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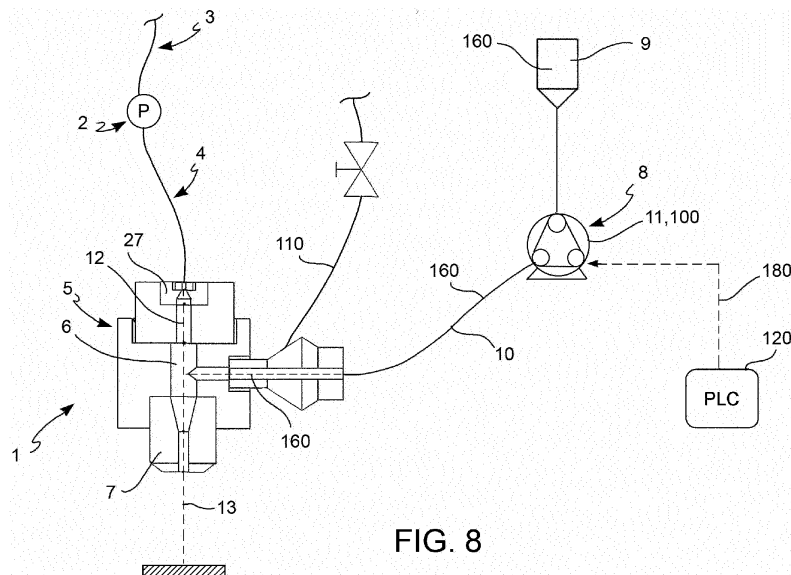
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(54) **ABRASIVE WATER-JET CUTTING MACHINE**

(57) An abrasive water-jet cutting machine (1), comprising pumping means (2), fluidly connectable to a water source (3), a cutting head (5), comprising a mixing chamber (6), a dispensing system (8) of powdered abrasive material, comprising a tank (9), a supply tube (10) and an actuator (11) interposed between the tank (9) and the supply tube (10), which delivers the powdered abrasive material contained in the tank (9) into the mixing chamber (6), through the supply tube (10); wherein the cutting

head (5) mixes, in the mixing chamber (6), the abrasive material with the water jet (12) forming a water-abrasive material mixture jet (13), and said cutting head (5) delivers the water-abrasive material mixture jet (13); wherein the powdered abrasive material delivered into the mixing chamber (6) is homogeneously dispersed in suspension in a water-based gelatinous fluid (60); and wherein the actuator (11) is a peristaltic pump (100).



**FIG. 8**

**Description**

**[0001]** The present invention relates to an abrasive water-jet cutting machine.

5 Background art

**[0002]** Abrasive water-jet cutting machines are machine tools which carry out the cutting and shaping of work pieces by means of a jet of a water-abrasive material mixture. Such technology is known as "abrasive water jet" (AWJ).

**[0003]** Generally, abrasive water-jet cutting machines comprise:

- 10
- pumping means, fluidly connectable to a water source, for the generation of a pressurized water flow;
  - a cutting head, comprising a primary nozzle, a mixing chamber and a focusing nozzle,

where the pressurized water flow from the pumping means is conveyed into the primary nozzle of the cutting head where the pressure energy of the pressurized water flow is converted into kinetic energy so as to form a water jet, and in which said water jet is then conveyed into the mixing chamber;

- 15
- a gravity dispensing system of powdered abrasive material, comprising
- 20
- a tank (e.g., a hopper) containing powdered abrasive material,
  - a supply tube, which fluidly connects the tank to the mixing chamber of the cutting head, in which the powdered abrasive material gravity dispensing system delivers said powdered abrasive material into the mixing chamber of the cutting head through the supply tube;

25 in which the cutting head mixes, in the mixing chamber, the powdered abrasive material with the water jet, thus forming a water-abrasive material mixture jet, and said cutting head delivers the water-abrasive material mixture jet through the focusing nozzle.

**[0004]** The gravity dispensing systems of powdered abrasive material have several critical issues. In particular, such systems are excessively inconvenient when used to perform finer and more precise cutting processes, i.e., for so-called "micro Abrasive Water Jet" ( $\mu$ AWJ) processes.

**[0005]** Specifically,  $\mu$ AWJ processes require the use of low abrasive material mass flow rates (less than 20 g/min) and the use of powdered abrasive material with a finer grain size (mesh greater than #200) compared to the usual one for macro applications (which instead use meshes in the range of #80 - #120).

**[0006]** The gravity dispensing systems cannot ensure a smooth and reliable delivery of abrasive material for  $\mu$ AWJ processes. In fact, the gravity dispensing systems have a variability in the delivery of the abrasive material mass flow rate which reaches values around 10%, which is not acceptable for  $\mu$ AWJ-type processes.

**[0007]** Furthermore, the abrasive water-jet cutting machines are often moved by means of handling systems such as, for example, beam, portal, anthropomorphic robotic arm, and such handling systems, when characterized by fast dynamics, generate further critical issues in the constant delivery of powdered abrasive material. Furthermore, the gravity dispensing systems of powdered abrasive material are incompatible with the use of the machine tool in an "overhead" configuration (implemented, for example, by anthropomorphic robots).

**[0008]** A further critical issue of these dispensing systems derives from the fact that the powdered abrasive material delivered by the dispensing system, which is particularly hygroscopic, is negatively exposed to the presence of environmental and process humidity present inside the ducts inside which the powdered abrasive material is conveyed.

**[0009]** In particular, at the interface between the supply tube and the mixing chamber of the cutting head, the hygroscopicity of the powdered abrasive material causes the agglomeration of a stationary layer of powdered abrasive material on the inner supply wall, which progressively reduces the useful section for delivering abrasive material into the mixing chamber, causing undesirable variations in the abrasive material mass flow rate.

**[0010]** In addition, the layer of powdered abrasive material agglomerated on the inner wall of the supply tube is subject to the risk of sudden detachments, which contribute to generating undesirable variations in the mass flow rate of the abrasive material, and which, in the most serious cases, can cause clogging of the cutting head focusing nozzle and damage to the machine tool.

**[0011]** An attempt was made to remedy these problems by using abrasive material dispensing systems according to the "Abrasive Suspension Jet" (ASJ) technology, in which the powdered abrasive material is previously dispersed in a dispersion liquid (for example water), so as to form a "hydro-abrasive" mixture stored in a tank. Such hydro-abrasive mixture is then delivered through a single nozzle for the formation of a pressurized jet of hydro-abrasive mixture.

**[0012]** However, such an abrasive material delivery system is usable only at low pressures (below 200 MPa), which are not high enough to perform cutting processes with the precision required in  $\mu$ AWJ applications.

**[0013]** Furthermore, in order to ensure an adequate dispersion of the powdered abrasive material in the dispersion substance, avoiding unwanted sedimentations, the mass ratio of the powdered abrasive material and the dispersion liquid of the aforesaid hydro-abrasive mixtures must be considerably low. This results in an exaggerated use of dispersion liquid in order to adequately disperse (and deliver) a low amount of powdered abrasive material.

A further problem of the known ASJ abrasive water-jet cutting machines lies in the abrasive material dispensing system. In fact, the known abrasive material tanks, of the hopper type, do not allow to deliver an amount of abrasive material which is constant over time. On the contrary, they provide an amount of abrasive material which decreases over time, due to the progressive emptying of the abrasive material tank placed upstream of the cutting head.

**[0014]** Therefore, it is the object of the present invention to provide an abrasive water-jet cutting machine, and in particular for  $\mu$ AWJ-type processes, provided with a dispensing system for abrasive material having such features as to solve at least some of the drawbacks of the prior art.

**[0015]** It is a particular object of the present invention to provide such a powdered abrasive material dispensing system as to ensure a regular and reliable dispensing of powdered abrasive material, even at low dosages of powdered abrasive material (less than 20 g/min).

**[0016]** It is a further particular object of the present invention to provide a powdered abrasive material dispensing system compatible with the use of the machine tool in an "overhead" configuration.

**[0017]** It is a further particular object of the present invention to provide a powdered abrasive material dispensing system in which stationary agglomerations of powdered abrasive material and other critical issues deriving from the exposure of the powdered abrasive material to environmental and process humidity present inside the ducts in which the powdered abrasive material is conveyed are avoided.

**[0018]** It is a further particular object of the present invention to provide an abrasive material dispensing system which also is usable at the pressures required to perform  $\mu$ AWJ-type processes (greater than 380 MPa).

