

F-SWITCH: NOVEL ‘RANDOM ACCESS’ MANIPULATOR FOR LARGE NUMBERS OF COMPOUND REFRACTIVE LENSES

G.M.A.Duller[†], A.Stallwood, D. R. Hall, Diamond Light Source, Didcot, UK

Abstract

The F-Switch is a new concept of device for the manipulation of large arrays of 2D CRLs or similar disc-shaped optical elements (12mm dia, 2mm thick) under high vacuum. Unlike the well-known transfocator devices the optical elements are randomly selectable. This enables a number of potential modes of operation, including the fine adjustment of focal length by adjusting the effective lens centre position when using CRLs or the use of some positions within the array to implement filters or reference foils. Actuation and guidance is achieved within the thickness of the element, so that the overall length of the device is minimised.

The device has been in user operation on the I04 MX beamline at Diamond Light Source (DLS) since 2015. Another device is being assembled for use on the I11 beamline at DLS. It is also hoped to install another device on the I03 beamline.

We present details of the mechanical design of the F-Switch and some examples of its operation.



Figure 1: A general view of the F-Switch from above. The leadscrew and claw actuator shaft are visible along with a number of the bistable springs. The lenses are all hidden below this view.

THE RATIONALE

The I04 end-station upgrade [1] created an adaptable and stable platform for the final beam-conditioning elements of the beamline. In order to further enhance its capabilities a specification was developed to add to this platform a transfocator [2, 3] style device. However, it was quickly appreciated that with the short focal length required the limitations of the binary basis of the transfocator would limit the system performance. To illustrate this problem consider a transfocator with a total of 63 lenses. This would consist of six individual moving parts holding 1, 2, 4, 8, 16 and 32 lenses each. To insert 31 lenses the first five holders have to be inserted into the beam. To change to 32 lenses all five of these parts have to be withdrawn and the sixth lens holder has to be insert-

ed. However, the effective centre of the lens has now been translated along the beam direction and so the resulting spot size at a fixed distance from the assembly may be very different from what is predicted if this effect is ignored.

The concept of the f-switch is that each of 120 lenses can be uniquely manipulated in and out of the beam. The benefit of this is obvious when the example above is considered, but it also allows for the number of lenses to be kept constant whilst the effective lens centre may be translated, thus allowing very fine control of the focal spot.

THE BISTABLE SPRING AND ACTUATION BLADE

The lenses used in the F-Switch are now a well-proven technology [4, 5] and are 2-D devices (rotational symmetry) mounted in a disk 2mm thick with a diameter of 12mm. The challenge was to design an actuation system within 2mm measured along the beam direction. The final design implemented a travelling actuator capable of operating on any one of the lenses, which implied that each lens then had to be securely retained in either of two states (in or out of beam) in the absence of an individual actuator. To allow beam to pass a lens which is nominally ‘out of beam’ the lens holder must be translated by a minimum of 6mm plus half the beam size. The acceptance of the lenses is 900µm, so the total motion required is a minimum of approximately 6.5mm.

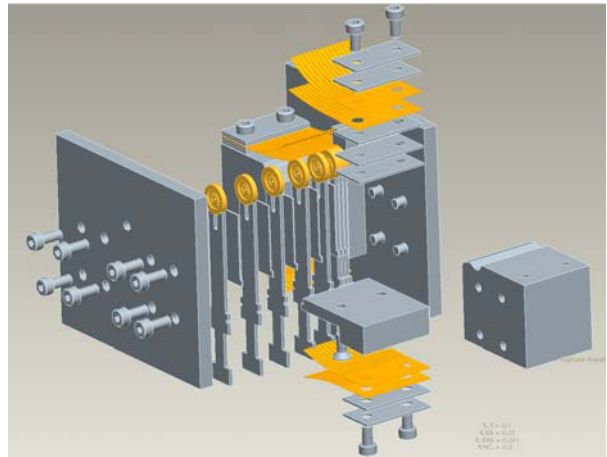


Figure 2: An exploded view of a prototype assembly. In this view the system is inverted wrt the final implementation, with the lenses shown at the top, acted on by a pair of leaf springs. Below this are the fixed spacers and the actuator blades with their bistable springs. The view of each spring is duplicated showing both the in-beam and out-of-beam condition.

