

CLAIMS

1. A method for determining the local position of at least one optical element associated with a transport optical path for a laser beam in a working head of a machine for laser
5 processing of a material, characterized in that it includes the steps of:
- generating a respective measurement low-coherence optical radiation beam, leading said measurement beam towards said optical element, and leading the measurement beam reflected or diffused by at least one back-reflective surface of said optical element, on which said measurement beam impinges with at least a partial back-reflection, towards optical
10 interferometric sensor means, wherein the measurement beam travels a measurement optical path from a respective source to said optical interferometric sensor means including a first section between said source and said back-reflective surface of said optical element and a second section between said back-reflective surface of said optical element and the interferometric sensor means, having a respective predetermined nominal geometric length
15 when said optical element is in a predetermined nominal position corresponding to a predetermined operating condition,
 - generating a respective reference beam of said low coherence optical radiation, and leading said reference beam towards said optical interferometric sensor means, wherein the reference beam travels a reference optical path having an optical length equivalent to the
20 optical length of the measurement optical path in a nominal operating condition in which the position of said optical element is the predetermined nominal position;
 - superimposing the measurement beam and the reference beam on a common region of incidence of said optical interferometric sensor means, along a predetermined illumination axis;
 - 25 detecting the position of a pattern of interference fringes between the measurement beam and the reference beam along said illumination axis on said common region of incidence, wherein the extension of said pattern of interference fringes along the illumination axis corresponds to the coherence length of said low coherence optical radiation, or detecting the frequency of a pattern of fringes in the wavelength spectrum, obtained by the interference
30 between the measurement beam and the reference beam by wavelength dispersion of said beams, whose extension in the frequency domain is determined by the coherence length of said low coherence optical radiation; and

- determining a difference in optical length between the measurement optical path and the reference optical path - indicative of a difference between (a) the current local position of said optical element and (b) the predetermined nominal local position of said optical element along the axis of the measurement beam - as a function respectively of the position of said pattern of interference fringes along said illumination axis of said region of incidence, or of the frequency of said pattern of interference fringes in the frequency domain.
2. The method according to claim 1, wherein said measurement optical path includes at least a third section intermediate between said first and second section and comprised between a first and a second back-reflection at said back-reflective surface of the optical element, which includes at least an at least partial back-reflection at a second back-reflective surface of said optical element, said third section having a respective predetermined nominal geometric and optical length when said optical element is in the predetermined nominal position and/or in the predetermined operating condition.
3. The method according to claim 1 or 2, wherein said measurement optical path includes at least a third section intermediate between said first and second section and comprised between a first and a second back-reflection at said back-reflective surface of the optical element, which includes at least an at least partial back-reflection at a back-reflective surface of a different optical element interposed along the optical transport path for the laser beam, said third section having a respective predetermined nominal geometric and optical length when said optical element is in the predetermined nominal position and/or in the predetermined operating condition.
4. The method according to claim 1, wherein said first and second sections of the measurement optical path include at least an at least partial back-reflection at a back-reflective surface of a different optical element interposed along the optical transport path for the laser beam or of the material being worked.
5. The method according to any one of the preceding claims, wherein the measurement beam is led on said common region of incidence of said optical interferometric sensor means along a first direction of incidence and the reference beam is led on said common region of

incidence of said optical interferometric sensor means along a second direction of incidence at a predetermined angle of incidence with respect to the first direction of incidence.

6. The method according to any one of claims 1 to 4, wherein the measurement beam and the reference beam are superimposed co-linearly along the same direction of incidence towards wavelength-dispersive optical means, adapted to separate the frequency components of the beam obtained by the superposition of the measurement beam and the reference beam on said common region of incidence of said optical interferometric sensor means.

7. The method according to any one of the preceding claims, wherein said predetermined operating condition is a machine stand-by condition or a working condition associated with pre-established working parameters.

8. The method according to any one of the preceding claims, wherein the position of the pattern of interference fringes along the illumination axis is the intrinsic position of the envelope of the intensity of the optical radiation of said pattern of interference fringes.

9. The method according to claim 8, wherein the intrinsic position of the envelope of the intensity of the optical radiation of said pattern of interference fringes is the position of the peak or maximum of the envelope of the intensity of said optical radiation.

10. The method according to any one of the preceding claims, wherein said optical interferometric sensor means comprise a linear or two-dimensional arrangement of photodetectors along said illumination axis.