**[0019]** It is a further particular object of the present invention to provide a powdered abrasive material dispensing system which uses a smaller amount of dispersion substance to adequately deliver a larger amount of powdered abrasive material.

**[0020]** It is a further particular object of the present invention to provide an abrasive material dispensing system capable of delivering a continuous amount of abrasive material, without however causing wear phenomena in the dispensing system.

#### Detailed description of the invention

**[0021]** The present invention relates to an abrasive water-jet cutting machine provided with an abrasive material dispensing system according to claim 1. The dependent claims relate to advantageous and preferred embodiments.

**[0022]** In a further aspect, a composition is claimed herein comprising a powdered abrasive material dispersed in a gelatinous fluid, as well as the use of said material in abrasive water-jet cutting methods.

**[0023]** According to an aspect of the invention, an abrasive water-jet cutting machine comprises:

- pumping means, fluidly connectable to a water source, for the generation of a pressurized water flow;
- a cutting head, comprising a primary nozzle, a mixing chamber and a focusing nozzle,

where the pressurized water flow from the pumping means is conveyed into the primary nozzle of the cutting head where the pressure energy of the pressurized water flow is converted into kinetic energy so as to form a water jet, and in which said water jet is then conveyed into the mixing chamber;

- a powdered abrasive material dispensing system, comprising:
  - a tank containing powdered abrasive material,
  - a supply tube, which fluidly connects the tank to the mixing chamber of the cutting head,
  - an actuator, which delivers the powdered abrasive material contained in the tank into the mixing chamber, through the supply tube;

in which the cutting head mixes, in the mixing chamber, the abrasive material with the water jet, thus forming a water-abrasive material mixture jet, and said cutting head delivers the water-abrasive material mixture jet through the focusing nozzle;

in which the powdered abrasive material delivered in the mixing chamber is homogeneously dispersed in suspension in a water-based gelatinous fluid;

and in which the actuator is a peristaltic pump.

Such a configuration of the dispensing system, and in particular of the abrasive material dispensed thereby, allows the

control of the hygroscopic properties of the abrasive material. In fact, since the powdered abrasive material is homogeneously dispersed in the water-based gelatinous fluid, it is completely saturated with water, therefore it is immune to the critical issues deriving from the exposure thereof to environmental and process humidity.

**[0024]** Furthermore, since the powdered abrasive material is completely saturated with water and is homogeneously dispersed in the water-based gelatinous fluid, said dispensing system delivers the abrasive material regularly and reliably, even at low dosages of abrasive material (less than 20 g/min).

**[0025]** Furthermore, such a dispensing system is compatible with the use of the cutting machine in an "overhead" configuration.

**[0026]** Furthermore, such a dispensing system also is usable at the pressures required to perform  $\mu$ AWJ-type processes (greater than 380 MPa).

**[0027]** Furthermore, the implementation of a peristaltic pump ensures a continuous amount of abrasive mixture, without causing wear phenomena in the dispensing system.

**[0028]** In order to better understand the invention and appreciate the advantages thereof, a description is provided below of certain non-limiting exemplary embodiments, with reference to the drawings, in which:

- figure 1 is a diagrammatic depiction of the abrasive water-jet cutting machine, according to an embodiment of the invention;
- figure 2A is a front view of a cutting head, according to an embodiment of the invention;
- figure 2B is an axial sectional view of the cutting head shown in figure 2A;
- figure 3A is a front view of an injector member, according to an embodiment of the invention;
- figure 3B is an axial sectional view of the injector member shown in figure 3A;
- figure 4 is a longitudinal sectional view of the assembled cutting head-injector member group;
- figure 5A is a front view of a dispensing system according to an embodiment of the invention;
- figure 5B is an axial sectional view of the dispensing system shown in figure 5A;
- figure 6 shows a sample of material cut by means of the abrasive water-jet cutting machine, according to an embodiment of the invention,
- figure 7 shows two samples of the same material, cut by means of an abrasive water-jet cutting machine according to the known art and according to the invention,
- figure 8 is a diagrammatic view of an abrasive water-jet cutting machine, according to a further embodiment of the invention,
- figure 9 is a diagrammatic view of an abrasive water-jet cutting machine, according to a further embodiment of the invention,
- figure 10 is a diagrammatic view of an abrasive water-jet cutting machine, according to a further embodiment of the invention.

**[0029]** With reference to the drawings, an abrasive water-jet cutting machine according to the invention is generally indicated by reference numeral 1.

**[0030]** In accordance with an aspect of the invention, the abrasive water-jet cutting machine 1 comprises pumping means 2, fluidly connectable to a water source 3, for the generation of a pressurized water flow 4.

**[0031]** The cutting machine 1 further comprises a cutting head 5, comprising a primary nozzle 27, a mixing chamber 6 and a focusing nozzle 7.

**[0032]** According to an aspect of the invention, the pressurized water flow 4 from the pumping means 2 is conveyed to the primary nozzle 27 of the cutting head 5 where the pressure energy of the pressurized water flow 4 is converted into kinetic energy so as to form a water jet 12, and, subsequently, the water jet 12 is conveyed into the mixing chamber 6.

**[0033]** The cutting machine 1 further comprises a dispensing system 8 of powdered abrasive material comprising a tank 9 containing abrasive material, a supply tube 10, which fluidly connects the tank 9 to the mixing chamber 6 of the cutting head 5, and an actuator 11 which delivers the powdered abrasive material contained in the tank 9 into the mixing chamber 6, through the supply tube 10.

**[0034]** According to a further aspect of the invention, the cutting head 5 mixes, in the mixing chamber 6, the abrasive material with the water jet 12 thus forming a water-abrasive material mixture jet 13, which is delivered by the cutting head 5 through the focusing nozzle 7.

**[0035]** The focusing nozzle 7 also has the task, upon mixing the abrasive material with the water jet 12, of increasing the efficiency of the mixing and of the transfer of momentum from the water jet 12 to the abrasive material.

**[0036]** According to a further aspect of the invention, the powdered abrasive material contained in the tank 9 is homogeneously dispersed in suspension in a water-based gelatinous fluid 60.

**[0037]** Therefore, the powdered abrasive material homogeneously dispersed in suspension in the water-based gelatinous fluid 60 forms an abrasive mixture 160.

**[0038]** According to a further aspect of the invention, the actuator 11 is a peristaltic pump 100.

**[0039]** Such a configuration of the dispensing system 8, and in particular of the powdered abrasive material dispensed thereby, allows the control of the hygroscopic properties of the powdered abrasive material. In fact, since the powdered abrasive material is homogeneously dispersed in the water-based gelatinous fluid 60, it is completely saturated with water, therefore it is immune to the critical issues deriving from the exposure thereof to environmental and process humidity.

**[0040]** Furthermore, since the powdered abrasive material is completely saturated with water and is homogeneously dispersed in the water-based gelatinous fluid 60, said dispensing system 8 delivers the abrasive material regularly and reliably, even at low dosages of abrasive material (less than 20 g/min).

**[0041]** Furthermore, such a dispensing system 8 is compatible with the use of the cutting machine 1 in an "overhead" configuration.

**[0042]** Furthermore, such a dispensing system 8 also is usable at the pressures required to perform  $\mu$ AWJ-type processes (greater than 380 MPa).

**[0043]** Furthermore, the implementation of a peristaltic pump 100 ensures a continuous amount of abrasive mixture 160, without causing wear phenomena in the dispensing system 8.

**[0044]** According to an embodiment of the invention, the supply tube 10 is made of polymeric material.

**[0045]** Advantageously, the supply tube 10 made of polymeric material further reduces any wear phenomena in the dispensing system 8, and further attenuates the pressure oscillations caused in the flow of abrasive mixture 160 by the peristaltic motion induced by the peristaltic pump 100.

**[0046]** According to an embodiment, the cutting machine 1 comprises an air duct 110 which converges into the mixing chamber 6.

**[0047]** Advantageously, the supply of air by means of the air duct 110 avoids the risk that the vacuum generated inside the mixing chamber 6 disturbs the amount of the abrasive mixture 160 introduced therein.

**[0048]** With a further advantage, the supply of air to the mixing chamber 6 through the air duct is self-stabilized, i.e., it does not require an external adjustment.

**[0049]** According to an embodiment of the invention, the cutting machine 1 comprises an electronic controller 120.

**[0050]** The electronic controller 120 is configured to adjust the amount of abrasive mixture 160 delivered by the dispensing system 8.

