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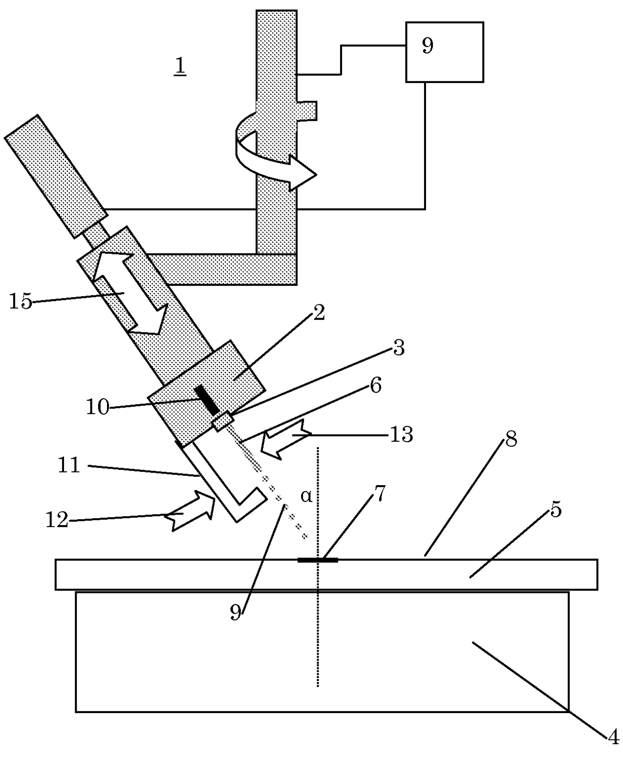
(54) Method and apparatus for polishing a workpiece surface

(57) The invention relates to a method for machining a workpiece surface, in which a machining area of the workpiece surface is machined under the influence of a polishing operation; the method comprising providing a fluid jet of abrasive liquid for impacting the machining area, wherein the fluid jet is arranged to break up in droplets prior to impacting the machining area.

Figure 1



EP 2 196 285 A1

Description

[0001] The invention relates to a method for machining a workpiece surface, in which an area to be machined of the workpiece surface is machined under the influence of a polishing operation.

[0002] It is known to form curved optical surfaces in optical materials, such as quartz or glass, by means of fluid jet polishing (FJP).

[0003] W09926764 discloses a technique wherein an abrasive liquid is sprayed onto the workpiece, via a nozzle. "Abrasive liquid" is in this context intended to mean a liquid which can be used to grind a surface to a relatively high roughness or to polish it to a lower roughness. W0992674 further discloses that the abrasive liquid provides controlled working of the surface of the workpiece, in particular, at relatively low pressures, such as 50 bar or lower. The abrasive liquid, which preferably contains abrasive particles, has a relatively low velocity at these low pressures, so that material is removed in a controlled manner. In one embodiment, abrasive liquid used is water containing 10 vol% silicon carbide particles with a size of approx. 20 micrometer as the abrasive, to polish a surface of BK7

[0004] In addition, it is known to provide a device for cutting glass using a high-speed jet of liquid in the order of magnitude of 2000 bar.

[0005] Fluid jet polishing results in nice polishing properties since the machining area can be very small, and a beam profile of the jet, due to the randomness of the polishing process, provides smooth transitions outside machining areas. In this context, a "machining area" is the part of a surface of an object where the fluid jet actively impacts the object. Furthermore, the technique is suitable to follow substantial inclinations of the surface to be machined, such as sharp corners and steep slopes.

[0006] However, a desire exists to further decrease the surface roughness due to the polishing operation. To that end, the invention provides method for machining a workpiece surface, in which a machining area of the workpiece surface is machined under the influence of a polishing operation; the method comprising providing a fluid jet of abrasive liquid for impacting the machining area, wherein the fluid jet is arranged to break up in droplets prior to impacting the machining area.

[0007] A non limiting explanation why this may provide improved polishing results is, that in a constitution with a fluid jet that is broken up in droplets prior to impacting the machining area, the abrasive particles are better surrounded by the fluid in the droplets, due to the surface tension properties of the droplets, than in a constitution with the fluid jet in a continuous jet form, which is a jet of fluid moving as a continuous elongate fluid volume, which is not broken up in smaller droplets prior to impacting the machining area. In the latter constitution, due to turbulent air mixing with the fluid jet, the abrasive particles impact the surface with too high force and may affect the polishing result. Further advantageous embodiments of the invention are represented in the subclaims.

