

(12) STANDARD PATENT
(19) AUSTRALIAN PATENT OFFICE

(11) Application No. **AU 2017325120 B2**

(54) Title
**INSTRUMENT FOR MOVING AND POSITIONING OF OPTICAL ELEMENTS WITH
NANOMETRIC MECHANICAL STABILITY AND RESOLUTION IMPLEMENTED AS A
DOUBLE-CRYSTAL MONOCHROMATOR IN SYNCHROTRON BEAMLINES**

(51) International Patent Classification(s)
G02B 7/182 (2006.01) **G21K 1/06** (2006.01)
G02B 26/08 (2006.01)

(21) Application No: **2017325120** (22) Date of Filing: **2017.09.06**

(87) WIPO No: **WO18/045441**

(30) Priority Data

(31) Number	(32) Date	(33) Country
BR 102016020900-5	2016.09.09	BR
BR 102017019178-8	2017.09.06	BR

(43) Publication Date: **2018.03.15**

(44) Accepted Journal Date: **2022.03.24**

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(56) Related Art
EP 1321822 A1
DE 102014204523 A1
US 8358039 B2

(12) PEDIDO INTERNACIONAL PUBLICADO SOB O TRATADO DE COOPERAÇÃO EM MATÉRIA DE PATENTES (PCT)

(19) Organização Mundial da
Propriedade Intelectual
Secretaria Internacional

(43) Data de Publicação Internacional
15 de Março de 2018 (15.03.2018)



(10) Número de Publicação Internacional
WO 2018/045441 A1

(51) Classificação Internacional de Patentes:

G02B 7/182 (2006.01) G21K 1/06 (2006.01)
G02B 26/08 (2006.01)

(21) Número do Pedido Internacional:

PCT/BR2017/050262

(22) Data do Depósito Internacional:

06 de Setembro de 2017 (06.09.2017)

(25) Língua de Depósito Internacional:

Português

(26) Língua de Publicação:

Português

(30) Dados Relativos à Prioridade:

BR 102016020900-5

09 de Setembro de 2016 (09.09.2016) BR

BR 102017019178-8

06 de Setembro de 2017 (06.09.2017) BR

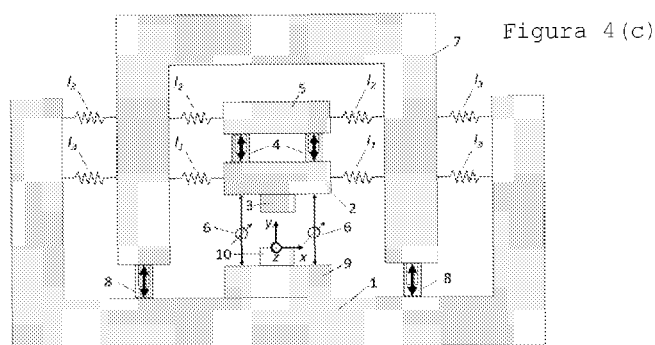
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(54) Title: INSTRUMENT FOR MOVING AND POSITIONING OPTICAL ELEMENTS WITH NANOMETRIC MECHANICAL STABILITY AND RESOLUTION IN LIGHT LINES

(54) Título: INSTRUMENTO PARA MOVIMENTAÇÃO E POSICIONAMENTO DE ELEMENTOS ÓPTICOS COM RESOLUÇÃO E ESTABILIDADE MECÂNICA NANOMÉTRICAS EM LINHAS DE LUZ



(57) Abstract: An instrument for moving and positioning an optical element (3) in light lines that includes a mounting structure (2) in which one or more optical elements (3) are mounted, and also a reference structure (1) on which the mounting structure (2) is directly or indirectly mounted. The mounting structure (2) is moved using movement means (4) with low mechanical rigidity and the position thereof in relation to the reference structure (1) is measured in high resolution using position measurement means (6). The instrument also includes reaction mass (5) to receive the reaction to the force exerted by the movement means (4) of the mounting structure (2). The structural elements are interlinked by elastic means (/1 and /2) with specific rigidity properties so that the aforementioned position control is effected in closed loop with a bandwidth exceeding 100 Hz. The instrument can be used to position a double crystal monochromator for synchrotron light radiation.

(57) Resumo: Um instrumento para movimentação e posicionamento de um elemento óptico (3) em linhas de luz o qual compreende uma estrutura de montagem (2), na qual um ou mais elementos ópticos (3) são montados, bem como uma estrutura de referência (1), à qual a estrutura de montagem (2) é direta ou indiretamente montada. A estrutura de montagem (2) é movida via meio de movimentação (4) de baixa rigidez mecânica e a posição da mesma em relação à estrutura de referência (1) é medida com alta resolução via meio de medição de posição (6). O instrumento compreende ainda massa de reação (5) para receber a reação à força exercida peio meio de movimentação (4) da estrutura de montagem (2). A interligação dos elementos estruturais é feita por meios elásticos (/1 e /2) com

(Continua na página seguinte)

(81) Estados Designados *(sem indicação contrária, para todos os tipos de proteção nacional existentes):* AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Estados Designados *(sem indicação contrária, para todos os tipos de proteção regional existentes):* ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasiático (AM, AZ, BY, KG, KZ, RU, TJ, TM), Europeu (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarações sob a Regra 4.17:

— *relativa à autoria da invenção (Regra 4.17(iv))*

Publicado:

— *com relatório de pesquisa internacional (Art. 21(3))*

**"INSTRUMENT FOR MOVING AND POSITIONING OF OPTICAL ELEMENTS
WITH NANOMETRIC MECHANICAL STABILITY AND RESOLUTION
IMPLEMENTED AS A DOUBLE-CRYSTAL MONOCHROMATOR IN
SYNCHROTRON BEAMLINES".**

TECHNICAL FIELD OF THE INVENTION

[001] The invention refers to an instrument for movement and positioning of optical elements with nanometric mechanical stability and resolution in beamlines, comprising:

- a reference structure (1);
- a complementary structure (7), attached in a movable manner to the reference structure (1);
- a mounting structure (2), in which an optical element (3) is mounted and which is movable in relation to the complementary structure (7);
- a complementary mounting structure (9), in which a complementary optical element (10) is mounted, and which is rigidly connected to the reference structure (1);
- measuring means of position (6) of the mounting structure (2) with respect to the complementary mounting structure (9);
- movement means (4) of low (or zero) mechanical rigidity, for moving the mounting structure (2) in

relation to the complementary mounting structure (9);

- a reaction mass (5), which is movable in relation to the complementary structure (7), and which undergoes the reaction force of the movement means (4) of the mounting structure (2); and
- a control system with a feedback loop with high bandwidth (> 100 Hz).