**[0051]** The electronic controller 120 can be, for example, a PC or a PLC.

**[0052]** Advantageously, the use of an electronic controller 120 further improves the precision of the dosage of abrasive mixture 160.

**[0053]** According to an embodiment, the tank 9 contains the abrasive mixture 160, in which the powdered abrasive material is homogeneously dispersed within the water-based gelatinous fluid 60.

**[0054]** According to an embodiment, the electronic controller 120 is configured to adjust the amount of abrasive mixture 160 delivered by the actuator 11, through an open-loop control 180.

**[0055]** Advantageously, the electronic controller 120 adjusts the amount of abrasive mixture 160 by adjusting the speed of the peristaltic pump 100. Following this adjustment, the dispensing system 8 self-stabilizes, so as to deliver a regulated and continuous amount of abrasive mixture 160 to the mixing chamber 6.

**[0056]** In particular, the relationship between the speed of the peristaltic pump 100 and the amount of the abrasive mixture 160 is given by calibration curves obtained with experimental tests for each type of abrasive mixture.

**[0057]** According to a further embodiment of the invention, the tank 9 comprises at least a first tank 130 containing water-based gelatinous fluid 60, and at least a second tank 140 containing powdered abrasive material.

**[0058]** Furthermore, the dispensing system 8 comprises a mixer 150 interposed between the tank 9 and the actuator 11. That is, the mixer 150 is placed at least downstream of the at least first tank 130 and second tank 140, and upstream of the actuator 11, with reference to the flow direction of abrasive mixture 160.

**[0059]** The mixer 150 is configured to mix the water-based gelatinous fluid 60 contained in the at least a first tank 130 with the powdered abrasive material contained in the at least a second tank 140, so as to form an abrasive mixture 160, and convey the abrasive mixture 160 into the actuator 11.

**[0060]** Advantageously, a tank 9 thus configured avoids preparing the abrasive mixture in a separate step, and subsequently introducing it into the tank, with the risk of introducing and forming air bubbles which would cause drastic local reductions in the amount of abrasive.

**[0061]** This risk is considerably reduced through a direct "in-line" preparation of the abrasive mixture 160 carried out by means of at least two separate tanks and a mixer.

**[0062]** With further advantage, such a direct production of the abrasive mixture 160 allows a high control over various properties of the abrasive mixture 160, such as composition, proportions, and rheology.

**[0063]** With further advantage, a tank 9 thus configured also allows mixing different powdered abrasives, which can be contained in several second tanks 140, even continuously during the cutting performed by the cutting machine 1.

**[0064]** According to an advantageous embodiment, the dispensing system 8 comprises a third tank 200 downstream of the at least first tank 130, the at least second tank 140 and the mixer 150. The third tank 200 is configured to contain

the abrasive mixture 160 prepared by the mixer 150, and to convey it towards the actuator 11.

**[0065]** According to an embodiment of the invention, the cutting machine 1 comprises a pulsation damper 170 fluidly connected to the supply tube 10.

**[0066]** Advantageously, the pulsation damper 170 further adjusts the amount of abrasive mixture 160 to be introduced into the mixing chamber 6, further dampening the pressure oscillations of the abrasive mixture 160 conveyed by the supply tube 10, and consequently increasing the precision of the cutting process performed by the cutting machine 1.

**[0067]** According to an advantageous embodiment, the pulsation damper 170 is a gas, or diaphragm, or spring, or weight hydraulic accumulator.

**[0068]** According to an embodiment of the invention, the electronic controller 120 is configured to adjust the amount of abrasive mixture 160 delivered by the mixer 150. Alternatively, or in addition, the electronic controller 120 is configured to adjust the amount of abrasive mixture 160 delivered by the actuator 11. Alternatively, or in addition, the electronic controller 120 is configured to adjust the air amount introduced from the air duct 110 into the mixing chamber 6. Alternatively, or in addition, the electronic controller 120 is configured to adjust the actuation of the pulsation damper 170.

**[0069]** Advantageously, this ensures high adjustment and precision of the amount of abrasive mixture 160 introduced into the mixing chamber 6.

**[0070]** According to an advantageous embodiment, the electronic controller 120 is configured to carry out the aforesaid adjustments by means of a closed-loop control 190.

**[0071]** Advantageously, a closed-loop control of one or more of the aforesaid parameters ensures a further improvement in the adjustment and precision of the amount of abrasive mixture 160 conveyed into the mixing chamber 6.

**[0072]** According to a preferred embodiment, in the abrasive mixture 160, the mass ratio of the powdered abrasive material and the water-based gelatinous fluid 60 in which the powdered abrasive material is homogeneously dispersed in suspension is between 1.0 and 3.5.

**[0073]** According to a preferred and advantageous embodiment, in the abrasive mixture 160, the ratio of the powdered abrasive material and the water-based gelatinous fluid 60 in which the powdered abrasive material is homogeneously dispersed in suspension is between 2.0 and 3.5.

**[0074]** According to a preferred and advantageous embodiment, in the abrasive mixture 160, the ratio of the powdered abrasive material and the water-based gelatinous fluid 60 in which the powdered abrasive material is homogeneously dispersed in suspension is about 2.0.

**[0075]** Advantageously, by virtue of such a dosage of powdered abrasive material homogeneously dispersed in the water-based gelatinous fluid 60, the dispensing system 8 uses a smaller amount of dispersion substance with respect to the dispensing systems of abrasive material according to the ASJ technology, to adequately deliver a greater amount of powdered abrasive material.

**[0076]** According to an embodiment, the supply tube 10 is connected to the cutting head 5 by means of an injector nozzle 38, and the injector nozzle 38 protrudes inside the mixing chamber 6.

**[0077]** Advantageously, this allows to convey the abrasive mixture 160 in the immediate vicinity of the water jet 12, so that the conveyed abrasive mixture 160 does not accumulate on the walls of the mixing chamber 6, nor is it suddenly released.

**[0078]** According to an embodiment, the particle size of the powdered abrasive material homogeneously dispersed in suspension in the water-based gelatinous fluid 60 is less than #200 mesh, preferably between #350 mesh and #600 mesh.

**[0079]** The average size of the granules of powdered abrasive material is less than 70 micrometers, preferably between 15 and 60 micrometers.

**[0080]** The nature and chemical composition of the abrasive used can be of different types, for example natural minerals such as Almandine Garnet or Olivine, synthetics, ceramics such as Silicon Carbide, metal compounds, biological material.

**[0081]** The water-based gelatinous fluid 60 is composed of distilled water and a gelling agent (e.g., a polymer) in sufficient amounts to keep the mixture in suspension without the granules of powdered abrasive material settling on the bottom of the tank 9.

**[0082]** According to an embodiment of the invention, the cutting head 5 comprises a mixing chamber 6 of a substantially tubular shape, which forms a front surface 14, a rear surface 15 parallel to the front surface 14, and a peripheral surface 29.

**[0083]** The terms "front" and "rear" refer to the flow direction of pressurized water 4 passing through the cutting head 5.

**[0084]** The mixing chamber 6 forms a front seat 16 at the front surface 14, and a rear seat 17 at the rear surface 15, in which the front and rear seats 16, 17 have a substantially cylindrical shape.

**[0085]** Furthermore, the mixing chamber 6 forms a water inlet opening 18 at the front seat 16, and a mixture outlet opening 19 at the rear seat 17.

**[0086]** The mixing chamber 6 forms a jet channel 20, transverse to the front surface 14 and to the rear surface 15, and in flow communication with the front seat 16 and the rear seat 17 by means of the water inlet opening 18 and the mixture outlet opening 19.

**[0087]** The jet channel 20 and the front seat 16 form a front shoulder 21 at the water inlet opening 18. Furthermore,

the jet channel 20 and the rear seat 17 form a rear shoulder 22 at the mixture outlet opening 19.

**[0088]** There is a primary nozzle housing 23 inside the front seat 16, abutting the front shoulder 21.

**[0089]** The primary nozzle housing 23 has a substantially cylindrical shape and defines a front base 24 and a rear base 25, in which the rear base 25 abuts against the front shoulder 21.

**[0090]** The primary nozzle housing 23 forms a primary nozzle seat 26 at the front base 24.

**[0091]** There is a primary nozzle 27 in the primary nozzle seat 26. The primary nozzle 27 transforms the flow of pressurized water 4 from the pumping means 2 into the water jet 12.

