PIEZO TECHNOLOGY IN SYNCHROTRON

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Abstract

Synchrotrons need robust products. That's why the association of piezo actuator technology and CEDRAT TECHNOLOGIES (CTEC) know-how has been successful for synchrotron mechanisms projects. The technological brick is the "Amplified Piezo Actuator" (APA®) tested and widely used in space applications, it is often implemented in CTEC piezo mechanisms and provides a high level of robustness. Modifying the layout and the number of APA® allows several needs to be addressed within beamlines. Three applications developed in collaboration with the EMBL, PAL and SOLEIL will be presented in this paper. The first application consists of cutting a beam with a piezo shutter. The maximum beam diameter is 3 mm. The second mechanism allows the energy of a beam to be modified by using a series of piezo actuated filters. And the last mechanism aims at modifying the beam section shape with an active piezo micro-slits mechanism.

PIEZO TECHNOLOGY AND SYNCHROTRONS

Synchrotrons need reliable products because most of the time the actuators are working in vacuum environments and it is very time consuming and expensive to break the vacuum for a maintenance operation. That's why the association of the piezo technology and the CEDRAT TECHNOLOGIES (CTEC) know-how has been successful for synchrotron mechanisms projects around the world for over 15 years.

LINEAR ACTUATOR APA

The Amplified Piezo Actuator APA® [1] was developed, tested and approved for space applications and then industrialised to be used in other markets, for example instrumentation. Thus, the APA® can withstand more than 10^{10} cycles. The actuator is composed of a piezo ceramic which generates a translation motion. The piezo ceramic has only a 0.1 % active deformation: to get a 0.5 mm displacement motion the piezo ceramic size should be 0.5 m. That's why the APA uses a shell around the piezo-ceramic to amplify the movement and increase this deformation. As an example the APA600M with 0.55 mm stroke is only 15 mm-height. The active deformation ratio is then 3.7%. The full stroke of the APA® is achieved with a 170 V range (-20 to +150 V).

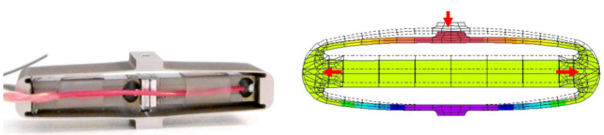

Figure 1: APA600M Actuator & Shell displacement.

In Figure 1 the dotted lines represent the actuator at rest thus not powered. When a positive voltage is applied the ceramic expands outwards and the shell moves downwards.

The robustness of the APA® is present in all CTEC mechatronics products and especially for synchrotron beamlines: the fast shutter, the fast beam attenuation actuator and the active micro-slits products.

FAST PIEZO SHUTTER (FPS)

For this mechanism 2 APA® face each other on a rigid frame, see Fig. 2. At rest the optical head cuts the beam and when a voltage is applied, the two APA200M retract and the shutter opens. The opening between the 2 APA is around 0.4 mm, giving a security factor, this shutter is designed for a beam diameter up to 0.3 mm.

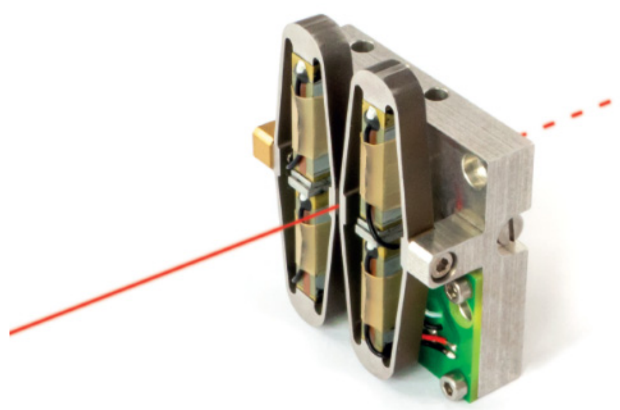

Figure 2: FPS200M.

These shutters are used to expose the sample behind it during a defined and controllable time. Aperture or closure time is directly linked to the resonance frequency of the actuator and so its stiffness. The APA200M has a mechanical resonance frequency of 900 Hz in blocked-free mode that is to say a period of 1.1 ms. The driver is optimised with a pre-shaped signal to minimise the excitation at this frequency. The mechanical ringing of the slits is reduced, even with a fast aperture and closing time of 2 ms. The APA200M actuator used in the FPS200M is a good compromise between stiffness required for fast response time, and aperture size. Other shutters FPS400M and FPS900M allow respectively a beam diameter of 0.7 and 1.1 mm with the same mechanical design but with larger strokes actuators.