[0008] The invention will now be further elucidated with reference to an exemplary embodiment represented in a drawing. In the drawing:

Figure 1 shows a schematic perspective view of a machining apparatus according to the invention; and
Figure 2 shows a schematic side view of the tooling setup of Fig. 1
Figure 3 shows a schematic impression of a chamber wall of Figure 2; and
Figure 4 shows another schematic impression of the chamber wall of Figure 2.

[0009] With reference to Figure 1, a machining apparatus 1 is shown having a polishing tool designed as a fluid jet-polishing device 2, in this example, rotatably mounted. The axis of rotation is transversal, preferably perpendicular to the machining surface 7, i.e. preferably parallel to a normal direction of the surface. The machining apparatus 1 further comprises a workpiece table 4 on which a workpiece 5 of e.g. BK7 is clamped which can be machined with the aid of a jet of polishing liquid 6 leaving a nozzle 3 of the fluid jet polishing device 2. The polishing fluid comprises, for instance, a slurry of 90 volume percent water and 10 volume percent of silicon carbide particles, each with a diameter of approximately 5 μm, which, via a spout nozzle with a cylindrical diameter of approximately 1.5 millimetre and a length of approximately 15 to 22 millimetres is spouted, at a pressure of approximately 5 bar, from a distance of approximately 3 cm at an acute angle onto the work piece 5, so that a substantially round area to be machined 7 is formed in the work piece surface 8. The workpiece table 4 and the fluid jet device 2 are disposed so as to be movable relative to each other with the aid of a table and/or nozzle control mechanism (not shown) which is numerically controlled by a central processing unit 9, so that the area to be machined 7 can be displaced over the workpiece surface 8. Further, the central processing unit 9 may be coupled to a measurement device (not shown) for measuring polishing progress. The device 2 may comprise a vibrating member arranged in the chamber, for example a piezo, magnetostrictic or voice coil actuated vibrating rod 10 near nozzle 2 to actively break up the fluid jet 6 in droplets 9 prior to impacting the machining area 7. In addition, or alternatively, the nozzle 2 may be vibrated as a whole, as indicated by arrow 15.

[0010] In an embodiment, it has been found that start up effects of creating the stream of droplets 9 may produce an unstable stream with impacting abrasive particles. This may affect the surface roughness and can be circumvented by a receptacle 11 arranged to receive a fluid jet or a stream of droplets 9 to prevent the jet and/or droplets from impacting the surface area 8. The receptacle may be mechanically movable by a receptacle actuator 12 to move the receptacle into the jet trajectory. Alternatively, a deflection mechanism 13 may be provided to deflect the droplet trajectory, for example, by electrostatic deflection or a Coanda deflector, to selectively pass a droplet 9 to the machining interface. This may improve polishing control since the amount of polishing fluid can be precisely tuned to achieve a predefined polishing effect. The receptacle 12 may be further provided with a recirculation system to recirculate the abrasive fluid to the pressure pump (not shown).

[0011] As shown in Figure 2, a nozzle 3 is moved to a distance above a workpiece 5. In this case, the distance between nozzle 3 and machining area 7 is a several millimetres, such as for example 30 mm. The abrasive liquid 3 is sprayed onto the workpiece 5 at a pressure of, for example, 5 bar. The nozzle may be of circular cross section with a diameter of between 0.2 and 3.5 mm directed towards an optical surface. Operating pressures may be between 0.5 and 10 bar but may suitably be varied to higher pressures, such as 100 or even 600 bar depending on the specific abrasive fluid, machining area and nozzle diameter. In the embodiment of Figure 2 the break up mechanism is formed by a revolving nozzle holder 20 and a stationary chamber wall side 21 opposite the nozzle holder 20. The stationary chamber wall side 21 may be formed on a stationary block 22 that cooperates with the rotatable nozzle holder 20. The wall side 21 comprises a plurality of surface deformations 23 arranged in annular fashion, shown in plenary view in Figure 3 (the chamber wall 21 showing upward). A distance between the wall deformations and the nozzle channel may be in the order of the interval of 0.01-5 millimeter, depending on fluid pressure and fluid viscosity, so as to be able to impart a pressure pulse to the fluid jet 6 to actively break up the fluid jet 6 into droplets 9. The pulse frequency may be determined by the rotor frequency and number of deformations on the wall. Preferably, the frequency is in the range of a natural break up frequency of the jet 6 determined by Rayleigh dynamics. An indication for the natural break-up frequency, for low viscosity fluids of less then 500 mPa*s, could be expressed by $f=u/(K *d)$ wherein f is the break up frequency, u de jet velocity and d de undisturbed jet diameter and constant K= 4,508. For higher viscosity fluids, a similar range is calculable, depending on another constant K. Stationary block 22 and rotating nozzle holder are preferably shaped to provide a pressurized chamber 24 formed and suitably sealed between opposite walls 21 of block 22 and nozzle holder 20. The stationary block 22 comprises a fluid inlet 25 connectible with a pressure pump (not shown).

