

CLAIMS

1. Method for determining the standoff distance between a working head in a machine for laser processing of a material, operating by means of a high power processing laser beam emitted by said head and led along a working trajectory on the material comprising a succession of working areas, and the surface of the material at said working areas, characterized in that it comprises the steps of:
- 5 - generating a measurement low coherence optical radiation beam, leading said measuring beam towards a working area through said working head, and leading the measuring beam reflected or diffused from the surface of the material in said working area through said head and towards optical interferometric sensor means along a first direction of incidence, in which the measuring beam travels a measurement optical path from a respective source to said optical interferometric sensor means including a first section comprised between said source and the working head and a second section comprised
10 between said working head and the interferometric sensor means having a respective predetermined and invariant geometric length,
 - generating a reference beam of said low coherence optical radiation, and leading said reference beam towards 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 of said measurement beam, wherein the reference beam travels a reference optical path whose optical length is equivalent to the optical length of the measurement optical path in a nominal operating condition in which the distance between the working head and the surface of the material corresponds to a predetermined nominal standoff distance;
 - 20 - 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;
 - 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; and
30 - determining a difference in optical length between the measurement optical path and the reference optical path - indicative of a difference between (a) the current standoff

distance between the working head and the surface of the material at the working area and
(b) a predetermined nominal standoff distance - as a function of the position of said pattern
of interference fringes along said illumination axis of said region of incidence.

5 2. The method of claim 1, 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.

3. The method according to claim 2, wherein the intrinsic position of the envelope of
10 the intensity of the optical radiation of said pattern of interference fringes is the position of
the peak or maximum of the envelope of intensity of said optical radiation.

4. The method according to claim 1 or 2, wherein said optical interferometric sensor
means comprise an arrangement of photodetectors along said illumination axis, and the angle
15 of incidence is controlled in such a way that the spatial frequency of said pattern of
interference fringes is greater than the spatial frequency of the photodetectors.

5. The method according to claim 4, wherein the spatial frequency of said pattern of
interference fringes is different from the multiples of the spatial frequency of the
20 photodetectors and preferably close to a half-integer multiple of said spatial frequency of the
photodetectors.

6. The method of claim 1, wherein said optical interferometric sensor means comprises
an arrangement of photodetectors along said illumination axis and said arrangement of
25 photodetectors is a linear arrangement of photodetectors.

7. The method of claim 1, wherein said optical interferometric sensor means comprises
an arrangement of photodetectors along said illumination axis and said arrangement of
photodetectors is a two-dimensional arrangement of photodetectors.
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8. The method according to any one of the preceding claims in a machine for laser
cutting, drilling or welding of a material or for the additive manufacturing of three-

dimensional structures by laser, wherein said machine comprises a working head having a nozzle for dispensing a flow of an assist gas, arranged proximate to said material, and the measurement optical radiation beam is led through said nozzle and directed towards a measuring region of the material which is coaxial to said current working area or adjacent to said current working area, preferably in front of it along the working trajectory.

9. The method according to any one of claims 1 to 7 in a machine for laser welding of a material or additive manufacturing of three-dimensional structures by laser, wherein said machine comprises a working head which has an output of the processing laser beam arranged in proximity of said material, and the measuring optical radiation beam is led through said output of the processing beam and directed towards a measuring region of the material which is coaxial to said working area current or adjacent to said current working area, preferably behind it along the working trajectory.

10. The method according to claim 8 or 9, wherein the measurement optical radiation beam is directed towards said material measurement region by means of an optical scanning system whose inclination is controlled according to the absolute value and the direction of the forward speed of the working head along the working path.

11. The method according to any one of the preceding claims, wherein said illumination axis of the region of incidence is determined by the intersection between the plane defined by said angle of incidence and the sensing surface of said optical interferometric sensor means.

