(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 110 529**
A2

(12) # EUROPEAN PATENT APPLICATION

(21) Application number: **83306212.8**

(22) Date of filing: **13.10.83**

(51) Int. Cl.³: **B 24 C 5/04**

(30) Priority: **22.10.82 US 436002**

(43) Date of publication of application: **13.06.84 Bulletin 84/24**

(84) Designated Contracting States: **AT BE CH DE FR GB IT LI NL SE**

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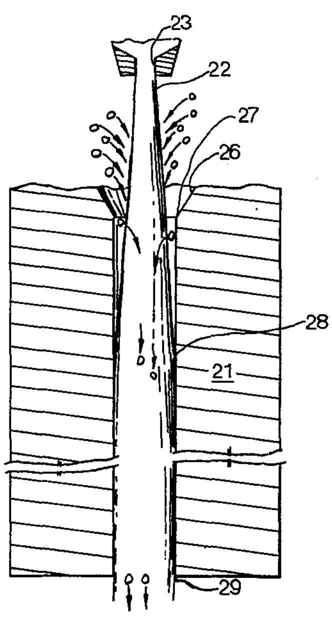
(54) **High velocity fluid abrasive jet.**

(57) In method and apparatus for producing a coherent stream of high velocity abrasive laden liquid, the method includes allowing particles of abrasive to assume the direction and velocity of a high velocity jet (22) of liquid. The method allows concentration of particles in the centre of the flow of liquid to reduce nozzle wear and increase cutting efficiency. The apparatus includes a nozzle (21) having a converging section (26, 27) attached to a straight section (28) that is sufficiently large that the abrasive particles approach the velocity of the fluid jet before leaving the exit (29) of the nozzle.



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"High Velocity Liquid Abrasive Jet."

This invention relates to abrasive loaded liquid jets, and particularly to high velocity abrasive liquid cutting jets.

It has long been known to accelerate abrasive particles with a jet of high velocity fluid. Such a jet may be used for cleaning and surface finishing applications. Dry and wet sand blasting are examples. In all such applications only the surface of the target material is removed and there is no deep penetration. The fluid used in such applications is usually air or other gas.

It has been proposed to create a jet of a liquid having entrapped abrasive particles that could be used to cut hard materials. Through proper choice of materials and careful design, it has been found possible to produce jets of liquid having velocities as high as 900 m/s. Such jets may be used to cut a wide variety of relatively soft materials. If such a jet could be charged with abrasive particles, it could cut even very hard materials such as steel or glass at a rapid rate. Attempts to produce such a stream have not met with success for several reasons. First, the high velocity abrasive stream is extremely erosive and has caused destruction of nozzles at a rate sufficient to render the process impractical. Second, existing nozzle designs do not allow the particles of abrasive to reach jet speed, or a substantial fraction thereof, resulting in far less than theoretical cutting capacity. Finally, existing nozzles do not produce a coherent stream of abrasive-charged particles, resulting in insufficient cutting power and a large kerf.

It has been found that to produce a nozzle for abrasive liquid jet cutting, it is necessary first to produce a coherent stream of abrasive loaded liquid; second to maximize the velocity of the particles in the stream; and third to accomplish the first two requirements with minimal nozzle wear.

The invention provides a method and apparatus for producing high velocity, abrasive loaded, coherent streams of liquid. The invention maximizes abrasive particle exit velocity and reduces nozzle wear to provide a long service life.

The method of the invention first forms a stream of high velocity liquid. The stream is directed through a chamber where abrasive particles of low velocity and random direction are added. Air flow in the chamber directs the particles into the entry of the mixing tube where they randomly impact the high velocity water jet. The result is a mixture of high velocity liquid and particles of abrasive having random direction and velocity. This mixture then continues into a reorientation zone where the particles of abrasive are allowed to orient their direction to that of the liquid. This results in a stream of liquid having abrasive particles entrapped at its core region. This stream is allowed to continue motion in a nozzle until the particles are accelerated to a velocity approaching that of the liquid. Finally, the stream of liquid and rapidly moving particles leave the nozzle.

The apparatus of the invention includes a nozzle having zones of curvature and profile necessary to accomplish the method. The entry zone is a converging conical section that may be produced by the action of the particles themselves. A change in outline forms the beginning of the reorientation zone. An accelerator zone follows which may be a straight section.

