Compact ultra-precision slits

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Abstract

An innovative mechanical design of a compliant compact slits system is presented. The system is compatible with a high vacuum environment and characterised by a travel range of several millimetres with concurrent nanometric accuracies.

1 Introduction

In experiments involving the investigation of samples with electromagnetic radiation (photonics, biology, chemistry, materials science, …), it is often necessary to define the size of the beam impinging on the sample in a plane perpendicular to the beam propagation direction. The advent of advanced electromagnetic radiation sources, such as 3rd and 4th generation synchrotron radiation facilities, which has dramatically improved the beam stability and size, has implied a need to perform the beam shaping with ever increasing accuracies and precisions. Beam definition with precision mechanical elements minimises also blurring effects arising from aberrations of the optical system, thus improving further the spatial resolution of the beam on the sample. Frequently the high precision requirements are also coupled with constrains given by the limited space availability, as well as by the need to build such equipment in clean (vacuum) environments [1].

Slits of suitable design are used for the cited purposes, but these are generally bulky and do not allow the required ultra-high accuracies to be obtained. In fact, the commercially available slits systems are characterised by the size in the plane perpendicular to the beam bigger than 150 x 150 millimetres, by the size in the in-beam direction larger than 50 millimetres, while the beam shaping capabilities are generally limited to micrometric ranges [2-4].

The aim of this work is thus the development of an innovative design of a large stroke compact slits system with nanometric beam shaping capability.

2 Design of an innovative slit system

The employment of compliant devices based on flexible elements is becoming a standard in high precision synchrotron radiation instrumentation. These devices are, in fact, characterised by the absence of mechanical non-linearities such as friction, backlash, hysteresis and wear, as well as by low weight and reduced production costs. Compliant structures are also well suited for operation in harsh (e.g. radiation) and special (i.e. vacuum) environments [5]. Moreover, by employing compliant mechanisms the main sources of errors are systematic and therefore, with respect to sliding and rolling mechanisms where the control typology to be applied in precision positioning applications is complex [6], simple control laws can be used.

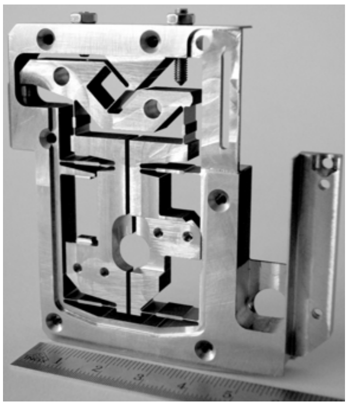

Figure 1: Compliant slits structure

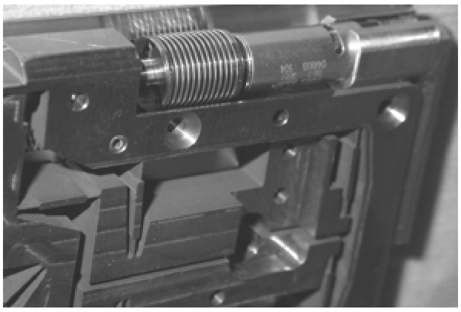

Figure 2: Actuating system

The design of the developed slits system is thus based on a compliant architecture with flexural hinge joints (Fig. 1). In the precision wire electro-discharge machined monolithic stainless steel (1.4542 (AISI 630)) structure, the chosen shape of the flexures is that of 140 microns thin beam elements with semicircular fillets joining them to the bulk material. Two parallel translators with four flexures each are the carrying elements for the slits blades. Pivoting the parallel translators in a 'seesaw' fashion around a common pivoting point, constituted by two additional flexures arranged as a cross spring pivot, allows a single actuator to be used for the required symmetrical motion of both blades. The resulting arrangement can be pivoted through a range of ± 3.5 degrees, which corresponds to the slits aperture of ± 3 millimetres. The overall travel of the device is limited at the upper end by the bulk material of the body and on the lower end via micro limit-switches.