11. The method according to any one of the preceding claims, wherein the measurement beam incident on said optical interferometric sensor means comprises a main measurement beam which results from the travel of a main measurement optical path with reflection from said at least one back-reflective surface of said optical element being measured and with transmission through any other optical element interposed along the optical path of the processing laser beam upstream of said optical element being measured, and at least one additional multiplexed measurement beam which results from the travel of an additional

measurement optical path, with reflection from said at least one back-reflective surface of said optical element being measured and having a geometric length greater than the geometric length of said main measurement optical path, which includes at least a partial back-reflection on the surface of a different optical element interposed along the optical path of the processing laser beam and of the measurement radiation beam,

5 the method comprising the steps of:

- detecting on said common region of incidence the position of an additional pattern of interference fringes having (i) a peak or maximum of intensity of the optical radiation distinct from the peak or maximum of intensity of the optical radiation of the main pattern of interference fringes between the main measurement beam and the reference beam, or (ii)
- 10 an intrinsic position of the envelope of the intensity of the optical radiation offset from the intrinsic position of the envelope of the intensity of the optical radiation of the main pattern of interference fringes; and
- determining a difference in optical length between the additional measurement
- 15 optical path and the reference optical path - indicative of a difference between (a) the current local position of said optical element and (b) the predetermined nominal local position of said optical element along the axis of the measurement beam - as a function of the position of said pattern of interference fringes along said axis of illumination of said region of incidence, or of the frequency of said pattern of interference fringes in the frequency domain,
- 20 respectively.

12. The method according to any one of the preceding claims, wherein the reference beam incident on said optical interferometric sensor means comprises a main reference beam which results from the travel of a main reference optical path and at least one additional multiplexed reference beam which results from the travel of an additional reference optical path having a geometric length different from the geometric length of said main reference optical path,

the method comprising the steps of:

- detecting on said common region of incidence the position of an additional pattern
- 30 of interference fringes having (i) a peak or maximum of intensity of the optical radiation distinct from the peak or maximum of intensity of the optical radiation of the main pattern of interference fringes between the measuring beam and the main reference beam, or (ii) an

intrinsic position of the envelope of the intensity of the optical radiation offset from the intrinsic position of the envelope of the intensity of the optical radiation of the main pattern of interference fringes; and

- determining a difference in optical length between the measurement optical path and the additional reference optical path - indicative of a difference between (a) the current local position of said optical element and (b) the predetermined nominal local position of said optical element along the axis of the measurement beam - as a function of the position of said pattern of interference fringes along said axis of illumination of said region of incidence, or of the frequency of said pattern of interference fringes in the frequency domain, respectively.

13. the method according to any one of the preceding claims, comprising determining the position of a plurality of optical elements interposed along the optical transport path for the high-power laser beam, characterized in that it includes the implementation of a plurality of measurement optical paths, associated with a plurality of corresponding reference optical paths, by extracting a corresponding plurality of measurement optical beams associated with each of said plurality of optical elements respectively, downstream of the reflection or diffusion from at least one back-reflective surface of each of said plurality of optical elements, said plurality of reference optical paths being arranged to lead respective separate or superimposed reference optical beams, or being determined by means of a continuous variation in the length of a base reference optical path through an optical element for the deflection and separation of said reference optical beams.

14. The method according to any one of the preceding claims, comprising determining a perturbation of the current optical length of at least a portion of the measurement optical path with respect to the current optical length of a corresponding portion of the reference optical path, and correcting the determined value of the current local position of the optical element along the axis of the measurement beam with respect to the nominal local position on the basis of said perturbation,

wherein the measurement beam incident on said optical interferometric sensor means comprises at least one calibration measurement beam which results from the travel of a calibration measurement optical path, wherein said measurement beam is reflected or

- diffused by at least one back-reflective surface of a static optical element interposed along the measurement optical path, and wherein the reference beam incident on said optical interferometric sensor means comprises a respective calibration reference beam which results from the travel of a calibration reference optical path having an optical length
- 5 equivalent to the optical length of the calibration measurement optical path in a nominal operating condition of calibration in which the geometric length and the refractive index of the transmission medium of the calibration measurement optical path are equal to the geometric length and to the refractive index of the transmission medium of the calibration reference optical path within a predetermined tolerance range,
- 10 and wherein determining the perturbation of the current optical length of at least a portion of the measurement optical path includes:
- superimposing the calibration measurement beam and the calibration reference beam on a common region of incidence of said optical interferometric sensor means, along a predetermined illumination axis;
 - 15 - detecting the position of a pattern of interference fringes between the calibration measurement beam and the calibration reference beam along said illumination axis on said common region of incidence, or the frequency of a pattern of interference fringes between the calibration measurement beam and the calibration reference beam obtained by wavelength dispersion of said beams; and
 - 20 - determining a difference in optical length between the calibration measurement optical path and the calibration reference optical path - indicative of a difference between (a) the geometric length of the calibration measurement optical path and the geometric length of the calibration reference optical path, and/or (b) the refractive index of the calibration measurement optical path and the refractive index of the calibration reference optical path -
 - 25 depending on either of the position of said pattern of interference fringes along said illumination axis of said region of incidence, or of the frequency of said pattern of interference fringes in the frequency domain,
- said optical length difference between the calibration measurement optical path and the calibration reference optical path being indicative of the aforementioned perturbation of
- 30 the current optical length of at least a portion of the measurement optical path.

15. The method according to any one of the preceding claims, comprising the control of the propagation axis of the measurement optical radiation beam in a predetermined neighbourhood of the propagation axis of the processing laser beam.