The invention will now be described by way of example, with reference to the drawings, in which:-

Figure 1 is a sectional view of a converging - diverging nozzle;

Figure 2 is a sectional view of a converging nozzle;

Figure 3 is a schematic sectional view of a high velocity water jet cutting system incorporating the invention;

Figure 4 is a schematic sectional view of a high velocity water jet cutting system incorporating the invention;

Figure 5 is a sectional view of a nozzle assembly incorporating the invention; and

Figure 6 is a block diagram of the method of the invention.

In sand blasting or abrasive jet machining two types of nozzles are in general use. Figure 1 illustrates the first type of nozzle, a converging - diverging or venturi type nozzle. This type of nozzle has been found unsuitable for use in high velocity abrasive water jet cutting due to extreme nozzle erosion problems. A second type of nozzle illustrated in Figure 2 has shown somewhat more promise. This nozzle, called a straight nozzle, includes a converging section 1 and a straight section 2 having a length (a) and a diameter (d). The sum of the length of straight section 2 and converging section 1 is the total length (L) of the nozzle. In present nozzles, the ratio of (a)/(d) is less than 20 and is much less for those nozzles where it is between 15.24 and 31.75 mm.

Figure 3 shows a typical arrangement of components used in abrasive water jet cutting. The drawing is broken for clarity. A high pressure water jet nozzle having an orifice 7 of diameter (dn) receives high pressure liquid having a pressure (P) from a source (not shown) of high pressure liquid which may be for example a hydraulic intensifier or equivalent device. A jet 8 emerges from orifice 7 and enters the convergent section 9 of a nozzle 11. Convergent section 9 of nozzle 11 is also connected to a source (not shown) of abrasive particles 10 having a predetermined size (dp) and a flow rate (m). The entrance of jet 8 into converging section 9 of nozzle 11 creates an area of low pressure 12 at the entrance to nozzle 11. The materials used and the geometry of the apparatus must be adapted to the parameters defined above to produce a satisfactory nozzle.

Figure 4 illustrates the characteristics of fluid flow in a high pressure fluid jet nozzle 21.

The drawing is broken away for clarity. A jet 22 of high pressure fluid leaves an orifice 23. Typical orifice diameters are from 0.254 to 12.70 mm. with operating pressures from 350 kg cm^2 to 7000 kg cm^2 or greater. This is a jet similar to that used in water jet cutting and orifice 23 may be made of for example synthetic sapphire. It will be noted that jet 22 is slightly divergent when it issues from orifice 23. Abrasive particles are introduced into the entry 26 of nozzle 21. The abrasive particles will normally have a random distribution of direction and velocity, but it is desirable to minimize the turbulence and try to direct toward exit point 29. As jet 22 enters nozzle 21 an area of low pressure will be created in the convergent area of nozzle 21 between points 26 and 27. The reduced pressure in this area causes abrasive particles to be entrained into jet 22. The direction and velocity of the abrasive particles between points 27 and 28 in nozzle 21 still retains a random component and if jet 22 were allowed to leave at point 27 the cutting efficiency would be low. Between points 27 and 28 in nozzle 21 the direction of the abrasive particles is oriented by jet 22 to ensure a predominant axial velocity, i.e. toward point 29, and the randomness of direction is removed. The abrasive particles are still moving much slower than jet 22, however, as time is required to transfer momentum from the relatively light liquid to the denser particles of abrasive. Accordingly, a section of nozzle 21 from point 28 to point 29 must be provided. The length of the section between point 28 and 29 must be sufficient so that the velocity of the particles entrained approaches that of jet 22 where point 29 is reached. If nozzle 21 is lengthened beyond point 29, frictional losses will occur resulting in deceleration of abrasive particle velocity and loss of cutting power. Prior nozzle designs have attempted to mix and accelerate the particles with the water in the region between 23 and 26 and have allowed exit of the jet either before axial orientation has occurred or before the abrasive particles have reached the approximate velocity of the liquid jet. It will be noted that at point 28 jet 22 is in contact with the wall of nozzle 21. Once such contact occurs, jet 22 will assume the flow characteristics of a fluid flowing down a tube at high velocity. The fluid will, accordingly, have a relatively low velocity in that area which is in contact with the wall of nozzle due to formation of a boundary layer. Flow velocity will be much higher as it progresses toward the centre of the diameter of the nozzle. This gradient of velocity will cause the abrasive particles to concentrate at the centre of jet 22. The formation of a boundary layer of relatively low velocity and lowered abrasive particle population allows an extended nozzle life and also can allow the area of nozzle 21 between points 28 and 29 to be made of relatively inexpensive material. Prior designs have allowed the jet to leave the nozzle before concentration of particles in the centre of the jet and have produced high wear rates.