[0012] A rotation shaft (not shown) may be provided extending through the chamber 24; coupled to a drive motor arranged opposite the stationary block and suitably sealed.

[0013] The abrasive fluid 6 used may be water containing H800 SiC abrasive particles. The jet diameter is, for example, 2 mm. In the exemplary embodiment shown, the angle alpha between the nozzle 3 and the workpiece surface 7 is 20, and the nozzle 2 is advanced with respect to the surface 8 of the workpiece 5. At the relatively low pressure and the given diameter of the nozzle 1, the flow of the abrasive liquid 3 will be laminar. The rate and level of fineness of the working can be adjusted by varying diameter of the nozzle, the pressure of the abrasive liquid 3, the angle alpha with respect to the workpiece 5 and the distance between the nozzle 3 and the workpiece 5.

[0014] Figure 4 shows another view of said chamber wall, wherein the deformations are formed by rotor shaped depressions. Other deformations, in particular, axisymmetric forms such as round, inclined, tapered or undulated rotor shaped forms may be used depending on a desired effect. The deformations, in particular, suitably formed depressions, protrusions, through holes and/or notches are shaped to provide a pressure pulse near the nozzle so as to break up the fluid jet ejected from the nozzle into droplets 9.

[0015] In an embodiment of the method according to the invention, multiple nozzles may be used, each of which is disposed at an angle with respect to the workpiece and the liquid jets from which intersect one another on or below the workpiece surface. The intersecting jets may impact a single machining area but do not have to hit the optical surface at the same time. The abrasive liquid may comprise a number of liquids, such as water or an organic liquid, such as octanol. Preferably, abrasive particles or polishing particles are added to an abrasive liquid, such as for example #800 silicon carbide or particles which have similar properties. Other suitable abrasive particles comprise diamond or aluminium oxide, while #1500 diamond, silicon carbide or cerium oxide can be used for polishing. The rate at which material is removed from the surface of the workpiece depends on the concentration, dimensions and hardness of the abrasive particles and on the type of abrasive liquid, the velocity of the abrasive liquid when it leaves the nozzle, the contact time, the geometry, the relative dimensions and orientation of the nozzle with respect to the workpiece surface, and the like. The diameter of the nozzle is relatively small compared to the dimensions of the workpiece, preferably between 1 cm and 0.05 mm, and particularly preferably between 5 mm and 0.2 mm.

[0016] Although the process according to the invention can be used on a multiplicity of materials, the method is particularly suitable for optical materials, such as for example BK7, ULE (a trademark of Corning and recognized in the industry), silicon, glass, sapphire, quartz, optical plastics, but also for metal or ceramic materials. Owing to the low energy of the abrasive liquid and the abrasive particles, material is removed gradually without pitting or scratches being formed. During the operation, one nozzle may be moved with respect to the workpiece, for example in a raster pattern. It is also possible to employ a series of nozzles and to rotate the workpiece about its axis of rotation at the same time. By linking the movement of the nozzle to the movement of the workpiece, it is possible to grind and polish complex geometric shapes, such as, for example, freeform surfaces described by higher order polynomials surfaces. The cross section of the nozzle may be circular, elliptical, triangular or rectangular, or may be in the form of a series specifically shaped openings in order to form a plurality of slots.

[0017] Although the invention has been discussed with reference to the exemplary embodiments represented in the drawing, it is not limited thereto but can comprise all sorts of variations and modifications thereof. Such variations are understood to fall within the reach of the invention as outlined by the following claims.

Claims

1. A method for machining a workpiece surface, in which a machining area of the workpiece surface is machined under the influence of a polishing operation; the method comprising providing a fluid jet of abrasive liquid for impacting the machining area, wherein the fluid jet is arranged to break up in droplets prior to impacting the machining area.

