter version of the prototype is under development at the Tech. Univ. in Prague.

CONCLUSIONS

We have developed and constructed an experimental set-up to measure the adjustment characteristics of mirror mounts for next RICH-detectors generation at CERN.

We have tested several mirror mount prototypes for the LHCb RICH-2 and COMPASS RICH-1 detectors. The three presented prototypes, with their characteristics, result from gradual design improvements based on the continuous feedback provided by the measurements. All three mounts feature precise adjustments and small crosstalk. The main differences between them are given by the range of adjustment, the distribution in space of the material budget (ex.: uniform for the first prototype, not uniform for the second) and the means of integrating them into the support structures.

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[1] LHCb, *"Technical Proposal"*, CERN/LNCC 98-4 LHCC/P4 (1998);
[2] COMPASS
[3] C. D'Ambrosio et al., "An Experimental Set-up to Measure the Long-term Stability of Large-mirror Supports", Public note, CERN/LHCb 2000 – 020 RICH, (2000)
[4] P. Yoder, "Opto-mechanical Systems Design", 2nd ed., Marcel Dekker, Inc. (1993)

Table 1

	$\left\langle \frac{d\alpha}{d\gamma} \right\rangle$	**R^2**	**crosstalk**	**Avr. Crosstalk per screw rotation**
A	0.19	0.996	0.015	
	0.19	0.965		
	0.18	0.995	0.009	
	0.19	0.996		
B	0.40	1.000	0.01	
C	0.15	0.998	0.04	

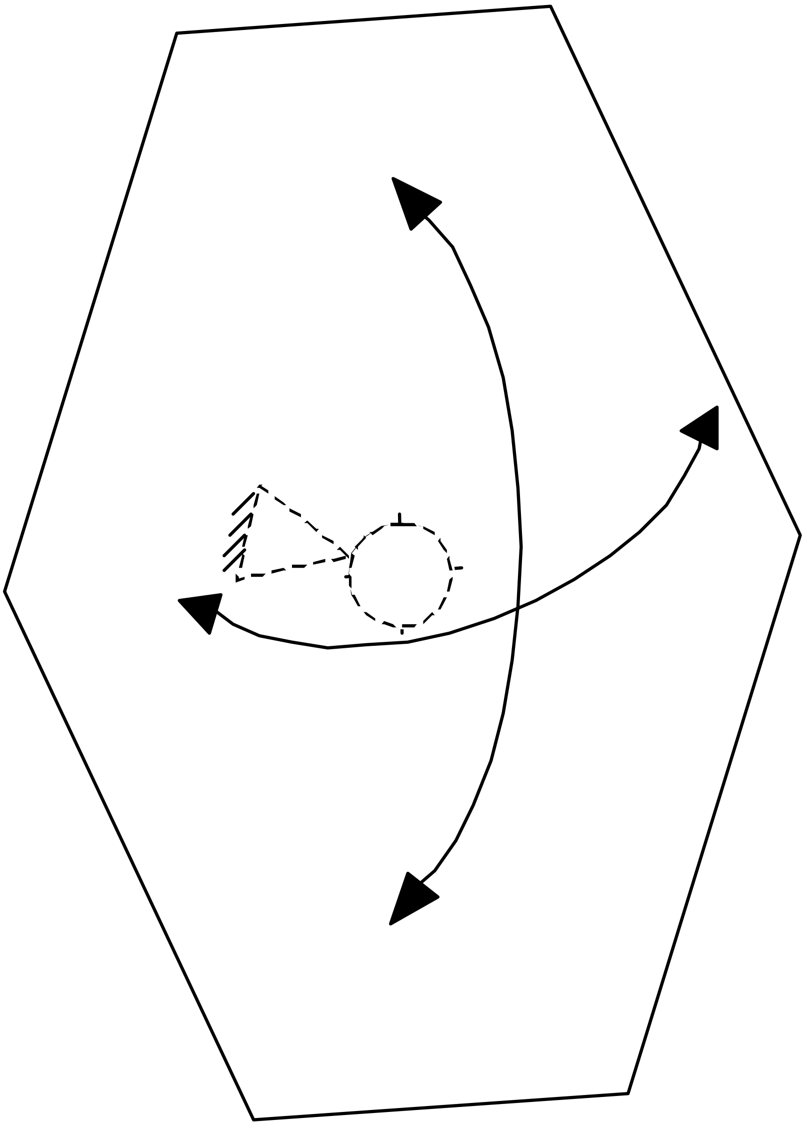


Fig. 1: The rotations corresponding to the two critical degrees of freedom.