If more stroke is needed, the FAPS400M (Fig. 3) developed for PAL uses a lever arm to amplify the APA movement. In this case the beam diameter could be up to 3 mm with a translation of each APA400M of 410 µm.

Even if the lever impacts on the stiffness of the mechanism the response time remains fast, with a closing time of 8 ms.

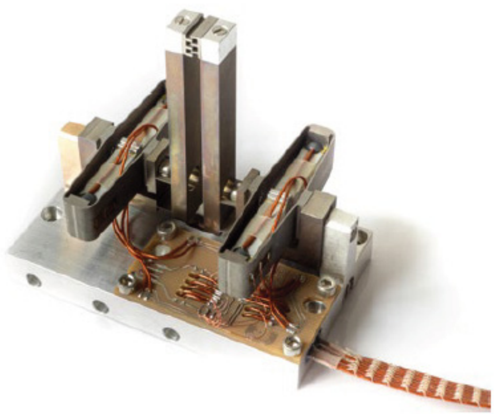

Figure 3: FAPS400M.

The FPS and FAPS piezo shutters family have a low jitter (<100 µs) thanks to a low self-heating compared to magnetics solutions.

FAST BEAM ATTENUATION ACTUATOR

When a motion greater than 1 or 2 mm is required, the APA can be integrated into a second level amplification mechanism.

For example, an APA fitted with a lever arm has been designed for the Fast Beam Attenuation project (Fig. 4) led by SOLEIL. The energy of the electron beam is controlled by putting more or less filters into the beam trajectory. It is useful to avoid detector damage and saturation. Thus the tip of each arm is moving 3 mm and a filter is mounted to it. To modify the beam attenuation, SOLEIL decides to play with 6 filters in a row.

This mechanism is installed in the SixS beamline at SOLEIL.

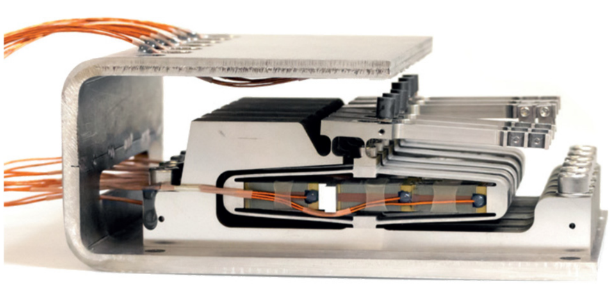

Figure 4: Fast Beam Attenuation Actuator.

The pivot links for the lever arm are done by bending and removed all mechanical friction disadvantages. Neither maintenance nor lubrication are required and the solution is cost effective.

The source of the movement is done by a piezo ceramic with a 40 µm stroke. A shell amplifies the movement to get 650 µm stroke, this actuator is the APA600MML. Then a lever arm amplifies again the translation to 3 mm (see Fig. 5, the blue area shows a 3 mm displacement). These two amplification stages leads to an 80 times amplification.

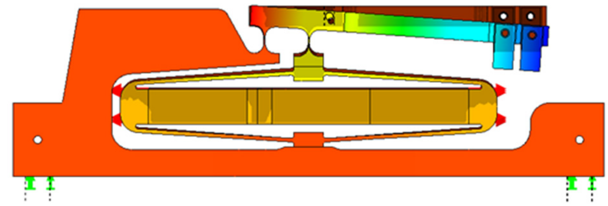

Figure 5: Displacement simulations.

The switch for each filter is achieved in 10ms that is to say a period of 100 Hz. To avoid filters ringing, the resonant frequency of the system must be twice higher than the movement period. That is why the mechanism has been designed and optimized to get a mechanical resonant frequency around 200 Hz.

Additional proprietary sensors are embedded to valid the status of the row (open or closed).

ACTIVE PIEZO MICRO-SLITS MECHANISM

Another actuator layout that has been designed with SOLEIL is to put a piezo actuator fitted with 4 lever arms to modify as required the shape of the synchrotron beam. Thanks to this mechanism the beam becomes a well-defined rectangle section and the section is adjustable in height and width. This mechanism is used in the SWING beamline at SOLEIL (Fig. 6).