**[0092]** The focusing nozzle 7 forms a focusing channel 28 adapted to concentrate the water jet 12.

**[0093]** The focusing nozzle 7 is arranged in the rear seat 17 by interference locking. Advantageously, this interference locking ensures the correct centering and positioning of the focusing nozzle 7 with respect to the primary nozzle 27.

**[0094]** The mixing chamber 6 forms an injection opening 30 at the peripheral surface 29, and the injection opening 30 is transverse to the jet channel 20 and fluidly connected to the jet channel 20.

**[0095]** The cutting head 5 further comprises a retaining flange 31, forming a cavity 32 which receives and seals the mixing chamber 6 therein. Furthermore, the retaining flange 31 forms a second injection opening 33, configured concentrically with respect to the injection opening 30 of the mixing chamber 6.

**[0096]** The injection opening 30 and the second injection opening 33 allow, through connection with the supply tube 10, the injection of the abrasive dispersed in the water-based gelatinous fluid 60 inside the mixing chamber 6.

**[0097]** According to an embodiment of the invention, the supply tube 10 is connected at a first end 34 thereof to the tank 9 and is connected at a second end 35 thereof to an injector member 36.

**[0098]** According to an embodiment of the invention, the injector member 36 comprises an injector housing 37 and an injector nozzle 38.

**[0099]** The injector housing 37 forms a connection portion 39 adapted to connect the injector member 36 to the supply tube 10.

**[0100]** Furthermore, the injector housing 37 forms a shaped channel 40 therein, adapted to receive the injector nozzle 38.

**[0101]** The injector nozzle 38 forms an injection channel 41 therein, and an end portion 45 of the injector nozzle 38 is configured to protrude into the jet channel 20 of the mixing chamber 6, so that the injection channel 41 places the supply tube 10 in fluid connection with the jet channel 20.

**[0102]** According to an embodiment of the invention, the end portion 45 of the injector nozzle 38 extends by a fraction of a millimeter, preferably 0.5 mm, inside the jet channel 20. Advantageously, this allows the abrasive, dispersed in the water-based gelatinous fluid 60, to be conveyed in the immediate vicinity of the water jet 12. Consequently, the conveyed abrasive does not accumulate on the walls of the jet channel 20 and is not suddenly released.

**[0103]** The positioning and connection of the injector nozzle 38 to the mixing chamber 6 is ensured through a threaded joint, bayonet connection or other attachment system which ensures strength and complete sealing.

**[0104]** According to an embodiment of the invention, the shaped channel 40 comprises an end portion 42 forming an air injection channel 43 concentric to the end portion 42, and a coupling portion 61 adapted to obtain a shape coupling with the injector nozzle 38.

**[0105]** Advantageously, the concentric configuration of the air injection channel 43 with respect to the end portion 42 reduces the dimensions of the injector member 36.

**[0106]** With further advantage, the concentric configuration of the air injection channel 43 allows an optimal projection of the abrasive material dispersed in the water-based gelatinous fluid 60 towards the water jet 12, keeping the air injection channel 43 clean and functioning.

**[0107]** The air injection channel 43 forms a gap 44, between the air injection channel 43 and the end portion 45 of the injector nozzle 38.

**[0108]** Furthermore, the injector housing 37 forms an air flow channel 47 flowing into the air injection channel 43 and forming a connection seat 46.

**[0109]** The air flow channel 47 is connected to a pneumatic duct 48 at the connection seat 46. Advantageously, the inner diameter of the pneumatic duct 48 is substantially identical to the diameter of the air flow channel 47, so as to avoid steps which can negatively impact the air flow.

**[0110]** According to an embodiment, the air duct 110 comprises the air injection duct 43, the air flow duct 47 and the pneumatic duct 48.

**[0111]** There is a valve 49 on the pneumatic duct 48 for adjusting the air flow entering the air flow channel 47. The air flow entering the air flow channel 47 is sucked in by the passage of the water jet 12 by Venturi effect.

**[0112]** Furthermore, a pressure gauge 50 and a flow meter 51 (analogue or digital) are arranged on the pneumatic duct 48, adapted to monitor and allow the control of the air flow introduced into the pneumatic duct 48.

**[0113]** Advantageously, by means of the adjustment valve 49 it is possible to reduce the air amount entering the pneumatic duct 48, so as to reduce the air dosage of the water jet 12. Thereby, the Venturi effect generated by the water jet 12 can be propagated to the abrasive dispersed in the water-based gelatinous fluid 60, which can therefore be sucked

into the mixing chamber 6 without the intervention of any upstream thrust.

**[0114]** Such a configuration of the pneumatic duct 48 also is usable for checking the assembly of the cutting head 5, for monitoring the state of wear of the components (for example the injector nozzle 38, the primary nozzle 27, the mixing chamber 6 and the focusing nozzle 7) and for the real-time verification of the correct execution of the cut.

**[0115]** To perform the assembly check, the access of air to the mixing chamber 6 must be completely blocked, so as to measure the level of pressure generated inside the mixing chamber 6 by the passage of the water jet 12. Pressure values greater than, equal to or close to the atmospheric value indicate an incorrect alignment of the components, with probable contact between the water jet 12 and the channel and the inner walls of the jet channel 20 or of the focusing nozzle 7. Values closer to vacuum (for example 0.2 or 0.1 absolute bar) indicate a valid alignment of the components, which generate a significant Venturi effect.

**[0116]** To check the state of wear of the components, the pressure variations in the mixing chamber 6 over a prolonged period must be recorded in order to determine the wear drift of the components of the cutting head 5. In particular, a less accentuated Venturi effect in the jet channel 20 reveals the progressive wear of the primary nozzle, with a consequent decrease in the outflow speed of the water jet 12.

**[0117]** In order to verify that the cut has been performed correctly in real time, the pressure variations in the mixing chamber must be recorded. Such events are attributable to malfunctions in the dispensing systems of the water jet 12, of the abrasive dispersed in the water-based gelatinous fluid 60, or of the air introduced through the air flow channel 47. By evaluating these phenomena, the correct function of the water jet 12 is determined at all times, so as to predict the success of the cutting operation and, if otherwise, stop the cutting.

**[0118]** According to an embodiment of the invention, the tank 9 is a substantially cylindrically-shaped container.

**[0119]** According to a preferred embodiment, the tank 9 is configured in the shape of a syringe, and comprises a cylindrical portion 52, inside which the abrasive material dispersed in the water-based gelatinous fluid 60 is loaded and stored, and a cannula portion 53.

**[0120]** According to an embodiment, the actuator 11 is configured as a thrust member 54 which is slidably arranged inside the cylindrical portion 52, and is configured to push the abrasive material dispersed in the water-based gelatinous fluid 60 contained in the cylindrical portion 52 of the tank 9 towards the cannula portion 53.

**[0121]** The cannula portion 53 is connected to the first end 34 of the supply tube 10 so as to obtain a fluid connection between the tank 9 and the supply tube 10.

**[0122]** According to a preferred embodiment, the thrust member 54 is configured to impart a thrust pressure of approximately 1 relative bar.

**[0123]** Advantageously, using such a pressure value causes the abrasive material dispersed in the water-based gelatinous fluid 60 to be substantially incompressible, therefore the advancement speed of the thrust member is easily and directly correlated to the delivered amount of abrasive material dispersed in the water-based gelatinous fluid 60.

**[0124]** According to a further embodiment, the dispensing system 8 comprises an auxiliary refilling syringe, adapted to refill the tank 9 "in real time", i.e., refilling the tank 9 with new abrasive material dispersed in the water-based gelatinous fluid 60 simultaneously with the execution of a cutting process by the same cutting machine 1.

**[0125]** Preferably, such a "real-time" replenishment is performed in a lapse of time between the processing of two successive geometries belonging to the same component being made or to different components.

**[0126]** According to a further embodiment, the dispensing system 8 comprises an abrasive tank dedicated to the storage of abrasive material and a gel tank dedicated to the storage of water-based gelatinous fluid, in which the simultaneous mixing and pressurization of the abrasive material with the water-based gelatinous fluid occurs in the supply tube 10, through a "turbulent" path.

**[0127]** Advantageously, the filling of the tank 9 occurs at the source through an auxiliary actuator to avoid the presence of air or other gas bubbles at the origin.

**[0128]** Furthermore, a rear discharge valve 56 is arranged on the thrust member 54 which expels air bubbles or other gases present in the water-based gelatinous fluid 60 inside which the abrasive material is dispersed, which could introduce compressibility or cause interruptions in the supply of the abrasive material dispersed in the water-based gelatinous fluid 60 to the cutting head 5.