Due to the complications of mixed phase high velocity flow inside and outside walls, it has not yet been found possible to determine a general equation for design of a nozzle that meets the above requirements. Ranges can be defined however for the above parameters which will produce satisfactory nozzles. First, nozzle 22 must be sufficiently long for the abrasives to accelerate to at least 80% of the speed of jet 22 and to have a direction nearly parallel to the tube wall in order to provide a coherent and nearly parallel, cohesive, abrasive jet at point 29. Second, the diameter of the section between points 27 and 29 should be sufficiently small so that the abrasive particles are forced to remain in contact with the liquid, but large enough to pass the abrasives and the liquid. Tubes as small as 1.52 mm. have been made to run in 0.76 mm. jets and 16 mesh abrasives. This bore should be straight and the material of the tube should have a knoop hardness over 1000 to reduce wear. To fulfil the above requirements, it has been found that the length of nozzle 22 between points 27 and 29 should be between 25 to 100 times its diameter. The diameter of this section should be at least 1.1 times the diameter of the abrasive particles ($D \geq 1.1d_p$). Finally, the diameter of this section should be between 1.1 and 10 times the diameter of orifice 23 ($10d_j \geq d \geq 1.1d_j$). This requires, for example, a nozzle length between point 27 and 29 of at least 10 cm. for an orifice 23 of diameter more than or equal to 0.89 mm. Similarly, a 5 cm., or larger, tube is needed for a 0.51 mm. or larger orifice 23. For an orifice diameter of 0.025 mm., the length of the nozzle between points 27 and 29 must be at least 12.7 mm. As stated earlier, the section of nozzle 21 between points 28 and 29 may be made of the material having a knoop hardness over 1000 which includes carbides, ceramics, and similar materials.

The upper section of nozzle 21 between points 26 and 28 should be thick walled so that the abrasive particles can erode the inlet section between points 26 and 27 into a nozzle inlet shape.

Figure 5 shows a nozzle incorporating the invention. High pressure liquid enters via a supply tube 31 from a high pressure intensifier (not shown). Supply tube 31 is attached to the nozzle body 32 by means of a gland 33 and collar 34, although any other connector appropriate for the pressures used could be substituted. The high pressure fluid then flows down the interior of nozzle body 32 which is closed at the end opposite supply tube 31 by a jewel holder 36. Jewel holder 36 is sealed to nozzle body 32 and includes a recess containing a jewel orifice 37. Jewel orifice 37 is constructed of a hard material for example synthetic sapphire having an orifice diameter of 0.025 mm. to 1.27 mm. and is similar to jewels used in high pressure water jet cutting. The feed water emerges from jewel orifice 37 as a high pressure jet 38 into the interior of the nozzle holder 39. Nozzle holder 39 includes a threaded attachment point 41 for nozzle body 32 and an introduction port 42 for particles of abrasive. The particles of abrasive flow down a line (not shown) attached to port 42 from a storage tank (not shown). Jet 38 and the abrasive particles then pass through a collar 43 in the interior of nozzle holder 39. Collar 43 prevents erosive wear of nozzle holder 39. The particles of abrasive and jet 38 then enter a tapered sleeve 44 before entering a nozzle 46. Nozzle 46 is constructed of carbide, or other hard material, and is from 51 to 200 mm. long with an inner diameter of from 0.76 to 3.80 mm. and an outer diameter of 9.22 mm. Nozzle 46 is attached to a steel adaptor 47 by a compression fitting nut 48 and compression fitting sleeve 49. Adaptor 47 is threadedly connected to nozzle holder 39, although equivalent attachment means could be used. Collar 43, tapered sleeve 44 and the upper portion of nozzle 46 form the mixing chamber of the device. The abrasive loaded stream 50 of liquid finally emerges at the end 51 of nozzle 46 and may be used for cutting such hard materials as steel or glass.