2. A method according to claim 1, further comprising imparting a pressure pulse to the fluid jet so as to actively break up the fluid jet.

3. A method according to claim 1, wherein the fluid jet is directed under an angle relative to the machining area.

4. A method according to claim 3, wherein the fluid jet is rotated along an axis transversal to the machining area.

5. A method according to claim 1, comprising providing a plurality of fluid jets directed to have the droplets impact a single machining area.

6. A device for machining a workpiece, comprising:

    - a chamber arranged to receive a pressurized abrasive liquid;
    - a nozzle, communicatively coupled to said chamber for ejecting a fluid jet of abrasive liquid, the nozzle arranged to be positioned relative to a machining area of a workpiece; and
    - a break up mechanism for breaking up a fluid jetted out of the nozzle; arranged to break up the jet into droplets prior to impacting the machining area.

7. A device according to claim 6, wherein the break up mechanism comprises a vibrating member arranged near the nozzle.

8. A device according to claim 6, further comprising a revolving nozzle holder holding the nozzle, so as to rotate the nozzle along an axis transversal to the machining area.

9. A device according to claim 8, wherein the break up mechanism comprises the revolving nozzle holder and a stationary chamber wall side opposite the nozzle holder, the stationary chamber wall side comprising a plurality of surface deformations shaped to provide a pressure pulse near the nozzle so as to break up the fluid jet ejected from the nozzle into droplets.

10. A device according to claim 9, wherein the deformations are provided in an annular arrangement of depressions, protrusions, through holes and/or notches.

11. A device according to claim 6, further comprising a receptacle and a mechanism for moving the receptacle and a droplet trajectory relative to each other to selectively pass a droplet to the machining interface.

12. A device according to claim 8, wherein the revolving nozzle holder is actuated by a rotation shaft extending through the chamber; coupled to a drive motor arranged adjacent to the chamber via a seal.

13. A droplet break up device according to claim 8, wherein the diameter of the nozzle channel is in the interval of 0.05-5 millimeter.

14. A droplet break up device according to claim 8, wherein the nozzle channel length is in the interval of 0.05-25 millimeter.

15. A droplet break up device according to claim 8, wherein a plurality of surface deformations is larger than 5; preferably larger than 100; wherein the rotation speed of the revolving nozzle holder is larger 100 rpm; preferably larger than 1000 rpm.