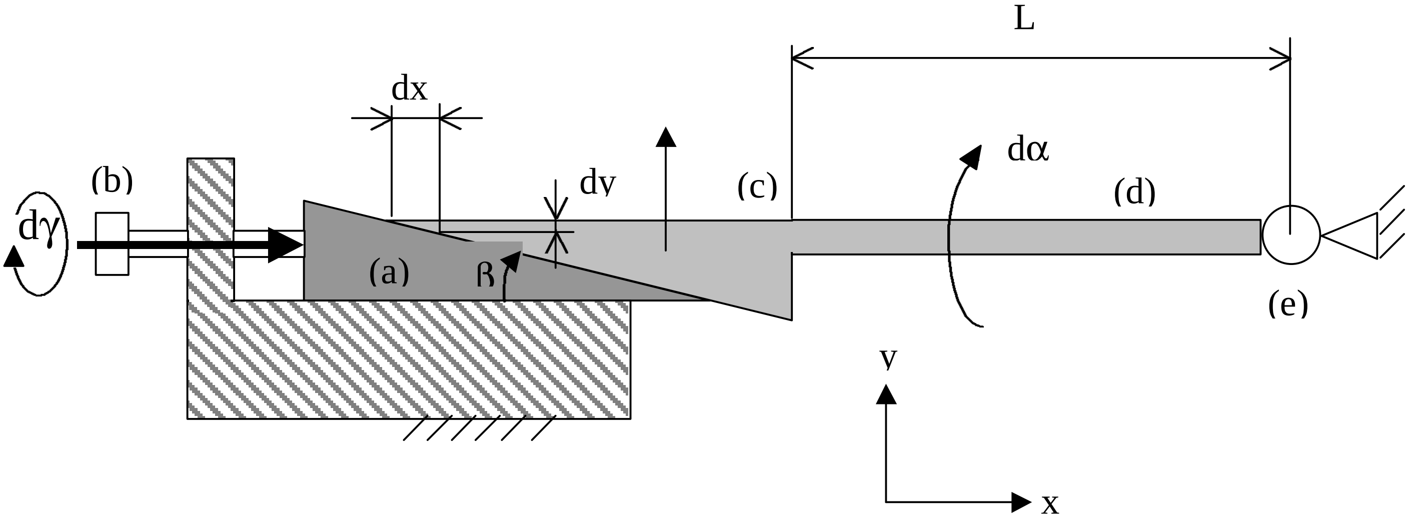


Fig. 2: The principle of the wedge (not to scale).