Figure 6 is a block diagram of the method of the invention. First a high velocity water jet is generated 61. This may be done much as is presently done in water jet cutting. Abrasive particles are then introduced with the stream 62 into an orienting tube. The particles are then orientated 63 into the direction of the stream. Time is next allowed for acceleration of the particles 64 to a sizeable fraction of stream velocity. The acceleration is accomplished by forcing the stream into an additional length to assume a pipe flow where a boundary layer of fluid having reduced velocity causes concentration of particles in the centre of the jet. Finally, the jet charged with particles exits 65 to do work.

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CLAIMS.

1. A method of producing an abrasive laden jet of high velocity liquid comprising the steps of:-
generating (61) a jet of high velocity liquid;
introducing (62) particles of abrasive into the jet;
orienting (63) the velocity vector of the particles to that of the jet; and
accelerating (64) the particles to a speed at least approaching that of the jet.

2. A method according to claim 1 wherein the particles (10) are accelerated to at least 80% of the velocity of the jet.

3. A method according to claim 1 comprising concentrating the particles (10) at the centre of the jet (22).

4. A method according to claim 3 wherein the concentration is accomplished by allowing the jet to contact a wall (28) to produce a velocity gradient providing an area of reduced velocity in the area of the wall.

5. A method according to any preceding claim wherein the orientation is accomplished by introducing the jet (22) with abrasive particles (10) into a converging section (9) of a nozzle (11); and allowing the particles to assume the vector velocity of the jet in the nozzle.

6. A method according to any preceding claim wherein the acceleration is accomplished introducing the oriented abrasive particle laden stream into a straight section (28) of a nozzle (21); and allowing the particles to accelerate to a speed at least approaching that of the jet before leaving the nozzle.

7. An apparatus for producing a jet of abrasive laden liquid comprising:-
jet means (36, 37) for producing a jet of high velocity fluid;
inlet means (42) for introducing particles of abrasive;
mixing means (43) attached to the jet means and the inlet means for mixing the jet of high velocity fluid and the particles of abrasive;
orientation means connected to the mixing means for orienting the velocity vectors of the particles of abrasive; and
acceleration means connected to the orienting means for accelerating the particles of abrasive to a velocity approaching that of the jet of high velocity fluid.

8. An apparatus according to claim 7 wherein the mixing and acceleration means comprises a nozzle having a converging section and a straight section.

9. An apparatus according to claim 8 wherein the length of the straight section of the nozzle is at

least 20 times its diameter.

10. An apparatus according to claim 9 wherein the diameter of the straight section is between 20 and 100 times its length.

11. An apparatus according to claim 8 wherein the diameter of the straight section is at least 1.1 times the diameter of the jet.

12. An apparatus according to claim 11 wherein the diameter of the straight section is between 1.1 and 10 times the diameter of the jet.

13. An apparatus according to claim 8 wherein the diameter of the straight section is at least 1.1 times the diameter of the largest of the particles.

14. A nozzle for use in an abrasive particle liquid cutting jet apparatus comprising a converging section (26, 27) for producing an area of low pressure at the inlet; and a straight section (28) for accelerating the velocity of particles in liquid wherein the straight section is at least 20 times as long as its diameter.

15. A nozzle according to claim 14 wherein the straight section is between 20 and 100 times as long as its diameter.

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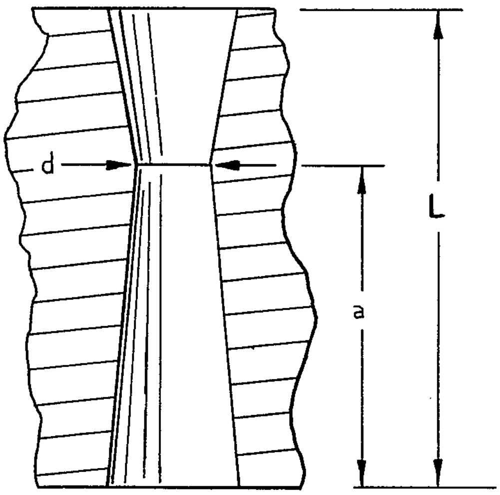