Figure 1

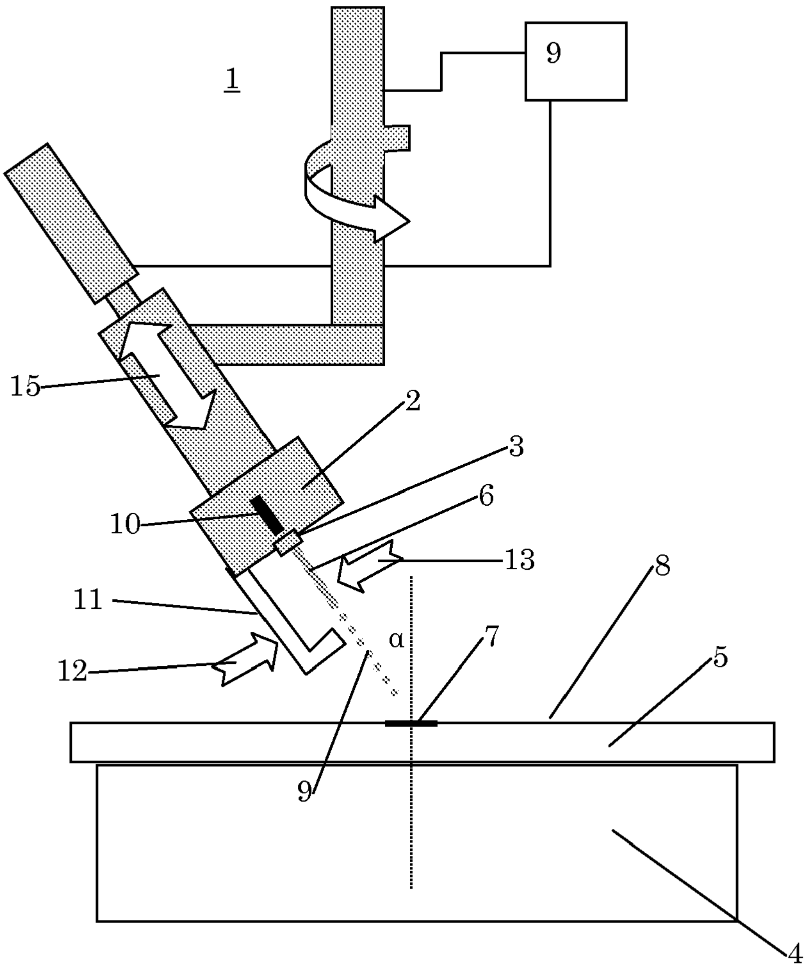


Figure 2

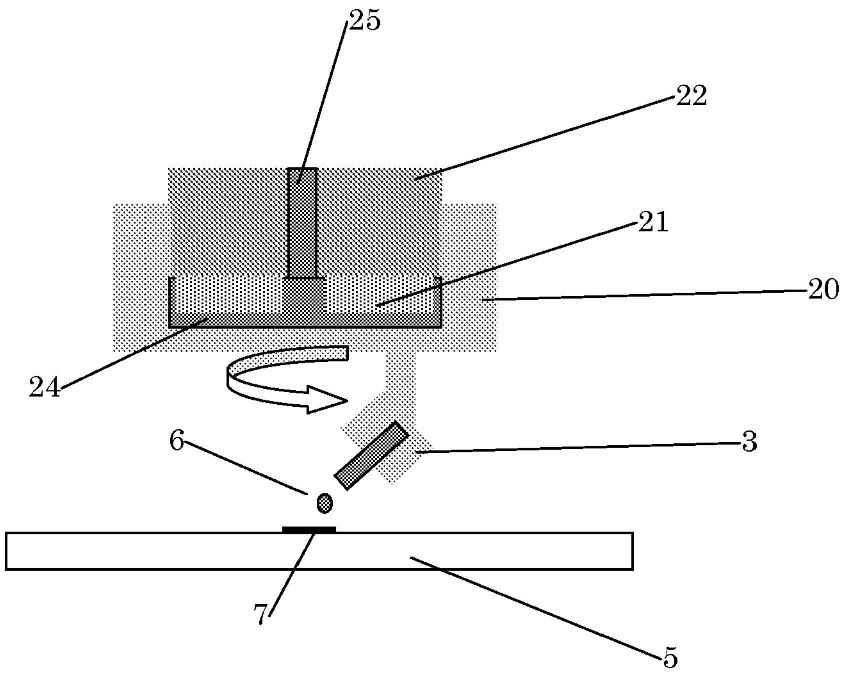


Figure 3

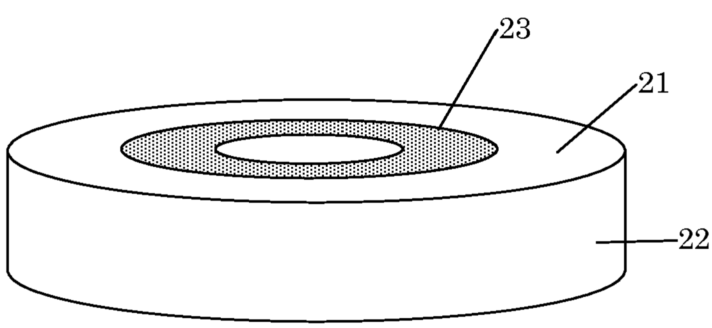
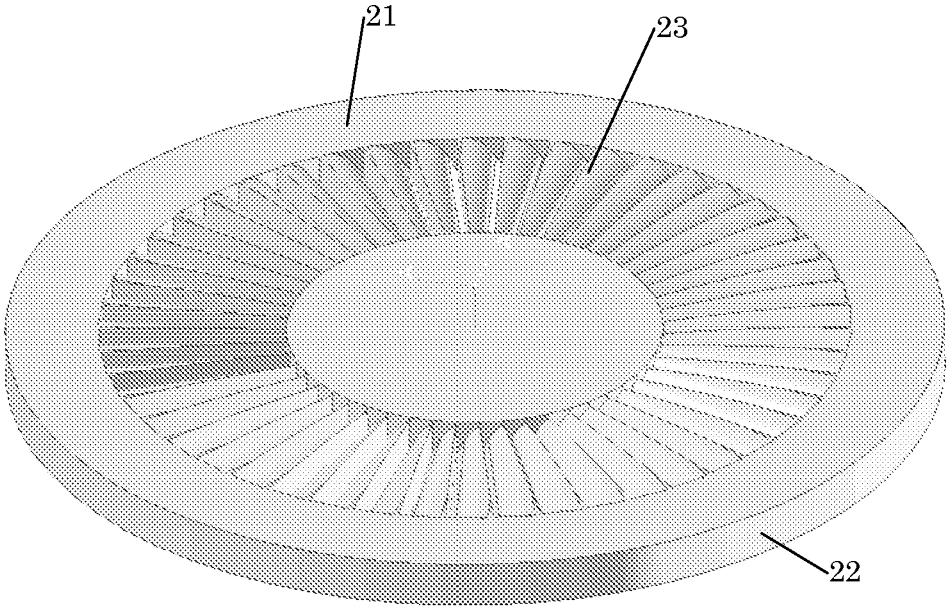