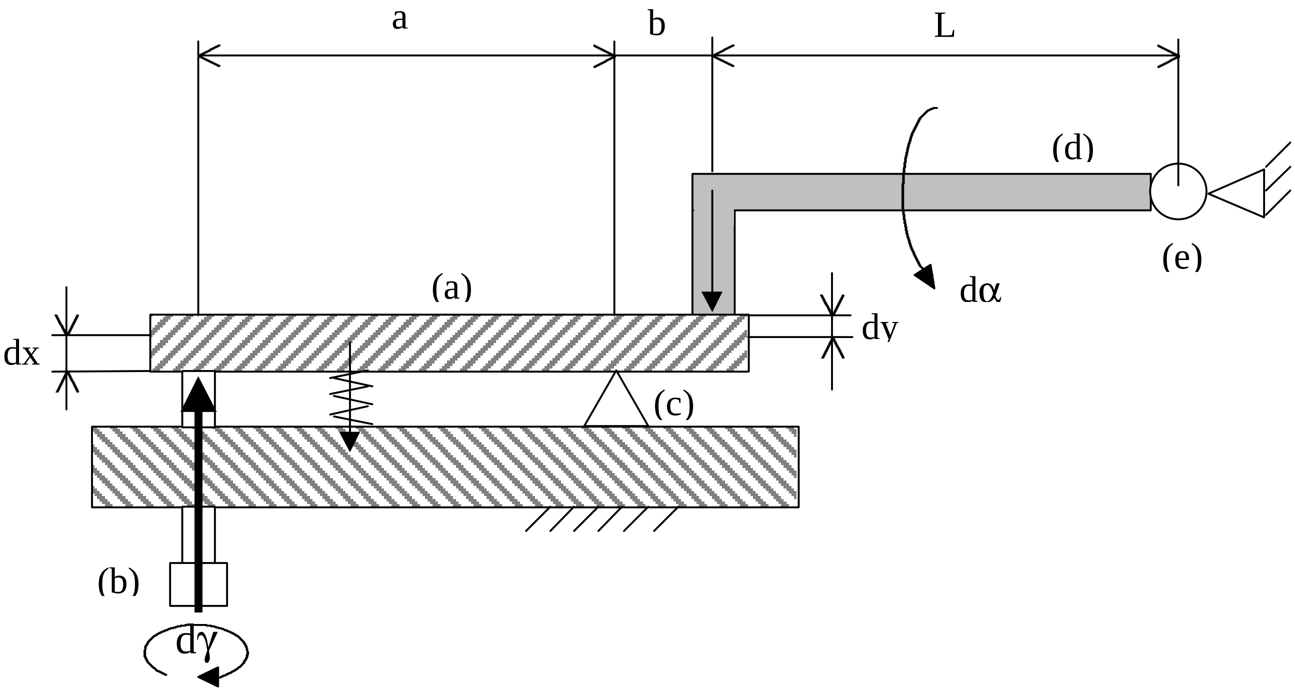


Fig. 3a: Inverting type lever (not to scale).