FIG. 1

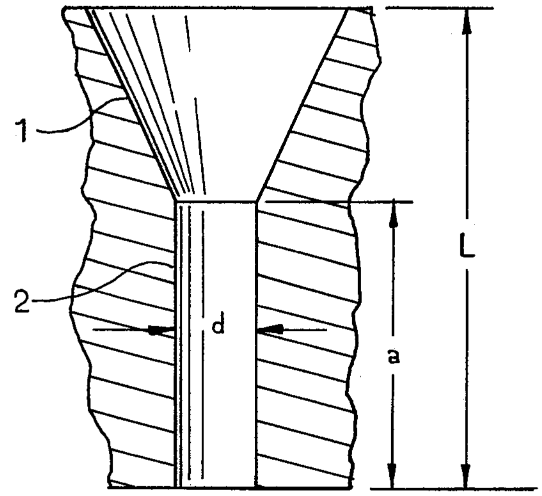

FIG. 2

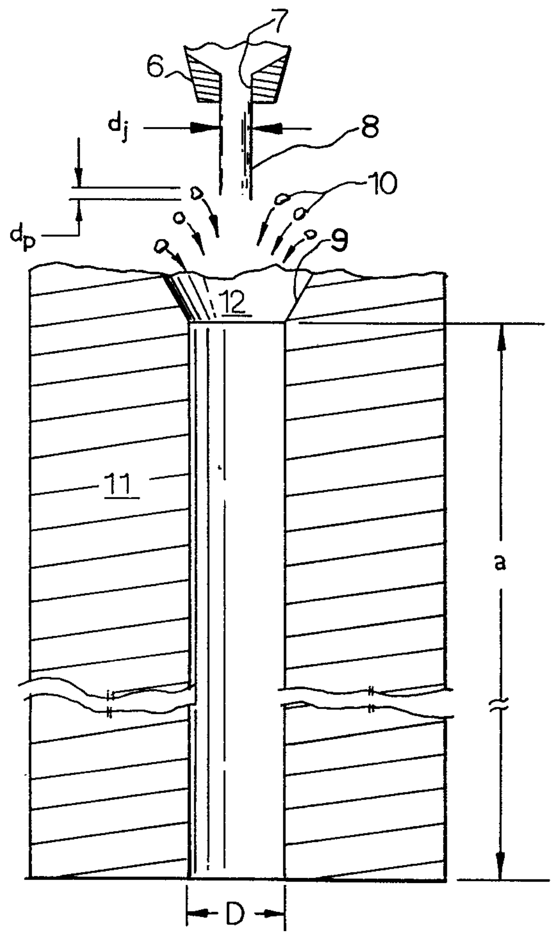

FIG. 3

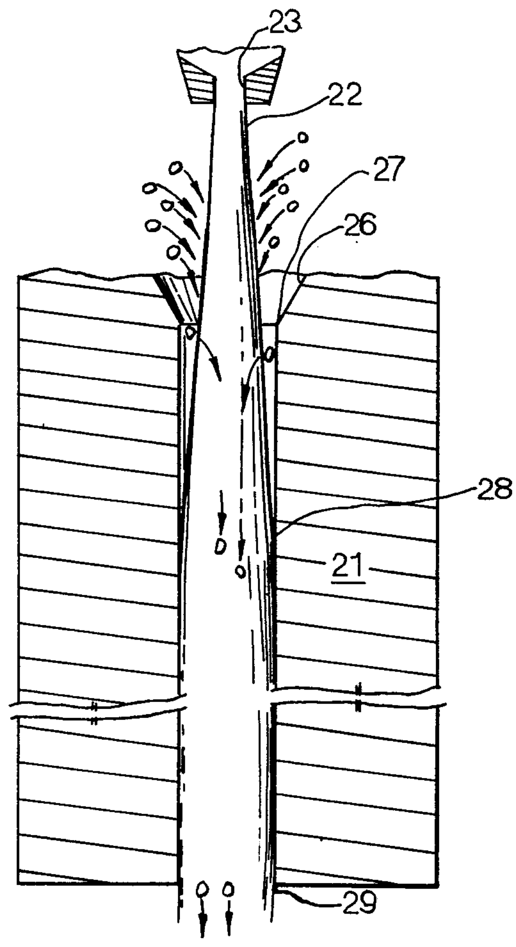

FIG. 4

FIG. 5

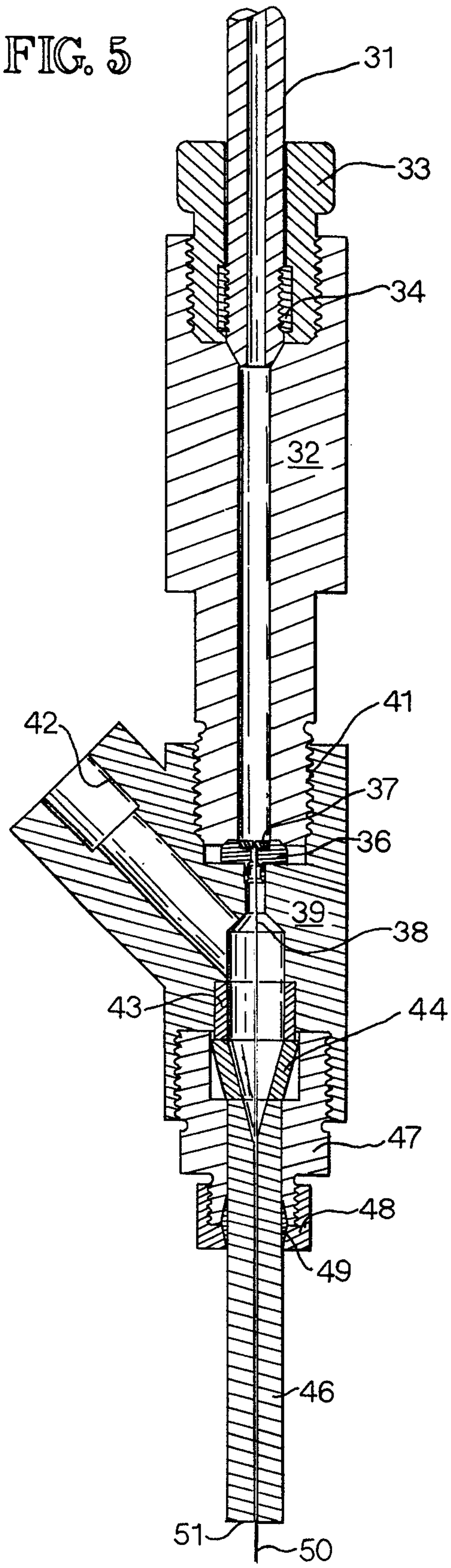
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