[002] An optical element of a beamline in this present invention refers to a diffraction crystal, or a set of multiple diffraction crystals .

BACKGROUND OF THE INVENTION

[003] Such instruments individually are known and among them there can be highlighted the monochromators. A monochromator is an optical instrument for selecting a narrow band of light wavelengths (or energy), or other radiation, from a wider range of wavelengths at the inlet of the instrument entry. It is important to note that it is generally possible to vary this band selection through different alignments or movements of the monochromator and, consequently, the delivery of the wavelength of interest by the instrument. In fact, an instrument capable of delivering monochromatic (or almost monochromatic, considering the existence of a band) light has many uses in scientific

studies and in optics, since the properties of the materials can depend or be investigated through their different interactions with different wavelengths. Although there are several ways to select a narrow band of wavelengths (that would be perceived on the visible range as a pure color), such ways are limited depending on the energy range of the radiation.

[004] In general, monochromators can use both the dispersion phenomenon, as in a prism, and the diffraction phenomenon, from a diffraction grating or a material with a crystalline structure, in order to spatially separate the wavelengths or ensure specific conditions of constructive interference for the radiation. Due to the spatial spreading characteristic, in case of prisms and diffraction gratings, exit slits are typically constituent parts of the monochromator. Crystalline structures, on the other hand, are typically used in Bragg or Laue configurations, and they can also use posterior slits to limit the light beam or to stop spurious dispersals.

[005] X-ray studies allow the investigation of properties of matter that may be inaccessible by other means. Methods that use absorption, transmission, fluorescence scattering and diffraction promote information about the composition and structure of matter, in addition to allow

the image and tomography acquisition. These methods are often non-destructive and constitute a powerful and important set of research tools, complementing many other methods, such as chemical analysis and conventional microscopy.

[006] Synchrotron light laboratories, hereinafter referred to only as synchrotrons, are research facilities where high brightness and wide range electromagnetic radiation is generated through a storage ring. In these storage rings, high-energy electrons in relativistic conditions are able to emit photons in a controlled manner, what is called synchrotron radiation, from their interaction with strong magnetic fields of dipoles or insertion devices (undulators and wigglers). A similar technology is used in so-called free electron lasers (FELs).

[007] Some of the synchrotron research fields include: condensed matter physics, materials science, chemistry, biology and medicine. Therefore, the experiments can cover applications that probe from sub-nanometric regions, for example, inside a cell, to samples of many centimeters, as in medical or veterinary image analysis. Naturally, besides the research purposes, industrial applications are also commonly found, among which it can be mentioned the microfabrication of devices as a practical case of interest.

[008] From the year 2016 onwards, new generation synchrotron light sources begin their operations. These new generation sources are characterized by their extremely high brightness, or, using a relevant technical term, by an ultra-low emittance, in which the diffraction limit of the light source itself is reached for the photons below a certain energy. Such extremely low emittance is, therefore, related to an extremely small light source (in the order of a few micrometers for X-rays, for example) and with very low divergence. For this new characteristic to be possible and useful, the stability demands for both the accelerator and the experimental stations, the so-called **beamlines**, are taken to extreme levels.

[009] Double crystal monochromators (DCMs) are a type of instrument commonly used in X-ray beamlines for energies above a few keV. In these instruments, the principle is that a given Bragg diffraction condition is obtained in two subsequent crystals, in order to select a narrow energy band from the inlet beam (incident), which has a wide energy range, and allow the monochromatic beam that leaves the instrument to be kept in a constant position, regardless of the Bragg angle variation for selecting different energies. The schematic diagram is shown in Figure 1.

[010] In fact, Bragg diffraction is a geometric

phenomenon, since the constructive interference condition for the selected radiation is a function of the angle (hence the Bragg angle) between the incident photon beam and the crystalline planes of the crystal. Consequently, the energy selection of a given experiment is provided according to the choice of the Bragg angle in the monochromator, that is, the crystal rotation with respect to the incident photon beam. Therefore, it is clear that one of the advantages of DCMs in relation to other types of X-ray monochromators is precisely that it allows the separation (transversal propagation distance or offset) between the incident and monochromatic beams to be kept constant, from the variation in the separation distance (gap) between the crystals as a function of the Bragg angle. Figure 2 schematically shows an example of DCM in which the photon beam propagates along the z axis, and the axis of rotation (rotation of the Bragg angle) is in the x direction and coincides with both the face of the first crystal and the position of the incident photon beam. Through the representation of the crystals in two different angles (θ_1 , θ_2), it is clear that to maintain the monochromatic beam in the same position (constant offset in relation to the incident beam) the distance between the crystals (gap) must be varied as a function from the Bragg angle. In the example of Figure 2, $\theta_2 > \theta_1$, where θ_1 represents a smaller operating angle and θ_2 represents a larger operating angle.

[011] For the condition of Bragg to occur in both crystals, it is necessary to ensure a proper alignment, which, in a simplified way, can be seen as the perfect parallelism between them. For this reason, in addition to a free degree of freedom for rotation to adjust the Bragg angle and a free degree of freedom for relative translation between the crystals for the gap variation, the DCMs typically have two degrees of freedom for relative rotation between the crystals, known as pitch and roll (terms derived from aviation), perpendicular to the translation direction. Therefore, a basic DCM has, besides the main free degree of freedom for the Bragg angle, three relative free degrees of freedom between the crystals: gap, pitch and roll, which can be concentrated in a single crystal or distributed according to any desired combination.