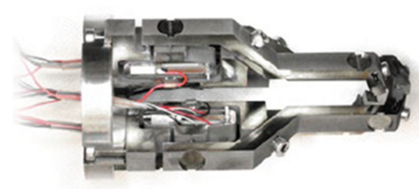

Figure 6: Active Piezo Micro-slits.

In this case, the source of the movement is done by a piezo ceramic with a 40 µm stroke. A shell amplifies the movement to get 66 µm stroke, this actuator is the APA50XS.

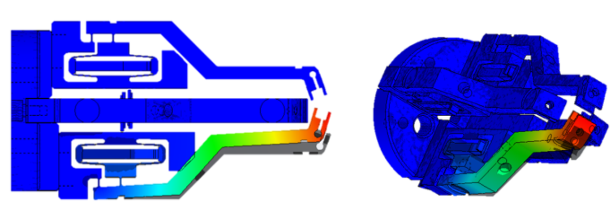

Figure 7: Displacement simulations.

Thanks to a lever arm again the stroke is increased up to 670 µm with a -20/+150 V supply (see Fig. 7, the red area shows a 400 µm displacement). These two amplification stages lead to an 18 times amplification.

The length and the height of the rectangular section can be adjusted up to 670 µm.

The thermal stability was a very important criteria for SOLEIL (+/- 0.5 µm for a 0.5 °C variation). Thanks to CTEC space heritage in mechanical designs and Strain

Gauge (SG) use [2, 3], the specification has been reached. A closed loop is required because of the accuracy. Indeed, the closed loop option removes the hysteresis phenomena inherent from the piezoelectric ceramics (Fig. 8).

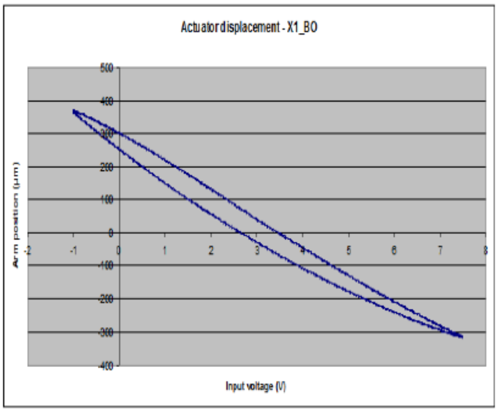

Figure 8: Mechanism displacement in open loop.

A linearization (with a 2nd order polynomial function) and calibration of the SG sensor has been done (Fig. 9).

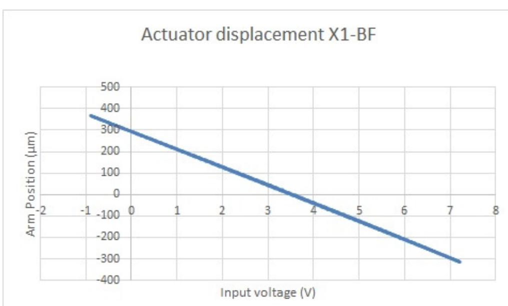

Figure 9: Mechanism displacement in closed loop.

A comparison between a laser interferometer measurement (yellow curve) and the position given by the SG (red curve) has been done (Fig. 10) in closed loop.

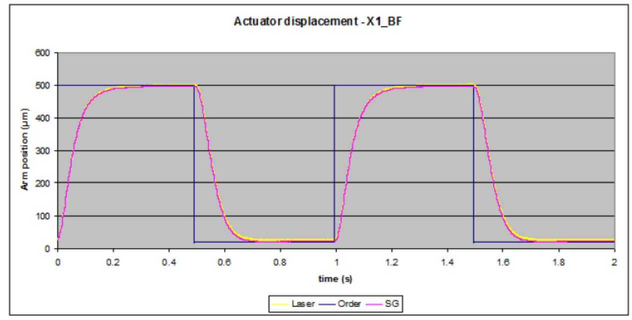

Figure 10: SG versus Laser Interferometer.

The results show that the maximal error between these two measurements is 0.4 %. SG sensors are a good solution in term of space (because they are stuck directly on the piezo stack) and accuracy to improve the performances of the mechanism.

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