[†]graham.duller@diamond.ac.uk

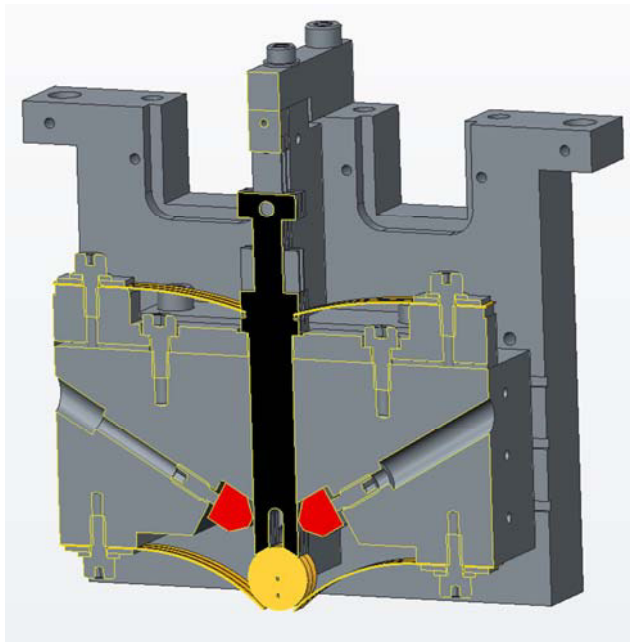


Figure 3: A section through the device showing the lenses (orange disks at the bottom of the view) held off the alignment vee (red) by the actuator blades (black). The beam passes through the slot in the actuator blade. The pair of bistable springs is seen at the centre of the image acting on the actuator blade.

When in beam the lens is held against a vee by a pair of CuBe leaf springs (Fig. 2, 3, 4). This ensures that the alignment of the lenses is repeatable.

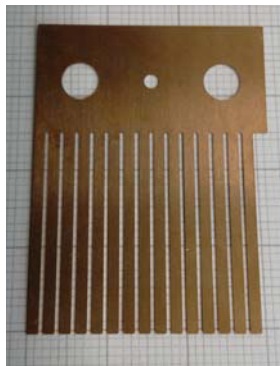


Figure 4: Atypical CuBe leaf spring. These are fabricated by chemical etching and each serves a bank of 15 lenses.

To remove the lens from the beam a narrow blade 1.2mm thick (Fig. 3, 5) is used to push the lens away from the vee and allow the beam to pass. This actuation blade is the key item allowing the operation in such a short space. The blade is supported from the sides by another pair of CuBe leaf springs, but in this case they are configured to give a bistable operation. When the blade is actuated (in either direction) the leaf springs are buckled. This is an intrinsically unstable condition so that in the event of incomplete operation the springs will always tend to return the lens to either the in or out positions. In the in and out positions the blade leaf springs return to a simple curved shape which ensures that they are stiff (and, therefore, stable).

For both types of spring it is important to apply the correct heat treatment. Half-hard was used for both sets of parts. Initial tests showed that the bistable springs would crack due to fatigue after about 5000 operations. This was solved by slightly lengthening the springs for the final design.



Figure 5: An actuator blade alongside a fixed spacer. Wire EDM was found to be the most cost-effective method of production for these parts. These examples are not yet DLC coated.

Finally, a 0.5mm fixed spacer blade separates each of the actuation blades to ensure no crosstalk between adjacent lenses (Fig. 2, 5).

ACTUATION

Actuation requires just two stepper motors, working in air. These drive a translation mechanism and a switching claw (Fig. 1, 6). The switching claw engages with tabs at the sides of the actuation blades to either pull them up to allow the lens to return to the in-beam position or to push them down, in which case the lens is then supported by the end of the actuation blade approximately 7.5mm away from the vee.