[012] The responsible mechanisms for these degrees of freedom must present not only sufficient fine movement resolution, but also adequate mechanical stability, in order to avoid undesirable dynamic effects, which can cause errors in energy selection, reduced photon flow and/or deviations in the direction of propagation of the monochromatic beam with respect to the incident beam. Among all mentioned degrees of freedom, the pitch and roll adjustments are the most demanding in terms of stability and resolution. That is why the mechanisms of these degrees of freedom typically use

high-resolution mechanical actuators, such as piezoelectric actuators and micromotors. Once integrated with feedback signals, these mechanisms can compensate for misalignments resulting from mounting limitations, thermal and/or gravitational effects, and parasitic movements in the gap mechanism. Figure 3 shows a schematic illustration of these three adjustment movements (y' , Rx' and Rz') of the second crystal in relation to the first, highlighting the possible use of local or external feedback signals, from the positioning sensors or beam, respectively.

[013] Current DCM construction technologies are limited in terms of stability of the relative parallelism between the crystals, that is, in pitch and roll. Especially in vertical offset DCMs between the inlet and outlet beams, that is, those in which the axis of rotation of the Bragg angle is horizontal, the best equipment suffers from angular variations greater than 100 nrad RMS (analyzed in a frequency band up to 2.5 kHz). Few vertical DCMs have already demonstrated the performance of around 50 nrad RMS under special conditions, that is, with the movement mechanisms fully braked. It is worth noting that horizontal offset DCMs, that is, with vertical axis of rotation, suffer less from the gravity effects and may present slightly better results, typically by a factor 2. However, in both cases, if the parallelism stability is evaluated while the Bragg angle and

gap mechanisms are in operation, which is necessary for experiments with continuous energy scanning (so-called flyscans), for example, the levels of vibration are easily increased over 10 times, easily exceeding 1 μ rad RMS.

[014] It turns out that, due to the exceptional characteristics of the new generation synchrotron light sources, the future beamlines will require stability levels below 10 nrad RMS, even during flyscans. This means that there will be required instruments with a performance of 5 and 100 times better than the current state of the art. The numbers mentioned for the instruments in operation are already the result of hard work from the manufacturers and users over the past few years to make incremental improvements regarding the existent technology. Thus, as the evolution in terms stability was only limited, there is a relative stagnation of the present technology, with virtually no real prospect of new demands being fulfilled.

[015] In fact, the current technology is based on mechanical designs with maximum rigidity focus, while, in a contradictory way, the relative degrees of freedom are typically obtained from the stacking of individual movement mechanisms for gap, pitch e roll. This approach is limited by the finite rigidity of the intermediate parts and mechanical connections, which quickly deteriorates the

effective rigidity of the assembly. In addition, the new required levels of stability are so low that such adjustment mechanisms must offer a high capacity to reject disturbances (noises). These disturbances are caused by floor vibrations, sources of neighboring vibrations, such as vacuum pumps, and yet sources of internal vibrations to the DCM itself, such as refrigeration systems, motors and mechanical actuators, and rolling bearings. For a reasonable minimum noise rejection capability, the adjustment mechanisms need to work with closed feedback loop control with a bandwidth above 100 Hz. The currently used piezoelectric actuators and micromotors would hardly be able to achieve control bands greater than 20 Hz.

SUMMARY OF THE INVENTION

[016] It is an object of the present invention to provide a beamline instrument that fulfill the high demands of the new generations of synchrotron light sources. For this purpose, the instrument according to the invention comprises:

- at least one reference structure (1), a mounting structure (2), movement means (4) and measuring means of position (6);

- at least one reaction mass (5) movably connected to the reference structure (1) in one or more directions, in the same way with the mounting structure (2), with the

movement means (4) of the mounting structure (2) acting with respect to the reaction mass (5), instead of acting in relation to the reference structure (1);

- measuring means of position (6), measuring the position of the mounting structure (2) directly in relation to the reference structure (1) for better accuracy,

- a closed feedback loop control including measuring means of position (6) and the movement means (4), where the information of the measuring means of position (6) is used to control the position of the mounting structure (2) in relation to the reference structure (1) through the movement means (4).

[017] The connection between the mounting structure (2) and the reference structure (1) is given by a first set of elastic means (l_1), comprised by an elastic leaf (leaf springs), or by a set (combination) of elastic leaves; as well as the connection between the reaction mass (5) and the reference structure (1) is given by a second set of elastic means (l_2), comprised by an elastic leaf (leaf springs), or by a set (combination) of elastic leaves.

[018] The instrument of the present invention is applied in the monochromatization of X-ray beams with fixed outlet in synchrotron beamlines.

[019] With the instrument according to the invention, active feedback can be improved (wider control band, typically above 100 Hz) depending on the use of the reaction mass (5) and an appropriate dynamic architecture. The reaction mass (5) acts as a low-pass filter in the path of the reaction forces, in such a way that only the dynamics of the direct path of the forces of the mounting structure (2) limits the possible bandwidth. In addition, the appropriate dynamics depends on low (or zero) rigidity between the mounting structure (2) and the reaction mass (5), so the movement means (4) must be low-rigidity actuators (inherently compliant actuator). Thus, in the device according to the invention, the critical degrees of freedom are controlled by means of a feedback loop with sufficiently high closed loop bandwidth, allowing a high rejection of disturbances and a high capacity for following references.

[020] An additional embodiment of the instrument according to the invention is characterized by comprising a complementary structure (7) movably connected to the reference structure (1) and the complementary movement means (8) of that complementary structure (7) in relation to the reference structure (1). Alternatively, the mounting structure (2) and the reaction mass (5) become movably connected to the complementary structure (7), instead of being movably connected to the reference structure (1).

[021] Preferably, the maximum displacement of the complementary structure (7) with respect to the reference structure (1) is greater than the maximum displacements of the mounting structure (2) and the reaction mass (5) in relation to the complementary structure (7), therefore allowing, due to this combination of levels, greater movement ranges of the mounting structure (2) with respect to the reference structure (1).