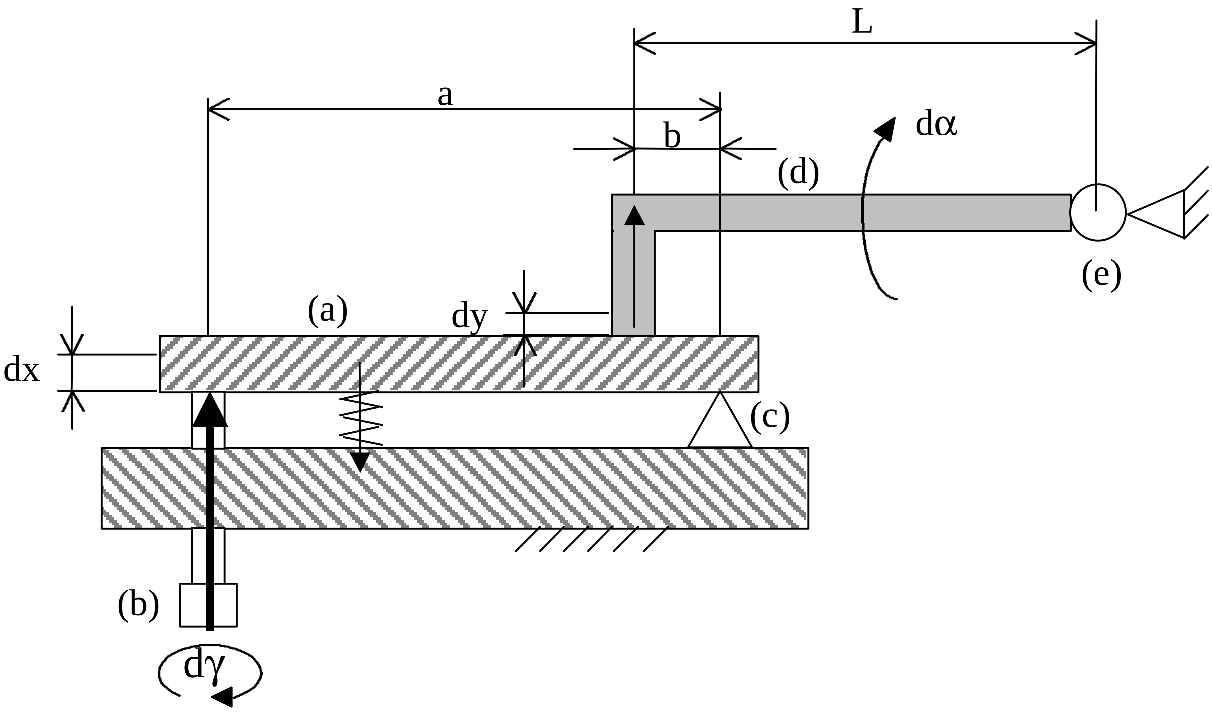


Fig. 3b: The non-inverting type lever (not to scale).

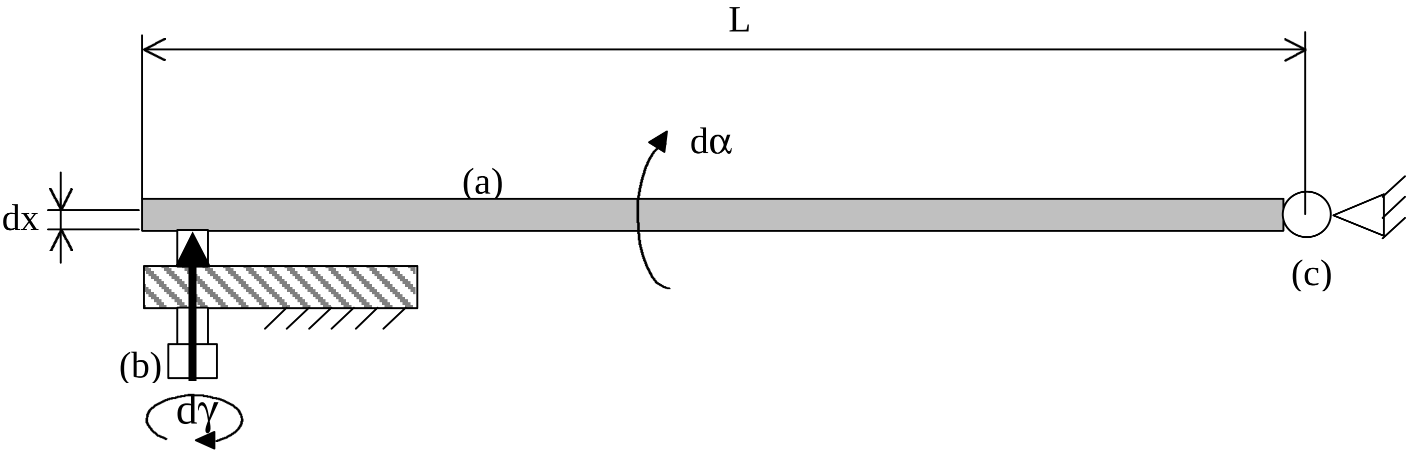


Fig. 4: The principle of the long arm (not to scale).