Figure 4



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PARTIAL EUROPEAN SEARCH REPORT

which under Rule 63 of the European Patent Convention shall be considered, for the purposes of subsequent proceedings, as the European search report

Application Number
EP 08 17 1346

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	DE 33 43 611 A1 (WOMA MAASBERG CO GMBH W [DE]) 13 June 1985 (1985-06-13) * page 3, paragraph 3 * * claim 7 * * figures 1,2 * * abstract * -----	1-8, 11-14	INV. B24C5/08 B24C5/02 B24C1/08
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X	US 5 512 318 A (RAGHAVAN CHIDAMBARAM [US] ET AL) 30 April 1996 (1996-04-30) * column 3, line 56 - column 5, line 5 * * abstract * -----	1-8, 12-14	
X	EP 1 036 633 A (SHIBUYA KOGYO CO LTD [JP]; SHIBUYA MACHINERY CO LTD [JP]) 20 September 2000 (2000-09-20) * paragraphs [0003], [0004], [0012] - [0014], [0018], [0019], [0024], [0026], [0035], [0036], [0040] * * claim 1 * ----- -/--	1-8, 12-14	TECHNICAL FIELDS SEARCHED (IPC) B24C

INCOMPLETE SEARCH

The Search Division considers that the present application, or one or more of its claims, does/do not comply with the EPC to such an extent that a meaningful search into the state of the art cannot be carried out, or can only be carried out partially, for these claims.

Claims searched completely :

Claims searched incompletely :

Claims not searched :

Reason for the limitation of the search:

see sheet C

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Place of search	Date of completion of the search	Examiner
Munich	27 May 2009	Eder, Raimund

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04E07)

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PARTIAL EUROPEAN SEARCH REPORT

Application Number
EP 08 17 1346

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (IPC)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
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A	US 2005/127037 A1 (TANNOUS ADEL G [US] ET AL TANNOUS ADEL GEORGE [US] ET AL) 16 June 2005 (2005-06-16) * paragraphs [0011], [0039], [0089] * * claims 2-4 * -----	2,7	TECHNICAL FIELDS SEARCHED (IPC)
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EPO FORM 1503 03.82 (P04C10)

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INCOMPLETE SEARCH SHEET C

Application Number
EP 08 17 1346

Claim(s) searched completely:
1-8,11-14

Claim(s) not searched:
9,10,15

Reason for the limitation of the search:

Claims 13 and 14 refer to a "droplet break up device of claim 8". Since claim 8 does not include a "droplet break up device", claims 13 and 14 are regarded as relating to "a device according to claim 8" for the purpose of assessing novelty and inventive step.

Claim 15 relates to features of claim 9 and is therefore regarded as being dependent upon claim 9.

Claims 9, 10 and 15 relate to features that are not sufficiently disclosed in the claims nor in the description.
Providing a rotating nozzle and a chamber wall with surface deformations located opposite to the nozzle holder does not suffice to produce the effect of creating a pressure pulse near the nozzle. It remains unclear how this effect is achieved and which features are meant to produce the effect.
Hence, the subject matter of claims 9, 10 and 15 is not sufficiently disclosed as required by article 83 EPC in order to carry out the invention as claimed in these claims.
Therefore, no search could be carried out for that subject matter.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 08 17 1346

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The members are as contained in the European Patent Office EDP file on
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27-05-2009

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 9926764 A **[0003]**
- WO 992674 A **[0003]**