- 5 16. System for determining the local position of at least one optical element associated with an optical transport path for a laser beam in a working head of a machine for laser processing of a material, characterized in that it comprises:
- means for generating a respective measurement low coherence optical radiation beam;
 - 10 - means for propagation of said measurement beam, adapted to lead said measurement beam towards said optical element, and to lead the measurement beam reflected or diffused by at least one back-reflective surface of said optical element, on which said measurement beam impinges with an at least partial back-reflection, towards optical interferometric sensor means, wherein the measurement beam travels a measurement optical path from a respective
 - 15 source to said optical interferometric sensor means including a first section between said source and said back-reflective surface of said optical element and a second section between said back-reflective surface of said optical element and the interferometric sensor means, having a respective predetermined nominal geometric length when said optical element is in a predetermined nominal position corresponding to a predetermined operating condition,
 - 20 - means for generating a respective reference beam of said low coherence optical radiation;
 - means for propagation of said reference beam, adapted to lead said reference beam towards said optical interferometric sensor means, wherein the reference beam travels a reference optical path having an optical length which is equivalent to the optical length of
 - 25 the measurement optical path in a nominal operating condition in which the position of said optical element is the predetermined nominal position;
- wherein the means for propagation of the measurement beam and the means for propagation of the reference beam are arranged to superimpose the measurement beam and the reference beam on a common region of incidence of said optical interferometric sensor
- 30 means, along a predetermined illumination axis;
- means for detecting the position of a pattern of interference fringes between the measurement beam and the reference beam along said illumination axis on said common

- region of incidence, wherein the extension of said pattern of interference fringes along the illumination axis corresponds to the coherence length of said low coherence optical radiation, or for detecting the frequency of a pattern of fringes in the wavelength spectrum obtained from the interference between the measurement beam and the reference beam by
- 5 wavelength dispersion of said beams, whose extension in the frequency domain is determined by the coherence length of said low coherence optical radiation; and
- processing means arranged to determine a difference in optical length between the measurement optical path and the reference optical path - indicative of a difference between (a) the current local position of said optical element and (b) the predetermined nominal local
- 10 position of said optical element along the axis of the measurement beam - as a function respectively of the position of said pattern of interference fringes along said illumination axis of said region of incidence, or of the frequency of said pattern of interference fringes in the frequency domain.
- 15 17. Machine for the laser processing of a material, operating by means of a high power processing laser beam led along an optical transport path for the laser beam comprising at least one optical element, characterized in that it comprises a system for determining the position of said at least one optical element, arranged to carry out a method according to any one of claims 1 to 15.
- 20 18. A method for determining the pressure in an assist gas chamber associated with a nozzle for supplying an assist gas flow, carried by a working head of a machine for laser cutting, drilling or welding of a material, or for the additive manufacturing of three-dimensional structures by laser, characterized in that it includes the steps of:
- 25 - determining the local position of an optical element of protection or delimitation of the assist gas chamber, interposed along the optical transport path for the processing laser beam or the local position of an optical assistance element facing said assist gas chamber, possibly outside the axis of the processing laser beam, by means of a method for the determination of the local position of at least one optical element associated with an optical
- 30 transport path for a laser beam in a working head of a laser processing machine of a material according to any one of claims 1 to 15, wherein the reference beam travels a reference optical path of optical length equal to the optical length of the measurement optical path in a nominal

operating condition including a partial back-reflection of the measurement beam at a surface of said protective optical element or of said optical assistance element when it is in the predetermined nominal position corresponding to a predetermined reference pressure value of the assist gas in the assist gas chamber, and

- 5 - determining the pressure of the assist gas in the assist gas chamber according to a predetermined reference model indicative of a nominal relationship between the position of an optical protection element of the assist gas chamber or an optical assistance element with respect to said predetermined nominal position and the assist gas pressure.

10 19. The method of claim 18, wherein the reference optical path comprises an optical element corresponding to said protective optical element or to said optical assistance element, arranged along said reference optical path in a position corresponding to the nominal position of said optical protection element or of said optical assistance element in the measurement optical path.

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20. The method of claim 18 or 19, wherein the reference optical path comprises an optical element corresponding to said protective optical element or to said optical assistance element, subject to a controlled pressure value which constitutes said predetermined reference pressure value of the assist gas in the measurement optical path.

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21. Method for determining the temperature of an optical element interposed along the optical transport path for a processing laser beam for a machine for the laser processing of a material, or for the additive manufacturing of three-dimensional structures via laser, characterized in that it includes the steps of:

- 25 - determining the local position of said optical element by means of a method for determining the local position of at least one optical element associated with an optical transport path for a laser beam in a working head of a machine for laser processing a material according to any one of claims 1 to 15, wherein the reference beam travels a reference optical path of optical length equal to the optical length of the measurement optical path in a nominal
- 30 operating condition including a partial back-reflection of the measurement beam at a surface of said optical element when it is in the predetermined nominal position corresponding to a predetermined reference temperature value, and

determining the operating temperature of the optical element according to a predetermined reference model indicative of a nominal relationship between the position of said optical element relative to said predetermined nominal position and the temperature of the element.