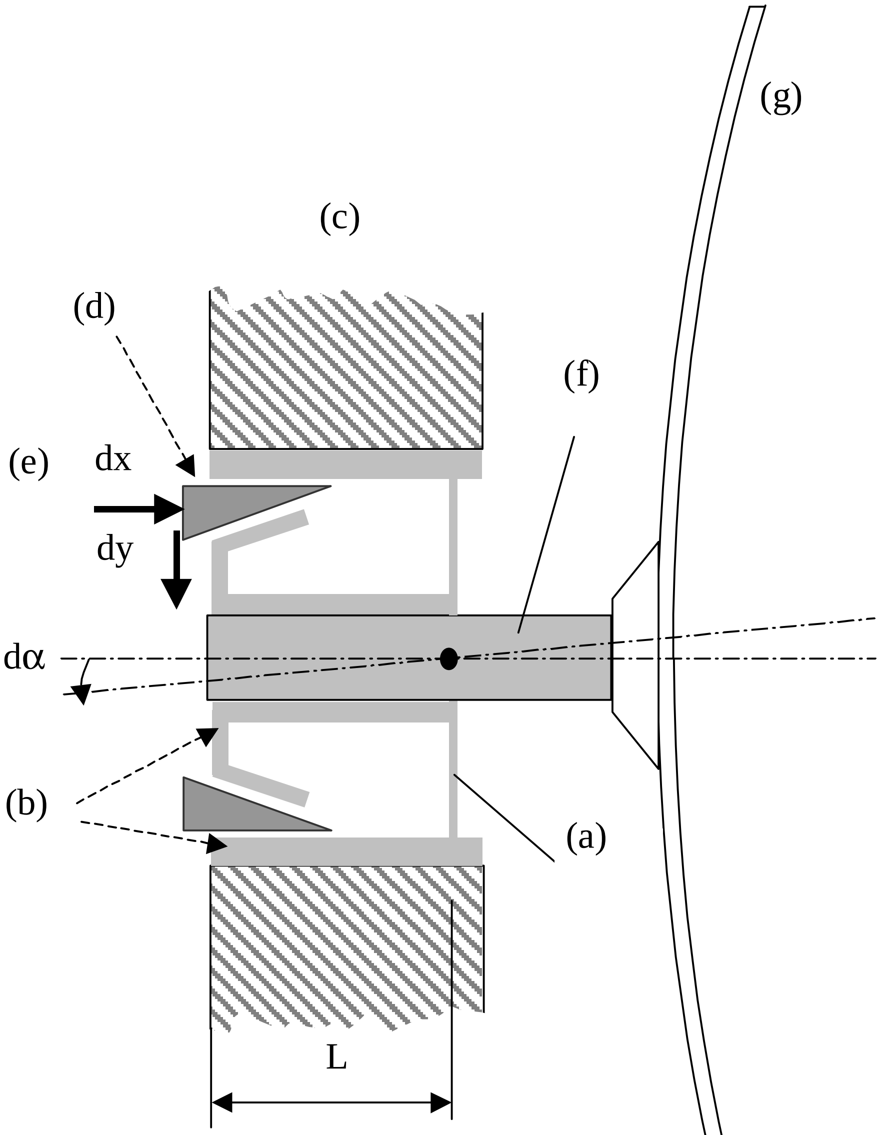
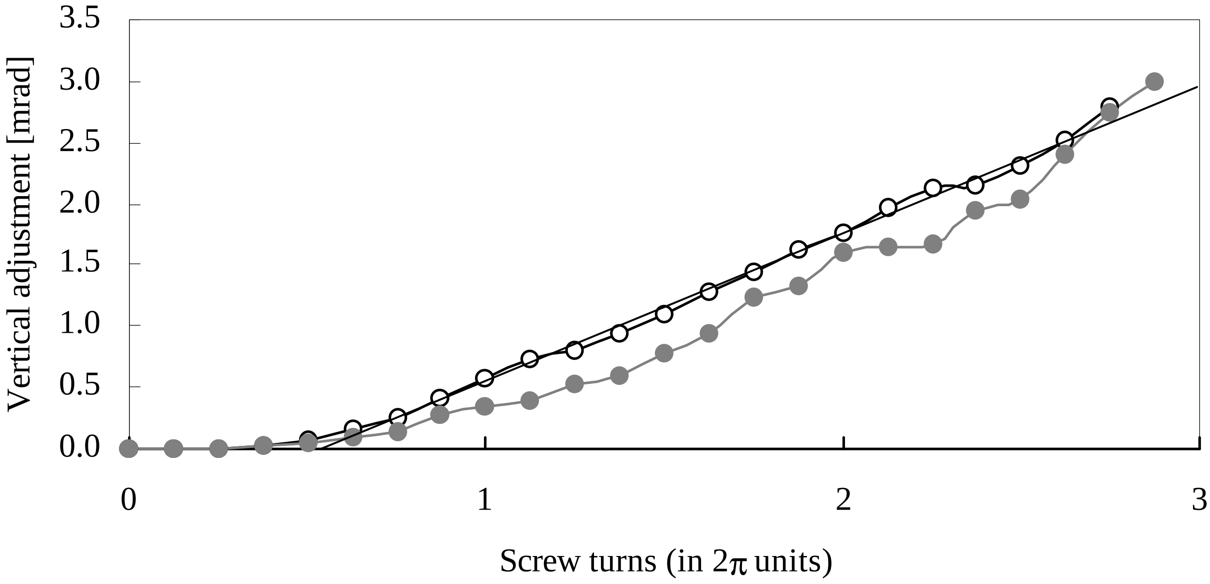