**[0129]** The thrust member 54 is connected to a motor 58, preferably an electric motor, through a transmission 57.

**[0130]** According to a preferred embodiment, a flow cut-off valve 59 is connected to the supply tube 10. The flow cut-off valve 59 has the purpose of interrupting or diverting the flow of the abrasive material dispersed in the water-based gelatinous fluid 60 in an emergency.

**[0131]** Advantageously, it is thereby possible to stop the injection of abrasive material dispersed in the water-based gelatinous fluid 60 into the cutting head 5, even if the dispensing system 8 continues the delivery of abrasive material dispersed in the water-based gelatinous fluid 60 from the tank 9.

**[0132]** With further advantage, the flow cut-off valve 59 has the auxiliary function of interrupting any rising flows from the cutting head 5, for example air or water if the focusing nozzle 7 is blocked, so as to protect the dispensing system 8 from overpressure damage.

**[0133]** In a further aspect, the present invention relates to a composition comprising a powdered abrasive material homogeneously dispersed in suspension in a water-based gelatinous fluid 60, in which the mass ratio of dispersed powdered abrasive material and the water-based gelatinous fluid 60 is between 1.0 and 3.5, or between 2.0 and 3.5, or about 2.0 and in which the particle size of the powdered abrasive material homogeneously dispersed in suspension in the water-based gelatinous fluid 60 is between #350 mesh and #600 mesh.

**[0134]** Preferably, the average granule size of the abrasive material in said composition is between 15 and 60 micrometers.

**[0135]** A further aspect according to the present invention is an abrasive water-jet cutting method, where said method comprises the use of the abrasive composition according to the present invention.

**[0136]** According to an embodiment, the abrasive water-jet cutting method comprises the steps of:

- providing an abrasive water-jet cutting machine 1 as described above,
- adjusting the amount of abrasive mixture 160 delivered by the actuator 11 by means of an open-loop control 180.

**[0137]** According to a further embodiment, the abrasive water-jet cutting method comprises the steps of:

- providing an abrasive water-jet cutting machine 1 as described above,
- performing at least one of the following adjustments by means of a closed-loop control 190:

- adjustment of the amount of abrasive mixture 160 delivered by the mixer 150;
- adjustment of the amount of abrasive mixture 160 delivered by the actuator 11;
- adjustment of the air amount introduced from the air duct 110 into the mixing chamber 6;
- adjustment of the actuation of the pulsation damper 170.

**[0138]** Obviously, in order to meet contingent specific needs, those skilled in the art will be able to make further changes and variations all contained within the scope of protection as defined by the claims.

**[0139]** Some experimental tests carried out with the abrasive water-jet cutting machine and the composition comprising the abrasive claimed herein will be described below, aimed at highlighting the effectiveness and technical advantages thereof.

#### Example 1: Cutting test on 2.0 mm thick austenitic stainless steel (AISI 301 / EN 1.4310)

**[0140]** The cutting test is performed on 2.0 mm thick austenitic stainless steel (AISI 301 / EN 1.4310), to verify the performance of the claimed cutting machine on a relatively thick material.

**[0141]** In fact, 2.0 mm is close to the maximum thickness which can be effectively cut with cutting machines in the  $\mu$ AWJ field of the state of the art known to the inventors.

**[0142]** The geometry of the cut groove and the roughness of the cut wall surface are measured at different depth levels:

- 0.2 mm from the top ("top")
- at half height (1.0 mm, "mid")
- 0.2 mm from the bottom ("bot")

**[0143]** The following Tables 1.1 and 1.2 report the results obtained from the test:

Table 1.1: cutting tests on 2 mm thick austenitic stainless steel (AISI 301 / EN 1.4310). Macro-geometric check of the cutting wall with varying advancement speeds.

| 2.0 mm thick austenitic stainless steel (AISI 301 / EN 1.4310) Cut groove width inspection |                |                |                    |              |
|--------------------------------------------------------------------------------------------|----------------|----------------|--------------------|--------------|
| $v_f$ [mm/min]                                                                             | $W_{top}$ [mm] | $W_{bot}$ [mm] | $W_{average}$ [mm] | $Taper$ [mm] |
| 3                                                                                          | 0.187          | 0.221          | 0.204              | -0.015       |
| 6                                                                                          | 0.172          | 0.158          | 0.165              | 0.007        |
| 9                                                                                          | 0.171          | 0.145          | 0.158              | 0.013        |
| 12                                                                                         | 0.165          | 0.128          | 0.146              | 0.018        |

(continued)

| 2.0 mm thick austenitic stainless steel (AISI 301 / EN 1.4310) Cut groove width inspection                                                                                             |                |                |                    |              |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|--------------------|--------------|
| $v_f$ [mm/min]                                                                                                                                                                         | $W_{top}$ [mm] | $W_{bot}$ [mm] | $W_{average}$ [mm] | $Taper$ [mm] |
| 15                                                                                                                                                                                     | 0.164          | 0.116          | 0.140              | 0.024        |
| 18                                                                                                                                                                                     | 0.157          | 0.108          | 0.133              | 0.024        |
| 21                                                                                                                                                                                     | 0.153          | 0.093          | 0.123              | 0.030        |
| 24                                                                                                                                                                                     | 0.152          | 0.090          | 0.121              | 0.031        |
| $v_f$ : head advancement speed<br>$W_{top}$ : upper groove width<br>$W_{bot}$ : lower groove width<br>$W_{average}$ : average groove width<br>$Taper$ : inclination of the single wall |                |                |                    |              |

Table 1.2: cutting tests on 2 mm thick austenitic stainless steel (AISI 301 / EN 1.4310). Roughness check of the cutting wall with varying advancement speeds.

| 2.0 mm thick austenitic stainless steel (AISI 301 / EN 1.4310) Roughness inspection                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                             |                             |                             |                                 |                             |                             |                             |                                 |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|-----------------------------|-----------------------------|---------------------------------|-----------------------------|-----------------------------|-----------------------------|---------------------------------|
| $v_f$ [mm/min]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | $R_a$ top [ $\mu\text{m}$ ] | $R_a$ mid [ $\mu\text{m}$ ] | $R_a$ bot [ $\mu\text{m}$ ] | $R_a$ average [ $\mu\text{m}$ ] | $R_z$ top [ $\mu\text{m}$ ] | $R_z$ mid [ $\mu\text{m}$ ] | $R_z$ bot [ $\mu\text{m}$ ] | $R_z$ average [ $\mu\text{m}$ ] |
| 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.36                        | 0.44                        | 0.56                        | 0.45                            | 3.02                        | 3.15                        | 4.00                        | 3.38                            |
| 6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.38                        | 0.49                        | 0.64                        | 0.51                            | 3.28                        | 3.95                        | 5.01                        | 4.01                            |
| 9                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.42                        | 0.48                        | 0.64                        | 0.51                            | 3.61                        | 3.70                        | 4.77                        | 3.92                            |
| 12                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 0.44                        | 0.59                        | 0.81                        | 0.67                            | 3.77                        | 4.34                        | 5.90                        | 5.05                            |
| 15                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 0.47                        | 0.66                        | 0.96                        | 0.72                            | 3.98                        | 5.16                        | 6.47                        | 5.25                            |
| 18                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 0.49                        | 0.83                        | 1.27                        | 0.90                            | 3.90                        | 6.69                        | 8.15                        | 6.57                            |
| 21                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 0.50                        | 0.94                        | 1.53                        | 1.04                            | 3.98                        | 6.33                        | 9.20                        | 6.79                            |
| 24                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 0.64                        | 1.29                        | 2.32                        | 1.52                            | 5.05                        | 9.27                        | 14.73                       | 9.91                            |
| $v_f$ : head advancement speed<br>$R_a$ top: arithmetic average roughness near the upper surface of the piece<br>$R_a$ mid: arithmetic average roughness at half thickness of the piece<br>$R_a$ bot: arithmetic average roughness near the lower surface of the piece<br>$R_a$ average: average of the $R_a$ values detected<br>$R_z$ top: roughness on the 10 extreme points near the upper surface of the piece<br>$R_z$ mid: roughness on the 10 extreme points at half thickness of the piece<br>$R_z$ bot: roughness on the 10 extreme points near the lower surface of the piece<br>$R_z$ average: average of the $R_z$ values detected |                             |                             |                             |                                 |                             |                             |                             |                                 |

**[0144]** Two operating conditions are revealed by the test:

- a full but irregular cut is made at high  $v_f = 24$  mm/min;
- a high-quality cut is made at lower  $v_f$ , among which  $v_f = 6$  mm/min is an ideal value as it minimizes the inclination of the wall, making both sides of the cut usable with a tolerance of 1 hundredth of a millimeter, without having to introduce head inclinations to compensate for the defect.