Figure 6: The actuation claw. The single blade actuation claw is to bottom left, while the three blade option is to top right. This item is DLC coated.

Full actuation requires less than 90° of rotation, so the claw has been manufactured with single-blade and triple-

blade options on opposite sides of its disk. To switch between single and triple blade actuation requires that the claw is translated to the end of travel, where it can be safely rotated through 180°.

The vacuum vessel and internals have all been designed to allow the implementation of a second actuation system (motors, feedthroughs, translation leadscrew and claw operating shaft) if required. This has not yet been implemented, but it is intended to install this soon during the next upgrade to the system.

DRIVETRAIN

The drivetrain has been designed to allow continuous operation by removing the stepper motors from the vacuum space. Currently, the motors drive toothed belts through a torque-limiting device. The torque-limit ensures that if a hard limit is struck (which is quite likely in the operation of the claw) then no damage is caused to the in-vac parts or to the drivetrain. At the driven end of the belt drive a ferrofluidic seal takes the rotary motions through the upstream vessel wall. The outer end of each of the ferrofluidic seal shafts is fitted with a compact magnetic rotary encoder. In order to make the unit even more compact the next upgrade will delete the belt drives and replace them with bevel gear drives.

The in-vacuum end of the ferrofluidic seal shaft is fitted with an Oldham coupling to allow easy assembly and setup. The leadscrew and claw-operating shafts are suspended between ball bearings, with one of the bearings being spring-energised to compensate for any expansion in the shafts due to operation.

THE PROBLEM OF SLIDING COMPONENTS

With such a compact space in which to implement the manipulation of each lens there are a great number of sliding surfaces in vacuum. The majority of the parts sliding against one another are stainless steel for vacuum compatibility and ease of manufacture. Because of concern that this could cause variable friction coefficients and/or the generation of particulate debris all sliding parts were initially Dicronite coated. Unfortunately, this was not found to be a good solution in this environment as a lot of particulate debris was formed. Following this, the Dicronite was stripped and all parts were Diamond-like-carbon (DLC) coated. This has provided a very hard, low friction coating which has not generated any noticeable debris to date.

TOLERANCES

The unit was designed to accept 128 lens elements initially. Early testing identified that tolerance build-up through such a long stack of components was excessive and could allow the actuation blades to develop excessive motion or to stick. A fixed divider was then introduced in seven positions to divide the lenses into eight blocks of fifteen lenses each, thus reducing the total number of lenses available to 120. The length of a block of fifteen

lenses is, essentially, defined by the thickness of the lenses themselves. Actuation blades were made in three different thicknesses to allow their selection during assembly to ensure that the stack of actuating blades matched the stack of lenses.

FEEDBACK

The unit is fitted with encoders on each of the two rotating shafts and microswitches to identify ends-of-travel. A pair of microswitches is also included which identify that the claw is in a safe position to translate along the unit. This was felt essential to ensure that a simple error of positioning could not cause significant damage to the rather delicate moving parts of the assembly. The encoders allow the speed of operation to be optimised, although the speed is still an aspect we would like to improve. Currently, a typical user-requested lens re-configuration takes about 30s (a single lens change is 1-2s), which should be halved when we install the second actuator drive. This, however, is still outside our original specification of 10s for a typical change. Further enhancement of the controls algorithms may allow us to increase performance to our desired level.

PERFORMANCE

The F-Switch has been operational for more than a year at the time of writing. Counters record the number of times lenses are operated, and in this time many of the lenses have been operated between 2000 and 2500 times with no issues.

The user is able to select beam sizes to match the size of crystal to be analysed over a wide range of sizes (5-100µm) and to work with focussed beam over a wide range of energies (6-18keV).

Speed of operation remains an issue, but the device can already make typical lens changes within ~30s. The addition of a second actuation system shortly should halve (or better) this figure.

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