Fig. 5: Scheme of the prototype A.



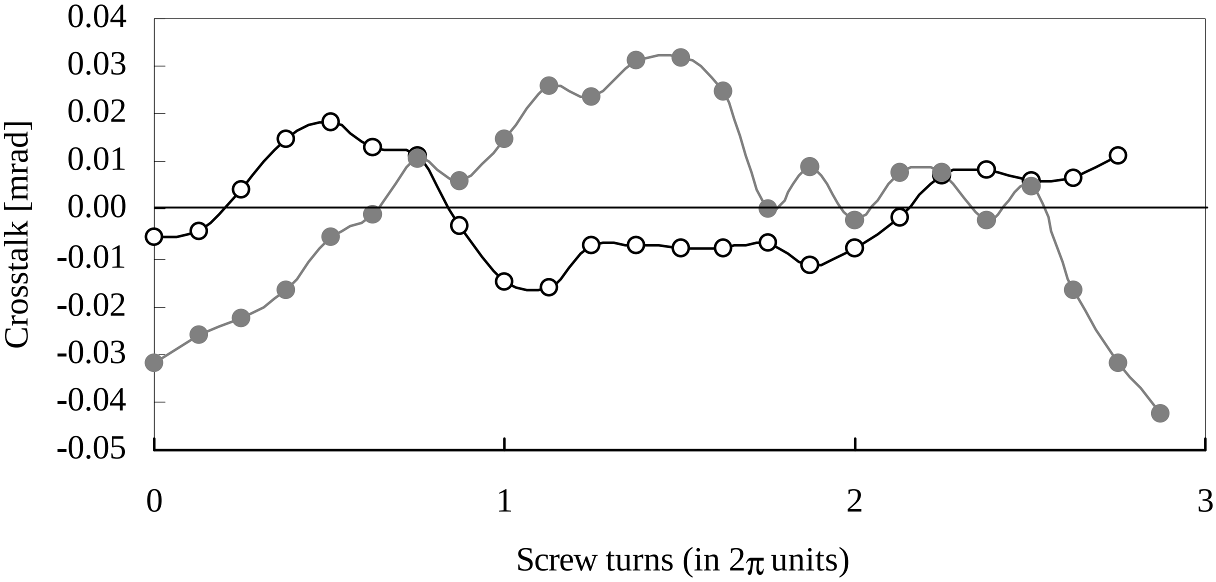


Fig. 9a: Results from prototype A with aluminum wedges. Measurement was repeated twice. A linear fit to the measurement is shown. The r.m.s. variation for the cross-talk is 0.015 mrad.