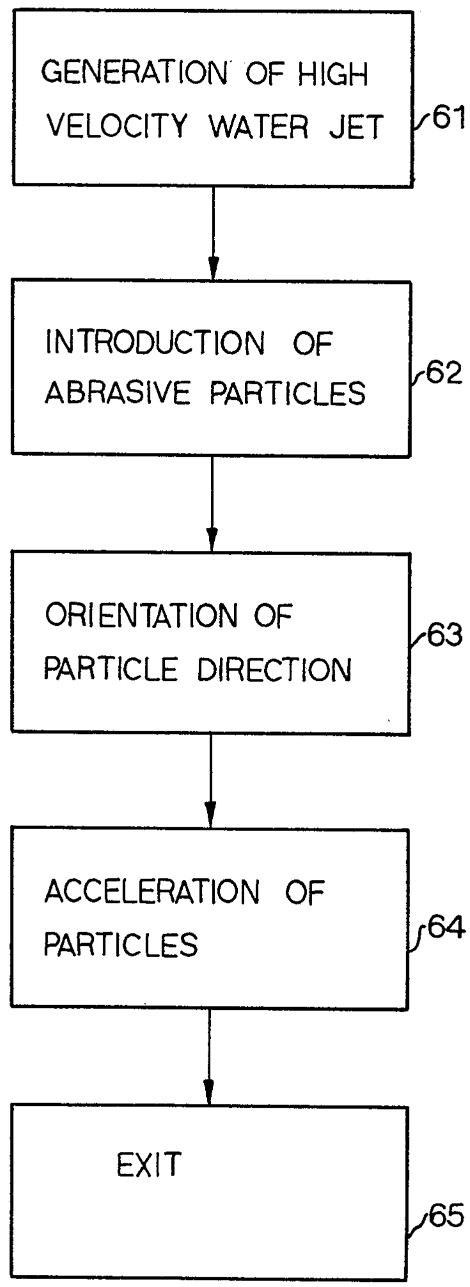
FIG. 6


GENERATION OF HIGH VELOCITY WATER JET
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ORIENTATION OF PARTICLE DIRECTION
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