#### Example 2: Complex cutting test

**[0145]** The new system proves effective in cutting thick metal plates (at least by abrasive micro-jet standards) at

different levels of  $v_f$  and also in drilling with different strategies.

**[0146]** A complex shape is chosen for a complete characterization of the new performance of the system. This is the letter "A" in a particular character, used as a reference piece, as it contains:

- straight lines, for measuring roughness and streaks due to irregularities in the formation of the jet;
- acute angles, both inner and outer, to show the precision of the jet in defining the edges with a low "jet lag" effect;
- small radius curves, to show the radius limit which can be reached according to the size of the jet;
- thin walls, to demonstrate the high stability and delicacy of the jet;
- long processing path, as a resistance test of system stability and robustness.

**[0147]** The smallest A obtainable with the focusing nozzle  $d_f = 0.20$  mm and the #230 mesh abrasive, the minimum jet size currently available in the micro AWJ commercial panorama, is 12 mm high and has a minimum radius of 0.12 mm. For the present study, the design is scaled down to 75%, thus achieving a final height of 9 mm and a minimum radius of 0.09 mm.

**[0148]** Table 2 summarizes the main processing parameters for the execution of this reference piece, cut with the claimed cutting machine, replicating the complete execution of the cutting program three times.

Table 2: process configuration and parameters for making the sample in 2 mm thick austenitic stainless steel (AISI 301 / EN 1.4310).

| Parameter / Operation                      | Value / Strategy |
|--------------------------------------------|------------------|
| Primary nozzle diameter [mm]               | 0.05             |
| Focusing nozzle diameter                   | 0.13             |
| Hydraulic pressure [MPa]                   | 350              |
| Abrasive [type and mesh]                   | Garnet #600 mesh |
| Abrasive amount [q/min]                    | 3                |
| Mixing chamber pressure [bar]              | 0.78 - 0.80      |
| Advancement speed [mm/min]                 | 6                |
| Drilling strategy                          | Circular         |
| Drilling time [s]                          | 4                |
| Distance from the piece being drilled [mm] | 1.2              |
| Distance from the piece being cut [mm]     | 0.2              |
| Cutting length [mm]                        | 90               |
| Cutting time [min]                         | 15               |

**[0149]** The sample is then detached from the base material to be observed and measured. Figure 6 shows the resulting sample in top view, where the precision and accuracy resulting from the cut can be observed. The sample is used to evaluate the width of the cut in different cutting directions, showing no significant variation in all the measurements.

#### Example 3: Comparison with the state of the art in the execution of a cut

**[0150]** The comparison between the abrasive water-jet cutting machine according to the invention and an abrasive water-jet cutting machine according to the state of the art is shown here, in the execution of a cut of a sample of 2 mm thick austenitic stainless steel (AISI 301 / EN 1.4310).

**[0151]** The technical specifications of the abrasive water-jet cutting machine according to the invention and of the abrasive water-jet cutting machine according to the state of the art are listed in Table 3.1, while the results obtained following the test are reported in Table 3.2.

**[0152]** As evidenced by Tables 3.1 and 3.2, and as seen in Figure 7, the abrasive water-jet cutting machine according to the invention boasts improvements with respect to the prior art, as regards the quality of the cutting groove, with cutting width reduced by 35%, and roughness quality, with  $R_a$  and  $R_z$  reduced by 57%.

**[0153]** Furthermore, the abrasive water-jet cutting machine according to the invention has obtained such results respecting the tolerance of 1 hundredth of a millimeter on the inclination of the wall (taper).

Table 3.1: Technical specifications

|                               | Background art | Cutting machine according to the invention |
|-------------------------------|----------------|--------------------------------------------|
| Primary nozzle diameter [mm]  | 0.08           | 0.05                                       |
| Focusing nozzle diameter [mm] | 0.20           | 0.13                                       |
| Hydraulic pressure [MPa]      | 350            | 350                                        |
| Abrasive                      | Garnet         | Garnet                                     |
| Abrasive mesh [# mesh]        | #230 mesh      | #600 mesh                                  |
| Distance from the piece [mm]  | 0.35           | 0.20                                       |

Table 3.2: Test results

|                                | Background art               | Cutting machine according to the invention |
|--------------------------------|------------------------------|--------------------------------------------|
| Groove width [mm]              | 0.245                        | 0.159                                      |
| Wall inclination [mm]          | -0.001                       | 0.007                                      |
| Roughness Ra [ $\mu\text{m}$ ] | top 1.10; mid 1.25; bot 1.38 | top 0.37; mid 0.51; bot 0.65               |
| Roughness Rz [ $\mu\text{m}$ ] | top 8.77; mid 8.80; bot 9.87 | top 3.17; mid 3.83; bot 4.62               |

**[0154]** Obviously, in order to meet contingent specific needs, those skilled in the art will be able to make further changes and variations all contained within the scope of protection defined by the following claims.

## Claims

1. An abrasive water-jet cutting machine (1), comprising:

- pumping means (2), fluidly connectable to a water source (3), for the generation of a pressurized water flow (4);
- a cutting head (5), comprising a primary nozzle (27), a mixing chamber (6) and a focusing nozzle (7), wherein the pressurized water flow (4) from the pumping means (2) is conveyed into the primary nozzle (27) of the cutting head (5) where the pressure energy of the pressurized water flow (4) is converted into kinetic energy so as to form a water jet (12), and wherein said water jet (12) is then conveyed into the mixing chamber (6);
- a dispensing system (8) of powdered abrasive material, comprising:

- a tank (9) containing powdered abrasive material,
- a supply tube (10), which fluidly connects the tank (9) to the mixing chamber (6) of the cutting head (5),
- an actuator (11) interposed between the tank (9) and the supply tube (10), which delivers the powdered abrasive material contained in the tank (9) into the mixing chamber (6), through the supply tube (10);

wherein the cutting head (5) mixes, in the mixing chamber (6), the abrasive material with the water jet (12), thus forming a water-abrasive material mixture jet (13), and said cutting head (5) delivers the water-abrasive material mixture jet (13), through the focusing nozzle (7); wherein the powdered abrasive material delivered in the mixing chamber (6) is homogeneously dispersed in suspension in a water-based gelatinous fluid (60); and wherein the actuator (11) is a peristaltic pump (100).

2. A cutting machine (1) according to claim 1, wherein the supply tube (10) is made of polymer material.

3. A cutting machine (1) according to claim 1 or 2, comprising an air duct (110) which converges into the mixing chamber (6).

4. A cutting machine (1) according to one of claims 1 to 3, comprising an electronic controller (120) configured to adjust

the amount of abrasive mixture (160) delivered by the dispensing system (8).

5. A cutting machine (1) according to one of claims 1 to 4, wherein the tank (9) contains an abrasive mixture (160).

6. A cutting machine (1) according to claim 4 or 5, wherein the electronic controller (120) is configured to adjust the amount of abrasive mixture (160) delivered by the actuator (11), through an open-loop control (180).

7. A cutting machine (1) according to one of claims 1 to 4, wherein the tank (9) comprises at least a first tank (130) containing water-based gelatinous fluid (60), and at least a second tank (140) containing powdered abrasive material, and wherein the dispensing system (8) comprises a mixer (150) interposed between the tank (9) and the actuator (11), and configured to mix the water-based gelatinous fluid (60) contained in the at least a first tank (130) with the powdered abrasive material contained in the at least a second tank (140), so as to form an abrasive mixture (160), and convey the abrasive mixture (160) into the actuator (11).

8. A cutting machine (1) according to any one of the preceding claims, comprising a pulsation damper (170) fluidly connected to the supply tube (10).

9. A cutting machine (1) according to claim 4 and according to one of claims 3, 7 and 8, wherein the electronic controller (120) is configured to adjust:

- the amount of the abrasive mixture (160) delivered by the mixer (150) and/or
- the amount of the abrasive mixture (160) delivered by the actuator (11) and/or
- the air amount introduced from the air duct (110) into the mixing chamber (6) and/or
- the actuation of the pulsation damper (170).

10. A cutting machine (1) according to claim 9, wherein the electronic controller (120) is configured to carry out the adjustment by means of a closed-loop control (190).