12. The method according to any one of the preceding claims, wherein the measurement optical path and the reference optical path include corresponding optical elements, the reference optical path including a reflective return element corresponding to the surface of the material interposed in the measurement optical path, and optical attenuator means adapted to balance the intensity of the reference optical radiation reflected by said reflective return element with respect to the intensity of the measurement optical radiation reflected by the material being processed.

13. The method according to claim 12, wherein said measurement optical path and said reference optical path originate from a common source, are separated by means of beam splitting means, led separately to the surface of the material being processed and to said reflective return element, respectively, and gathered in a detection optical path, in the
5 detection optical path the measurement beam being separated from the reference beam, said beams being directed with controllable orientation towards said common region of incidence of the optical interferometric sensor means, the controllable orientation determining the angle of incidence between the measurement beam and the reference beam.

10 14. The method according to claim 1, wherein in a machine for laser cutting, drilling or welding of a material, or for the additive manufacturing of three-dimensional structures by laser comprising a working head having a nozzle for dispensing a flow of an assist gas in which the measurement optical radiation beam is led through said nozzle, the determination of the difference in optical length between the measurement optical path and the reference
15 optical path is based on a normalized optical length of the measurement optical path which is calculated starting from the geometric length and from a normalized refractive index of a portion of said measurement optical path which passes through a chamber of the assist gas of the nozzle, which is calculated as a function of the pressure of the assist gas in said chamber, according to a predetermined nominal relationship of dependence of the refractive
20 index of the assist gas upon the pressure of said gas.

15. The method according to claim 1, wherein the determination of the difference in optical length between the measurement optical path and the reference optical path is based on a normalized optical length of the measurement optical path which is calculated from the
25 geometric length and from a normalized refractive index of a transmission medium of a portion of said measurement optical path, which is calculated as a function of the temperature, pressure or other physical parameter of said at least a portion of the optical path according to a predetermined nominal relationship of dependence of the refractive index upon the temperature, pressure or other physical parameter of the transmission medium of
30 the measurement optical radiation beam .

16. The method according to claim 1, wherein the determination of the difference in optical length between the measurement optical path and the reference optical path is based on a normalized optical length of the measurement optical path which is calculated starting from the normalized geometric length and from a refractive index of a material transmission medium of a portion of said measurement optical path, in which the normalized geometric length is calculated as a function of the mechanical deformation of said material transmission medium according to a predetermined nominal relationship of dependence of the geometric length upon the mechanical deformation of the material transmission medium of the measurement optical radiation beam.

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17. 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 standoff distance between the working head and the surface of the material on the basis of said perturbation,

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wherein the measurement beam incident on said optical interferometric sensor means comprises at least one calibration measurement beam which results from the travel of an calibration measurement optical path, wherein said measurement beam is reflected or diffused by at least one retro-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 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 the refractive index of the transmission medium of the calibration reference optical path within a predetermined tolerance range,

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and wherein determining the perturbation of the current optical length of at least a portion of the measurement optical path includes:

30 - 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;

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; and

- 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 - respectively depending on the position of said pattern of interference fringes along said illumination axis of said region of incidence,

said optical length difference between the calibration measurement optical path and the calibration reference optical path being indicative of the aforementioned disturbance in the current optical length of at least a portion of the measurement optical path.

18. The method according to claim 14, wherein the pressure of the assist gas in the assist gas chamber of the nozzle is detected directly by means of pressure sensors facing said chamber.

19. The method according to claim 14, wherein the pressure of the assist gas in the assist gas chamber of the nozzle is derived indirectly from a measure of the variation in the local position of a surface of an optical element of protection or delimitation of the assist gas chamber along the axis of the measurement beam according to a predetermined nominal relationship between the position of the surface of said optical element of protection or delimitation of the assist gas chamber with respect to a respective predetermined nominal position and the pressure of the assist gas, the measurement of the variation of the local position of said surface of the optical element of protection or delimitation of the assist gas chamber being determined as a function of the difference in length between an additional measurement optical path for measuring said optical element of protection or delimitation including at least one among (i) a first section between a source of the measurement beam and the optical element of protection or delimitation on a first surface of which said measurement beam impinges with partial back-reflection and (ii) a second section between the surface of the material being processed and the optical element of protection or

delimitation on a second surface of which said measuring beam impinges with partial back-reflection, and a respective additional reference optical path having an optical length equal to the optical length of the additional measurement optical path of said optical element of protection or delimitation in a nominal operating condition including a partial back-reflection of the measurement beam to said first or second surface of said optical element of protection or delimitation when it is at said predetermined nominal position along the axis of the processing laser beam for a predetermined reference pressure value of the assist gas in the assist gas chamber of the nozzle.