[022] Preferably, the mounting structure (2) is connected to the complementary structure (7) by a first set of elastic means (l_1) and the reaction mass (5) is connected to the complementary structure (7) by a second set of elastic means (l_2), the complementary structure (7) being connected to the reference structure (1) by a third set of elastic means (l_3). These sets of elastic means (l_1 , l_2 , l_3) are still preferably an elastic leaf (leaf spring), or a combination of elastic leaves, in order to confer the movement capabilities of interest with appropriate dynamics.

[023] An embodiment of the instrument according to the invention is characterized by having the reference structure (1) rotating around a main axis (x axis) perpendicular to the incident photon beam (z axis) and by having the complementary structure (7) movable in relation to the

reference structure (1) in just one translation, in the plane of the photon beam and perpendicular to the axis of rotation of the reference structure (1), such that the first set of elastic means (l_1) is not very rigid in the direction of travel, but rigid in the two other translation directions perpendicular to the direction of travel, as well as rigid in rotations in the three directions (R_x' , R_y' , R_z'). The mounting structure (2) is preferably movable in relation to the complementary structure (7) in just one translation, parallel to the movement direction of the complementary structure (7) in relation to the reference structure (1), but also in two rotations, around the axes perpendicular to the axis of translation, wherein the second set of elastic means (l_2) is not very rigid in the translation direction and in the two perpendicular directions, but rigid in both directions perpendicular to the direction of travel, as well as rigid in the rotation around it.

[024] Similarly, the reaction mass (5) is preferable movable in relation to the complementary structure (7) in just one translation, parallel to the movement direction of the complementary structure (7) with respect to the reference structure (1), but also in the two rotations, around the axes perpendicular to the axis of translation, such that the third set of elastic means (l_2) is not very rigid in the translation direction and in the two perpendicular rotations, but rigid in the two directions perpendicular to

the direction of travel, as well as rigid in the rotation around it.

[025] In addition, the actuation of the movement means (4) between the mounting structure (2) and the reaction mass (5) is preferably performed by three Lorentz actuators (voice-coils), capable of acting in the three degrees of freedom from low rigidity of the mounting structure (2) and the reaction mass (5).

[026] Furthermore, an embodiment of the instrument according to the invention is characterized by having a complementary mounting structure (9) rigidly connected to the reference structure (1) and to which the at least one complementary optical element (10) is rigidly connected. Preferably, the measuring means comprises at least three position sensors (6), such as interferometric distance measurers, measuring, at three degrees of freedom of interest, the position of the mounting structure (2) directly in relation to the complementary mounting structure (9), in order to increase the accuracy of the measurement between the optical element (3) and the complementary optical element (10).

[027] The instrument, according to the invention and the embodiment detailed above, is especially advantageous in the

realization of a double crystal monochromator, in which the optical element (3) and the complementary optical element (10) are crystals, fixed to the mounting structure (2) and to the complementary mounting structure (9). In addition, it is a common practice to use more than one pair of crystals, with different crystalline orientations, in the same instrument. In this way, it is perfectly possible for one or more crystals (3) to be rigidly mounted on the mounting structure (2), while their respective complementary pairs (10) are rigidly mounted on the complementary mounting structure (9). The realization of the instrument according to the invention as a DCM with closed feedback loop with high bandwidth is able to satisfy the stability demands of a new generation of DCMs (as described in the Background of the invention section).

BRIEF DESCRIPTION OF THE FIGURES

[028] The invention will be clarified in more details based on diagrammatic drawings as follows:

[029] Figure 1 illustrates the situation in which a given condition of Bragg diffraction occurs in two subsequent crystals, filtering out an incident beam of wide range and delivering a monochromatic beam;

[030] Figure 2 illustrates the principle of a DCM, in which the separation (gap) between the two crystals changes according to the rotation angle (Bragg angle) (θ_1, θ_2) , in order to maintain the monochromatic beam position constant. In the example in Figure 2, $\theta_2 > \theta_1$, where θ_1 represents a smaller angle and θ_2 represents a larger angle;

[031] Figure 3 shows a schematic view with a possible configuration to the three basic movements of relative adjustment between two crystals of a DCM and with local or external feedback signals, from sensors of position or beam, respectively, highlighting between the figures (a) and (b) an important difference in the form of local feedback;

[032] Figure 4 shows an embodiment of the instrument according to the present invention, consisting of a reference structure (1), a mounting structure (2), a reaction mass (5), movement means (4), optical element (3), complementary optical element (10), first, second and third sets of elastic means (l_1, l_2, l_3) , measuring means of position (6), a complementary structure (7), complementary movement means (8) and a complementary mounting structure (9).

DETAILED DESCRIPTION OF THE INVENTION

[033] Figure 1 illustrates the situation in which a given

condition of Bragg diffraction occurs in two subsequent crystals, filtering out an incident beam with wide range and delivering a monochromatic beam. A base coordinate system (x, y, z) and a rotated coordinate system (x, y', z') around the Bragg angle (θ) , placed in the example on the x axis, are also indicated.

[034] Figure 2 illustrates the principle of a DCM, in which the separation (gap) between the two crystals varies as a function of the angle of rotation (Bragg angle), in order to maintain the position of the monochromatic beam constant in relation to the incident beam with a fixed separation (offset). It is possible to see for a given Bragg angle θ_1 , smaller than another arbitrary Bragg angle θ_2 , the corresponding gap (gap 1) is smaller than that (gap 2) corresponding to θ_2 .