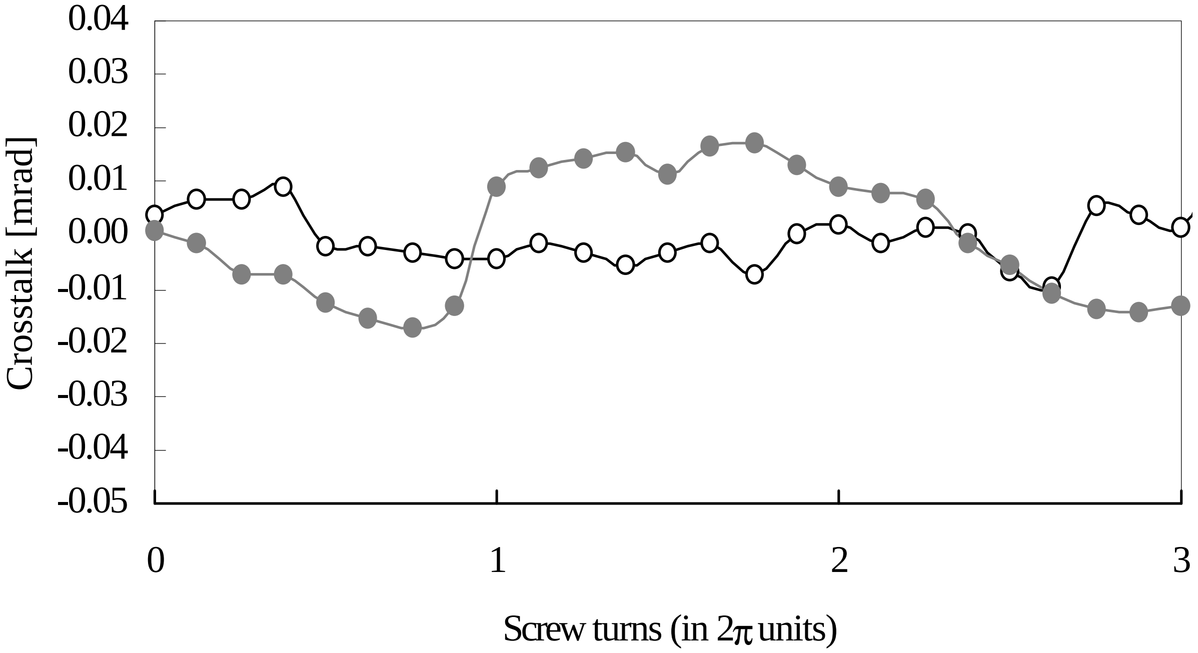
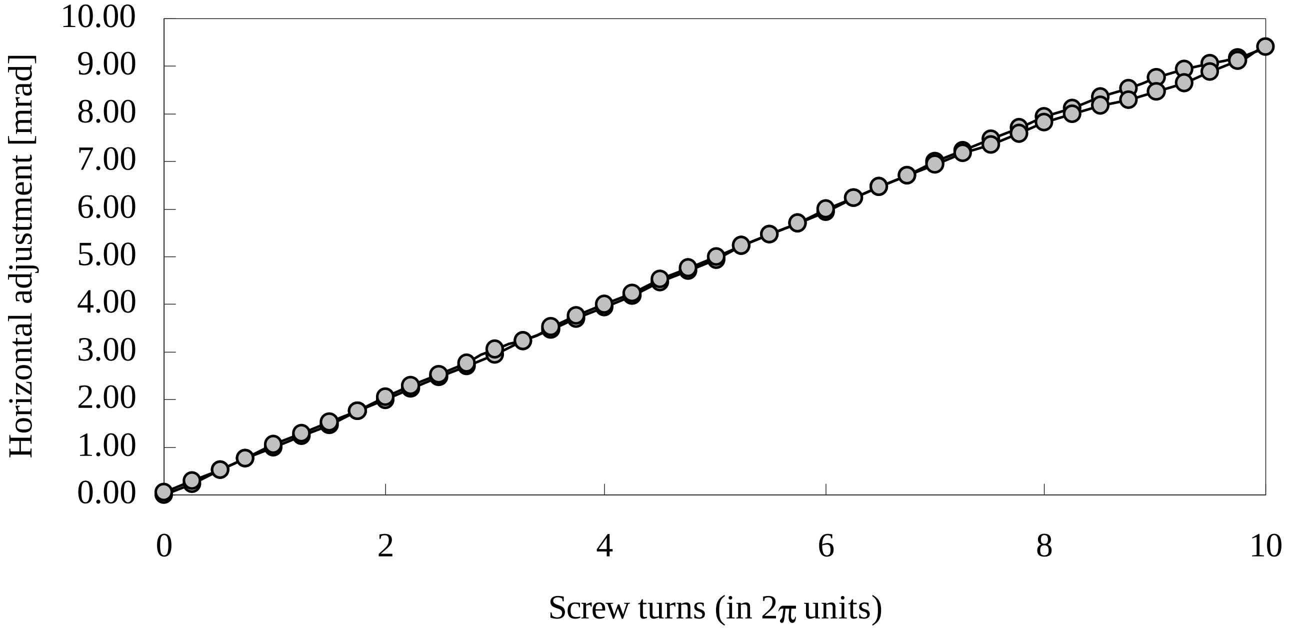