The employed actuating system (Fig. 2) is constituted by an assembly of a two phase 20 steps/revolution stepper motor and a zero-backlash spur gear-head (1:120 reduction ratio). This is laser welded to a bellow-type compliant coupling, which is in turn joined to a M4 x 0.25 mm spindle. Such a configuration allows a nominal resolution of 100 nm to be obtained with a 0.2 mm/s velocity.

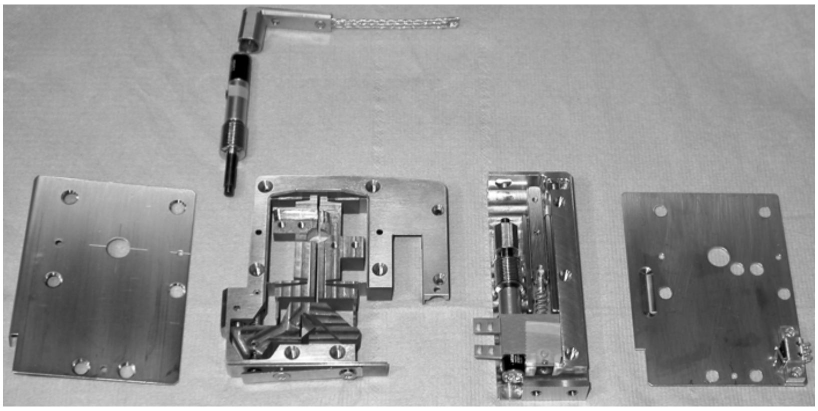

Figure 3: Slits system sub-assemblies

A lateral linear slide coupled to the same actuating system is then used to scan the whole slits with a fixed aperture through the beam. For use in the foreseen vacuum environment, the described components are cleaned in an ultrasonic bath and assembled in a clean room. The spindles and the slide are then either not lubricated, or a special vacuum fat is used.

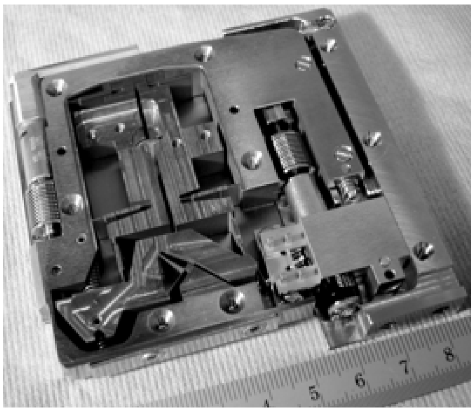

Figure 4: Complete slits assembly

Mounting the thus obtained sub-components (Fig. 3) results in a 87 x 84.5 x 11 millimetre slits assembly (Fig. 4). By putting two such assemblies next and orthogonal to each other, a device suited to perform the beam definition in both beam planes is achieved. A valid alternative in some applications might be the usage of a single assembly with rhomboidal slits blades, which allows a symmetric beam shaping to be easily obtained.

3 Applications and future work

It has been experimentally proven that the developed extremely compact, low cost and reliable design allows in a high vacuum environment sub-micrometric accuracies and precisions on millimetre travel ranges to be achieved with simple control typologies. What is more, the illustrated slit system is characterised by higher precisions and accuracies than the commercially available solutions with significantly smaller space requirements especially in the in-beam direction.

The slits system has therefore been adopted as a standard solution on some of the synchrotron radiation beamlines situated at the Swiss Light Source (SLS) facility located at the Paul Scherrer Institut in Switzerland.

In a following development step the working range of the device will be further extended, while concuretly allowing to minimise the parasitic shifts induced by the geometric non-linearities, by employing the high strenght and high complinace optimised flexural hinge shapes developed in [7]. A provision of adding a cooling system, thus making the slits suitable also for applications on some of the high energy beamlines, is also considered.

References:

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