Figure 3 shows two crystals of a DCM in a given Bragg angle, with the essential relative adjustments between the first and the second crystals, namely: gap (y'), pitch (Rx') and roll (Rz') (wherein the indication ' refers to the coordinate system rotated according to the Bragg angle). Figure 3 (a) shows the feedback signals typically used, namely: local feedback, typically performed next to the movement mechanism of the crystal and measuring the crystal position with respect to its holder; and external feedback, using the

signal from a beam sensor downstream of the DCM to act on the crystal adjustment mechanisms. There are instruments that are based only on one type of feedback, as well as instruments that use both in a complementary way. Figure 3 (b) also shows both the local and external feedback signals, but emphasizes, according to the present invention, that in the local feedback the position measurement must be performed between the crystals, or between the mounting structures of the crystals, not in relation to a holder of one of the crystals, which does not provide any direct information regarding the position and stability of the complementary crystal. Furthermore, according to the invention, for a sufficiently high closed feedback loop control bandwidth (> 100 Hz) to be possible, the speed of the feedback system must be high, that is, in the order of 10 kHz. Such speeds are not typically available on beam sensors, so the measurement means in relation to the reference structure has been placed as mandatory. However, and in fact, if the signal from a beam sensor exhibits the required position and speed characteristics, it could replace the local position measurement means of the instrument.

[035] Figure 4 shows an embodiment of the instrument according to the present invention. Figure 4 shows the essential realization of a synchrotron beamline instrument

according to the present invention, wherein the optical element (3) is rigidly mounted to the mounting structure (2), whose position in relation to the complementary mounting structure (9) is measured through measuring means of position (6). The complementary optical element (10) is rigidly attached to the complementary mounting structure (9). The movement of the mounting structure (2) occurs through the movement means (4) depending on the position measurement of the measuring means of position (6), both of which (4, 6) being integrated in the closed feedback loop of the instrument. Unlike the traditional instruments, the forces of the movement means (4), necessary for moving the mounting structure (2), have their reaction in a reaction mass (5), which acts as a dynamic filter and allows the bandwidth of the feedback system to be limited only by the internal dynamics of the mounting structure (2) and the optical element (3), and not by the dynamics (resonances) of the other components of the instrument, as in the case of common instruments. Both the connection of the mounting structure (2) and the reaction mass (5) to the complementary structure (7) are preferably made by sets of elastic means (l_1 and l_2), which are able to guarantee the proper rigidity properties, that is, to define *free* and *restricted* degrees of freedom, according to the movements of interest for the optical element in relation to the photon beam, as well as eliminate non-linearities resulting from frictional mechanical guides.

The inclusion of a complementary structure (7) between the reference structure (1) and the assembly formed by the mounting structure (2) and the reaction mass (5) aims at increasing the amplitude of movement between the mounting structure (2) and the reference structure (1), since the spring means (l_3) necessarily present limited amplitude of movement. Systems of two (or more) levels are, in fact, common in equipment from several areas demanding great dynamic range, that is, many orders of magnitude between the resolution (and/or accuracy) and the range of a given movement. According to the coordinate system of the Figure, the photon beam propagates along the z axis, coplanar with the axis of rotation of the reference structure (1) (x axis), where it reaches the first DCM crystal, or the first set of DCM crystal pairs, the complementary optical element (10).

[036] The complementary optical element (10) is rigidly fixed to the complementary mounting structure (9), which is rigidly fixed to the reference structure (1), that is, there are no free relative degrees of freedom for adjustment between the complementary optical element (10) and the reference structure (1). The complementary structure (7) is connected to the reference structure (1) by a set of elastic means (l_3), being preferably composed by 5 (or 6) folded elastic leaves, giving a single degree of relative freedom free of translation between these structures. This single

degree of freedom had the function of allowing the gap adjustment on a first level. The performance of the complementary movement means (8) of the complementary structure (7) can be carried out in different ways, such as, for example, by means of a stepper motor, a servomotor or a linear motor, among others. Finally, both the mounting structure (2), to which the second DCM crystal, or second set of DCM crystal pairs, the optical element (3), is rigidly fixed, and the reaction mass (5) are connected to the complementary structure (7) through a set of elastic means (l_1 and l_2), being preferably composed by 3 folded elastic leaves, giving three relative degrees of freedom between them and the complementary structure (7), namely: *gap* (second level), *pitch* and *roll*. In fact, by properly projecting folded elastic leaves, they can be combined to achieve mechanical guides with only the desired free degrees of freedom, suppressing the movement of the elements in uncontrollable degrees of freedom due to high rigidity features. To act on these three free degrees of freedom and to position and stabilize the mounting structure (2) with respect to the complementary mounting structure (9), the movement means (4) are conceived as three Lorentz actuators (voice coils), which have their forces acting between the mounting structure (2) and the reaction mass (5), providing an "internal" dynamic of forces for the precision adjustment of the gap and for the control of the parallelism between

the crystals, and preventing these forces from propagating as disturbances to the reference structure (1), the complementary structure (7), the complementary mounting structure (9) and/or the complementary optical element (10). The feedback is provided by the measuring means of position (6), performed as 3 (or 4) interferometric distance sensors, which can be combined to measure the distance and the two angles of interest between the metrological references of the two crystals, that is, the mounting structure (2) and the complementary mounting structure (9). Interferometric distance sensors include: the characteristics of a large dynamic range, being able to measure with nanometer resolution and precision over tens of millimeters; and high measurement speeds, making possible the high stability and high dynamic performance required in new generation DCMs. It was chosen here, for simplification purposes, not to describe in detail how this rotation of the reference structure (1) would be done with respect to the photon beam, but, preferably, using a double bearing system (on both sides of the reference structure (1)) and a direct drive type motor for rotating the DCM in relation to a base installed on the beamline.

[037] Eventually, it should be emphasized again that, although the invention is exemplified by means of a synchrotron light source beamline mounted DCM in most of the

Figures, that it is not limited anyway to the exemplified embodiments in these drawings. The invention may be extended, therefore, to any and all embodiments that can deviate from the embodiments utilized as example, since they are within the context defined by the claims. Therefore, the instrument of the present invention can be an instrument to position mirrors, FZPs, CRLs, steps of manipulation of samples, slots, detectors, or any other system of high-mechanical performance beamlines, wherein the quick and accurate positioning and/or high stability are needed.