Fig. 9b: Results from prototype A with POM wedges. Measurement was repeated twice. A linear fit to the measurement is shown. The r.m.s. variation for the cross-talk is 0.009 mrad.

Fig. 10: Results from prototype B. The r.m.s. variation for the cross-talk is 0.01 mrad.



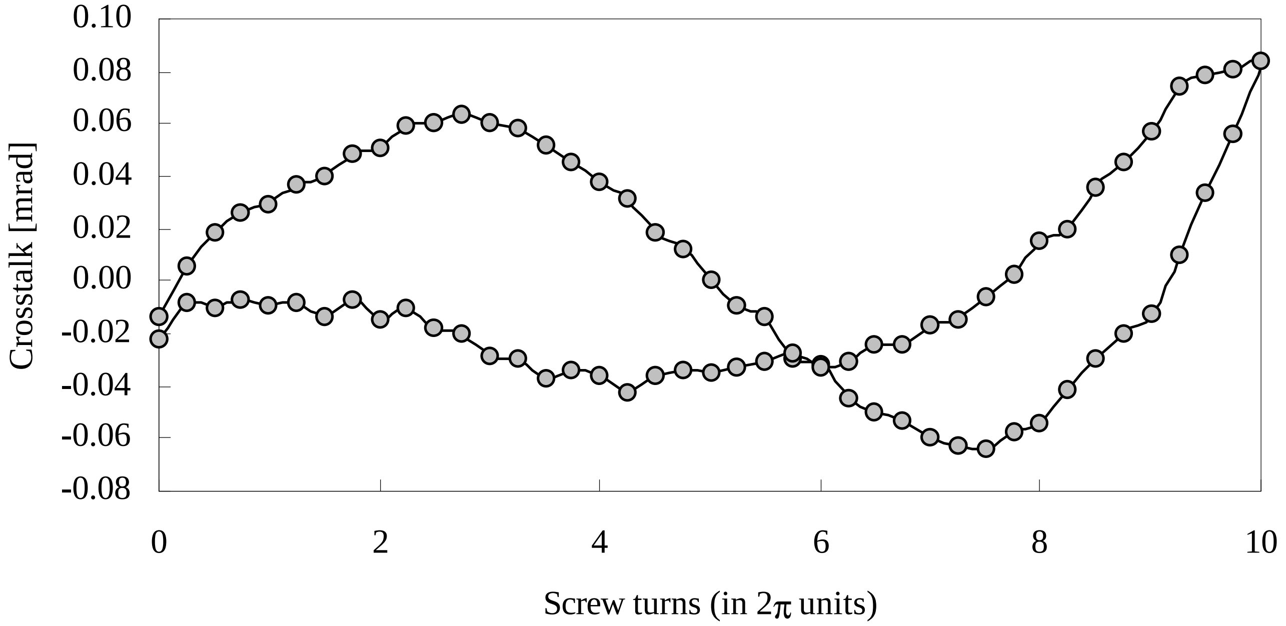


Fig. 11: Results from prototype C. The r.m.s. variation for the cross-talk is 0.04 mrad.