20. 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 the surface of the material in the working area and with transmission through each optical element interposed along the optical path of the high-power processing laser beam, and at least one additional multiplexed measurement beam which results from the travel of an additional measurement optical path, with reflection from the surface of the material being processed and having a geometric length greater than the geometric length of said main measurement optical path, which includes at least a partial back-reflection at the surface of an optical element interposed along the optical path of the high power processing laser beam, 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 different 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) 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 optical path and the reference optical path - indicative of a difference between (i) the current standoff distance between the working head and the surface of the material at the working area and (ii) the predetermined nominal standoff distance - as a function of the position of

said additional pattern of interference fringes along said illumination axis of said region of incidence.

21. 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,
- 10 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 different 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 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 (i) the current standoff distance between the working head and the surface of the material at the working area and (ii) the predetermined nominal standoff distance - as a function of the position of said additional pattern of interference fringes along said illumination axis of said region of incidence.
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22. A method for controlling the relative position between a working head of a machine for laser processing of a material, operating by means of a high power processing laser beam emitted by said head and led along a working path on the material comprising a succession of working areas, and the material at said working areas, characterized in that it includes carrying out a method for determining the standoff distance between the working head and the surface of the material according to any one of claims 1 to 21, and moving the working head towards or away from the material or in translation or inclination relative to the surface
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as a function of a predetermined working design and the determined standoff distance between the working head and the surface of the material.

23. A system for determining the standoff distance between a working head in a machine
5 for laser processing of a material, operating by means of a high power processing laser beam emitted by said head and led along a working trajectory on the material comprising a succession of working areas, and the surface of the material at said working areas, characterized in that it comprises:
- means for generating a measurement low coherence optical radiation beam;
 - 10 - means for propagation of said measurement beam adapted to lead said measurement beam towards a working area through said working head, and for leading the measurement beam reflected or diffused by the surface of the material in said working area through said head and towards optical interferometric sensor means along a first direction of incidence, in which the measurement beam travels a measurement optical path from a respective source
15 to said optical interferometric sensor means including a first section between said source and the working head and a second section between said working head and the interferometric sensor means, having a respective predetermined and invariant geometric length,
 - means for generating a reference beam of said low coherence optical radiation;
 - means for propagation of said reference beam, adapted to lead said reference beam
20 towards said optical interferometric sensor means along a second direction of incidence, at a predetermined angle of incidence with respect to the first direction incidence of said measurement beam, wherein the reference beam travels a reference optical path of optical length equivalent to the optical length of the measurement optical path in a nominal operating condition in which the distance between the working head and the surface of the
25 material corresponds to a predetermined nominal standoff distance;
- 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 means, along a predetermined illumination axis;
- 30 - 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; 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
- 5 (a) the current standoff distance between the working head and the surface of the material at the working area and (b) a predetermined nominal standoff distance - as a function of the position of said pattern of interference fringes along said illumination axis of said region of incidence.
- 10 24. Machine for laser processing of a material, operating by means of a high-power processing laser beam emitted by a working head and led along a working trajectory on the material comprising a succession of working areas, and including means for controlling the relative position between said working head and said material, characterized in that it comprises a system for determining the standoff distance between said working head and the
- 15 surface of the material at said working areas, arranged to carry out a method according to any one of claims 1 to 21, said means for controlling the relative position between said working head and said material acting according to a predetermined working design and the determined standoff distance between the working head and the surface of the material.