CLAIMS

1. An instrument for moving and positioning of optical elements with nanometric mechanical stability and resolution in synchrotron beamlines, comprising at least a reference structure (1), a mounting structure (2), moving means (4) and position measurement means (6), **characterized in** that it comprises:

- a complementary structure (7), attached in a movable manner to the reference structure (1), where

the connection between the complementary structure (7) and the reference structure (1) is given by a third set of spring means (1₃);

- an optical element (3) mounted in the mounting structure (2), where

the mounting structure (2) is attached in a movable manner to the complementary structure (7), allowing its relative translation and rotation movements along one or more directions, and

which attachment is provided by a first set of spring means (1₁), comprised by at least one leaf springs;

- a moving means (4) for movement of the mounting structure (2) in relation to the reference structure (1);

- a complementary actuation means (8) for movement of

the complementary structure (7) in relation to the reference structure (1);

- at least one reaction mass (5), attached in a movable manner to the complementary structure (7), allowing its relative translation and rotation movements in one or more directions, where

the connection between the reaction mass (5) and the complementary structure (7) is given by a second set of spring means (l_2), comprised by at least one leaf springs, and

the reaction mass (5) receives the reaction force resulting from the positioning of the mounting structure (2) in relation to the reference structure (1), through the actuation of the moving means (4);

- a means of position measurement (6) measuring the position of the mounting structure (2) in relation to the reference structure (1);

- a main feedback loop including the means of position measurement (6) and the moving means (4), in which the information from the means of position measurement (6) is utilized to control the position of the mounting structure (2) through the moving means (4); and

- a complementary optical element (10), rigidly mounted to the reference structure (1).

2. The instrument, according to the claim 1, **characterized in** that the stiffness characteristics of the first spring means (l_1) to be equal to the stiffness characteristics of the second spring means (l_2), allowing for the translations and rotations of interest (free degrees of freedom) of the mounting structure (2) and of the reaction mass (5), respectively, in relation to the reference structure (1), limiting complementary translations and rotations (restricted degrees of freedom).

3. The instrument, according to the claim 1, **characterized in** that the moving means (4) are actuators of Lorentz type (voice-coils), comprising a minimum number of actuators equal to the number of free degrees of freedom of the mounting structure (2) and of the reaction mass (5).

4. The instrument, according to the claim 1, **wherein** the means of position measurement (6) consists of a minimum number of position sensors equal to the number of free degrees of freedom of the mounting structure (2) and of the reaction mass (5).

5. The instrument, according to the claim 1, **characterized in** that the mounting structure (2) and the reaction mass (5) are attached by the first and second spring means (l_1 and l_2) to the complementary structure (7).

6. The instrument, according to the claim 1, **characterized in** that each of the first, second and/or third spring means (l_1 , l_2 , l_3) are composed by a leaf spring or a

set of (combination) leaf springs.

7. The instrument, according to claim 1, **characterized in** that the reference structure (1) has a main rotation axis (x -axis), perpendicular to the direction of propagation of the incident beam in the beamline (z -axis).

8. The instrument, according to claim 1, **characterized in** that the complementary structure (7) is movable in relation to the reference structure (1) only in one direction (y' -axis), wherein

the rotation axis (x -axis) of the reference structure (1) is parallel to the (x' -axis) of the complementary structure (7);

the rotation axis (x -axis) of the reference structure (1) and the movable direction (y' -axis) of the complementary structure (7) are perpendicular to each other; and

the third set of leaf springs (l₃) is softer in the direction of offset (y' -axis) and stiffer in the two other perpendicular directions (x'- and z' -axes) and in relation to the rotation directions (Rx, Ry' and Rz' rotations).

9. The instrument, according to the claim 1, **characterized in** that the mounting structure (2) is movable in relation to the complementary structure (7) in one translation (y' -axis) and two rotation (Rx and Rz'

rotations) directions, wherein

the translation direction (y' -axis) is parallel to the moving direction (y' -axis) of the complementary structure (7);

the first rotation (R_x rotation) is around the axis (x'), where the rotation axis (x' -axis) of the mounting structure (2) is parallel to the rotation axis (x' -axis) of the complementary structure (7);

the second rotation ($R_{z'}$ rotation) is around the axis (z'), where the rotation axis (z' -axis) of the mounting structure (2) is parallel to the rotation axis (z' -axis) of the complementary structure (7); and

the third set of leaf springs (l_3) is softer in the translation (y' -axis) and in the two rotation (R_x and $R_{z'}$ rotations) directions, and stiffer in the two perpendicular translation directions (x' - and z' -axes) and the third rotation direction ($R_{y'}$ rotation).

10. The instrument, according to the claim 1, **characterized in** that the reaction mass (5) is movable in relation to the complementary structure (7) in only one translation (y' -axis) and two rotation (R_x and $R_{z'}$ rotations) directions, wherein

the translation direction (y' -axis) is parallel to the moving direction (y' -axis) of the complementary structure (7);

the first rotation (R_x rotation) is around the axis (x'), where the rotation axis (x' -axis) of the reaction mass (5) is parallel to the rotation axis (x' -axis) of the complementary structure (7);

the second rotation ($R_{z'}$ rotation) is around the axis (z'), where the rotation axis (z' -axis) of the reaction mass (2) is parallel to the rotation axis (z' -axis) of the complementary structure (7); and

the second set of leaf springs (l_2) is softer in the direction of translation (y' -axis) and in the two rotation directions (R_x and $R_{z'}$ rotations) and stiffer in the two perpendicular translation directions (x' - and z' -axes) and the third rotation direction ($R_{y'}$ rotation).

11. The instrument, according to the claim 1, **comprising** an additional complementary mounting structure (9) is rigidly fixed to the reference structure (1), and the complementary optical element (10) is rigidly mounted to the complementary mounting structure (9).

12. The instrument, according to the claim 11, **characterized in** that the means of position measurement (6) measures the position of the mounting structure (2) in relation to the additional complementary mounting structure (9), rather than in relation to the reference structure (1).

13. The instrument, according to the claim 1, **wherein**

the instrument is a double-crystal monochromator and the optical element (3) and the complementary optical element (10) are diffraction crystals, the first one being rigidly mounted to the mounting structure (2) and the second one being rigidly mounted to the complementary mounting structure (9).

14. The instrument, according to the claim 1, **characterized in** that the optical element (3) and the complementary optical element (10) comprises multiple pairs of crystals with distinct characteristics, with one element of each pair rigidly mounted to the mounting structure (2) and the other element of each pair rigidly mounted to the reference structure (1).

15. The instrument, according to the claim 13, **characterized in** that the optical element (3) and the complementary optical element (10) comprises multiple pairs of crystals with distinct characteristics, with one element of each pair rigidly mounted to the mounting structure (2) and the other element of each pair rigidly mounted to the complementary mounting structure (9).

16. The instrument, according to claim 1, **characterized in** that the position sensors of the means of position measurement (6) comprises interferometric offset sensors, with high reading rates and subnanometric resolutions.

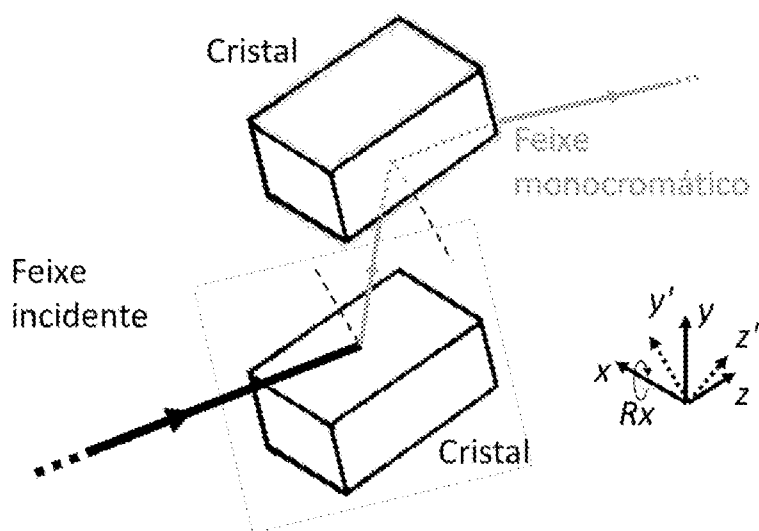


Figura 1

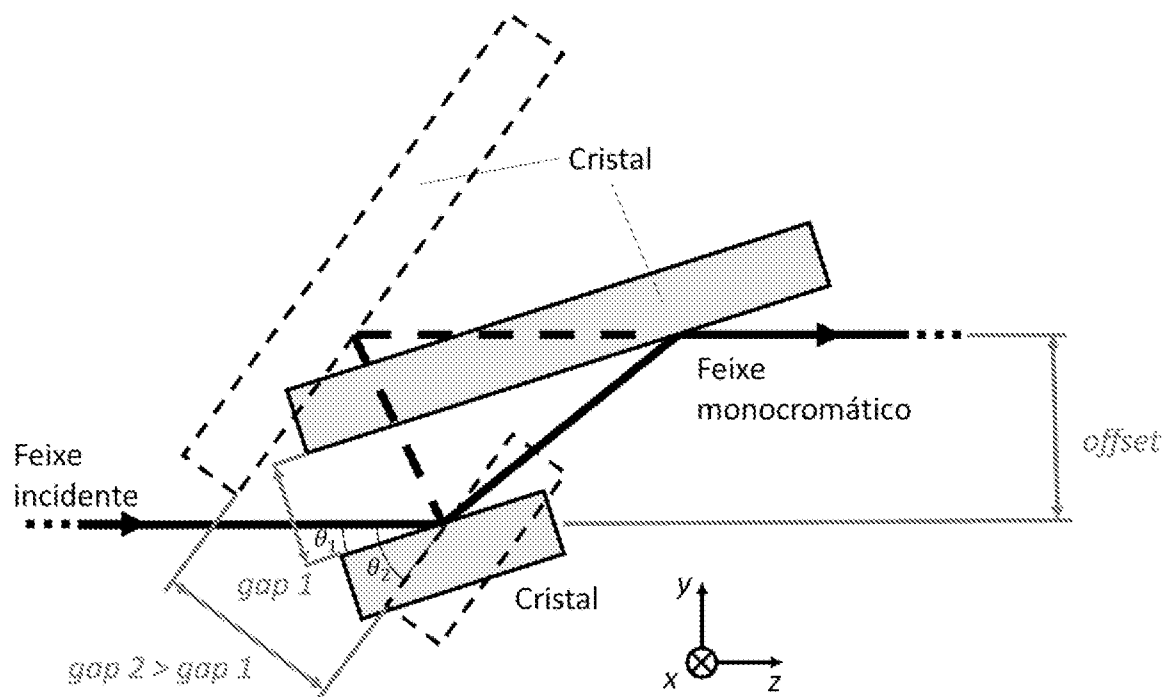


Figura 2

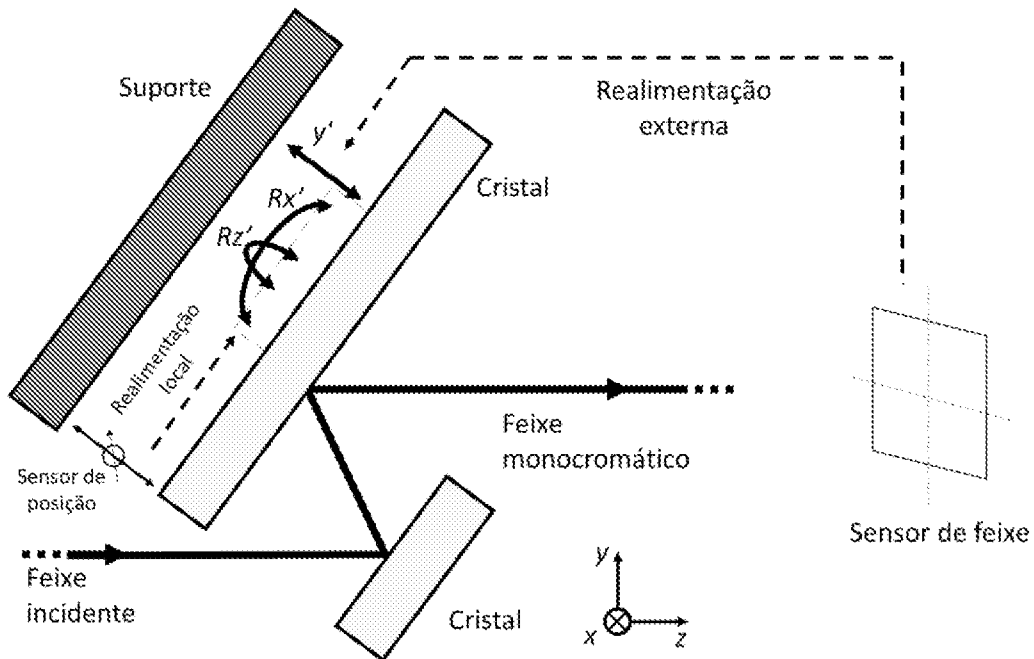


Figura 3 (a)

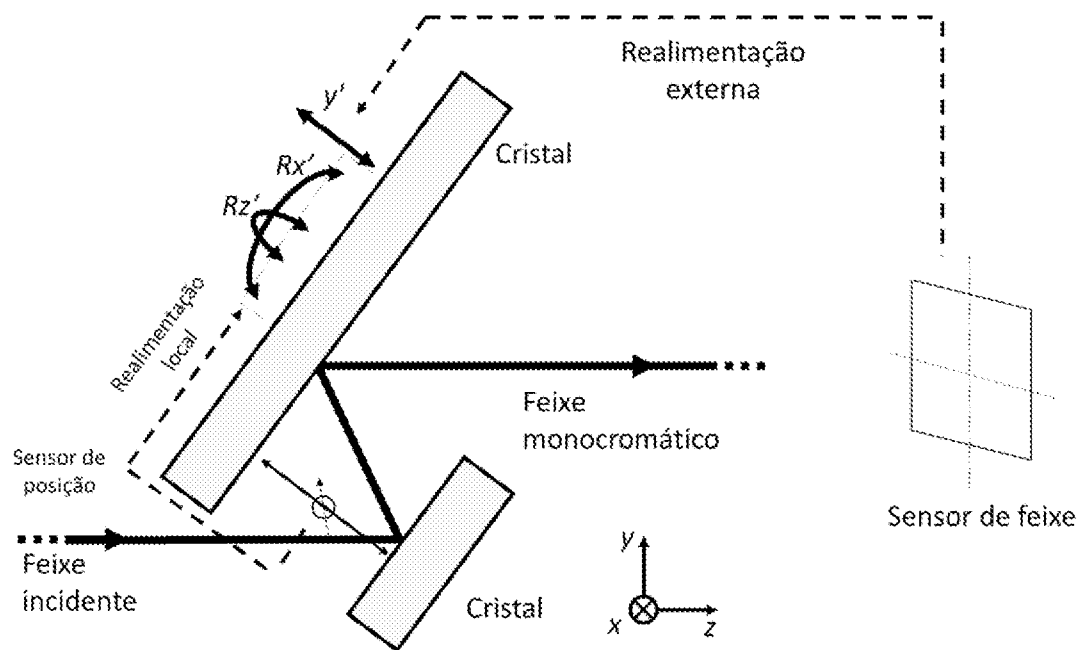


Figura 3 (b)

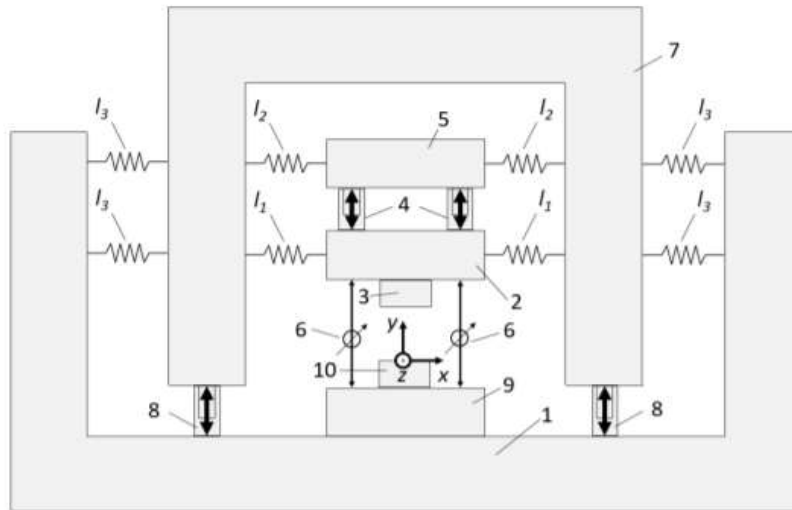


Figure 4 (a)

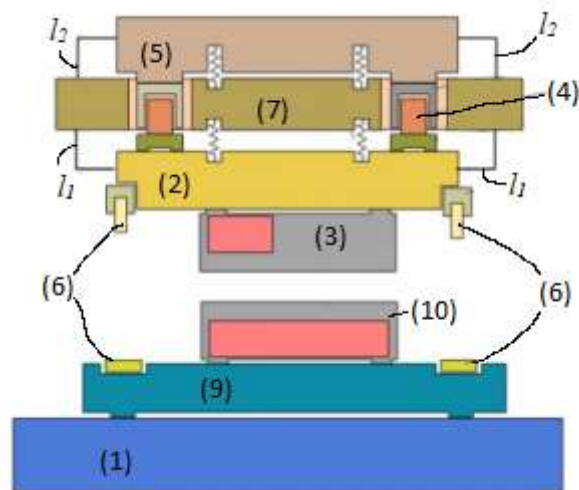


Figure 4 (b)