11. A cutting machine (1) according to any one of the preceding claims, wherein, in the abrasive mixture (160), the mass ratio of the powdered abrasive material to the water-based gelatinous fluid (60) is between 1.0 and 3.5.

12. A cutting machine (1) according to any one of the preceding claims, wherein the supply tube (10) is connected to the cutting head (5) by means of an injector nozzle (38), and wherein the injector nozzle (38) protrudes into the mixing chamber (6).

13. An abrasive waterjet cutting method, comprising the steps of:

- providing an abrasive waterjet cutter according to one of the preceding claims and according to claim 4;
- adjusting the amount of the abrasive mixture (160) delivered by the actuator (11) by means of an open-loop control (180).

14. An abrasive waterjet cutting method, comprising the steps of:

- providing an abrasive waterjet cutter according to one of the preceding claims and according to claims 4 and 9;
- performing at least one of the following adjustments by means of a closed-loop control (190):
  - adjustment of the amount of abrasive mixture (160) delivered by the mixer (150);
  - adjustment of the amount of abrasive mixture (160) delivered by the actuator (11);
  - adjustment of the air amount introduced from the air duct (110) into the mixing chamber (6);
  - adjustment of the actuation of the pulsation damper (170).

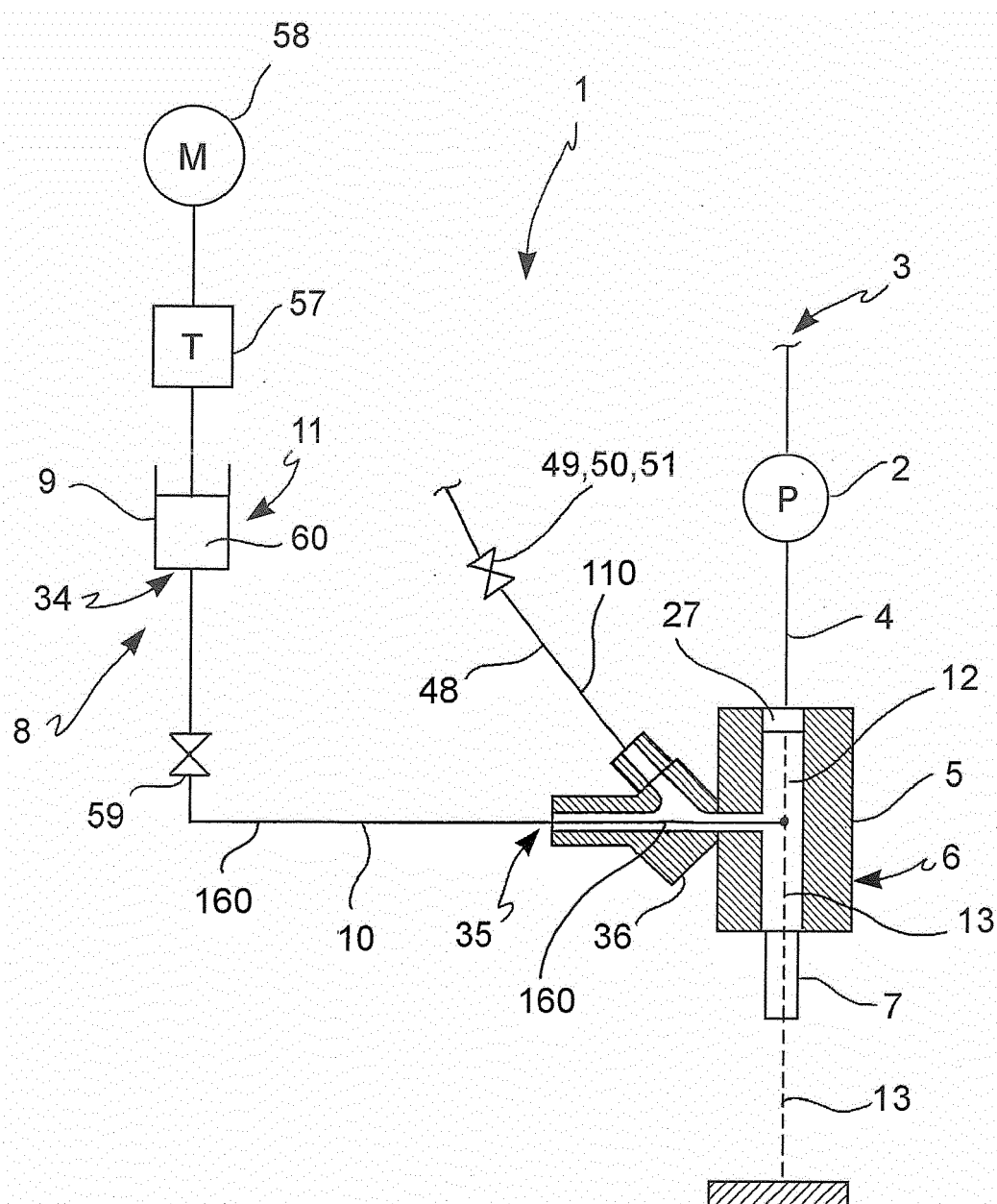


FIG. 1

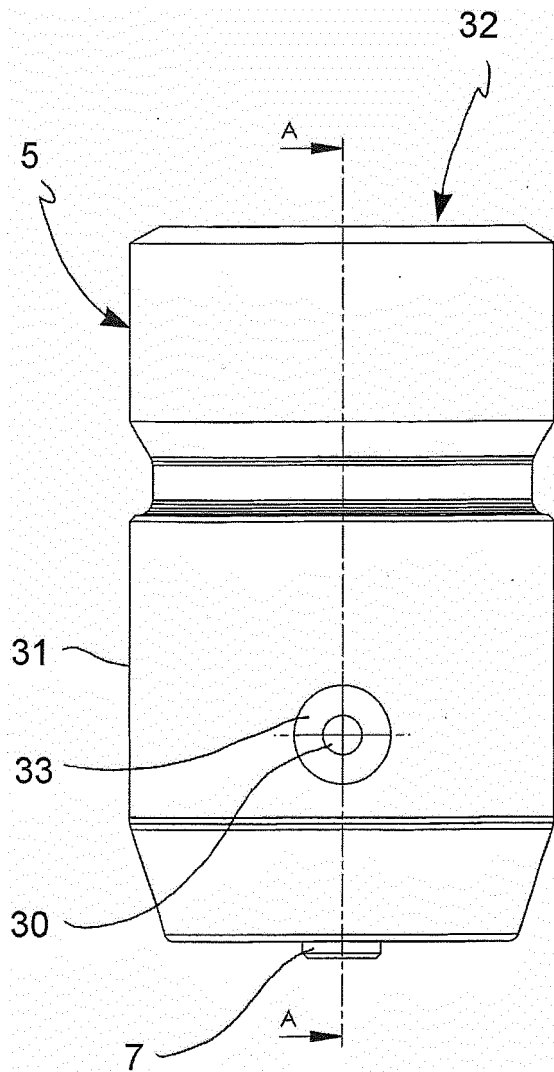


FIG. 2A

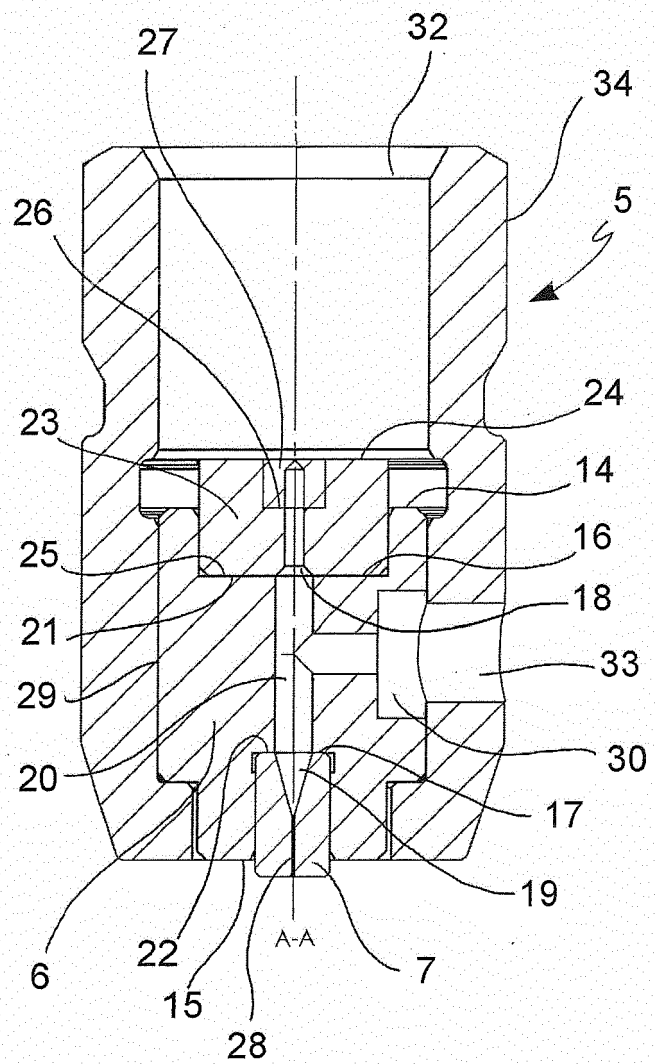


FIG. 2B

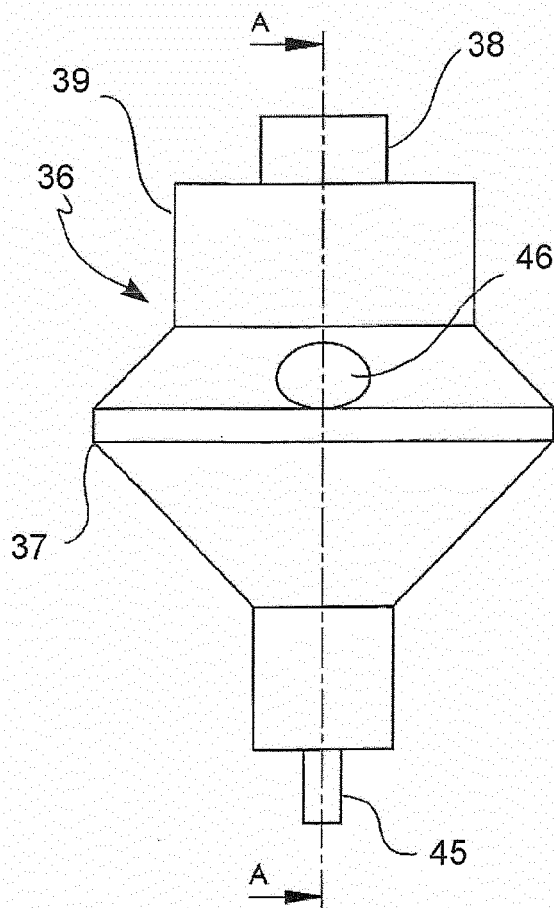


FIG. 3A

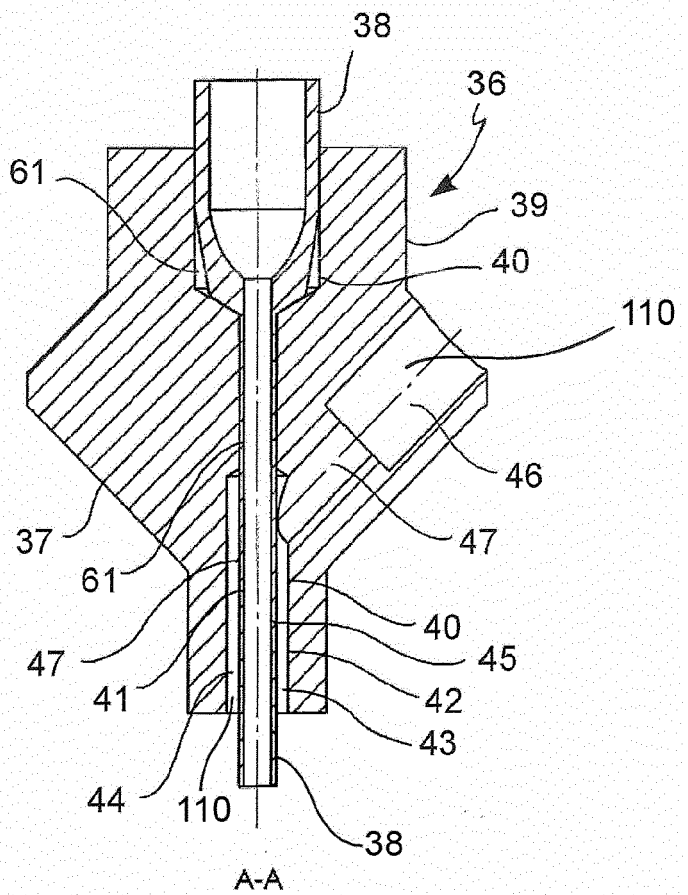


FIG. 3B

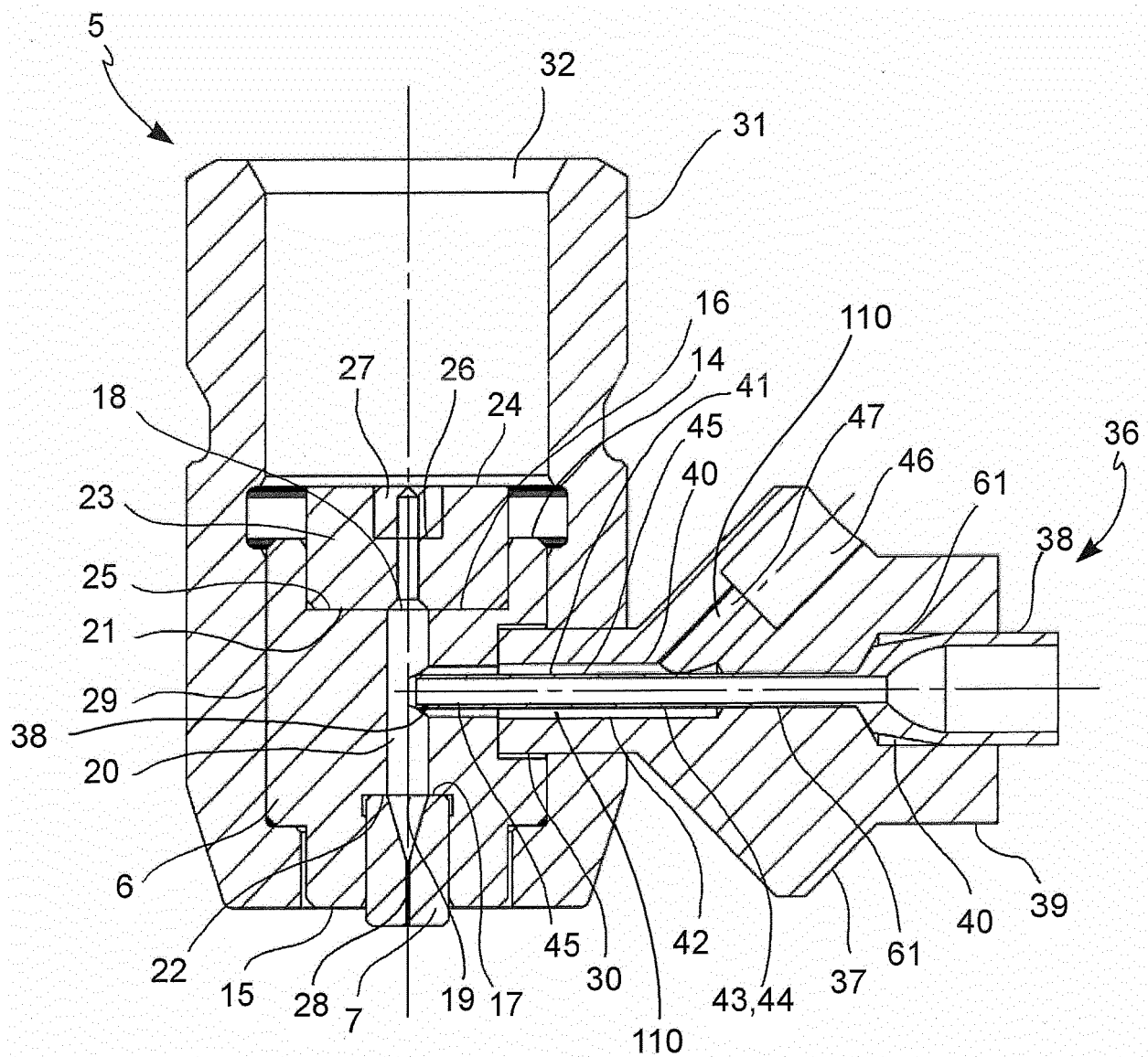
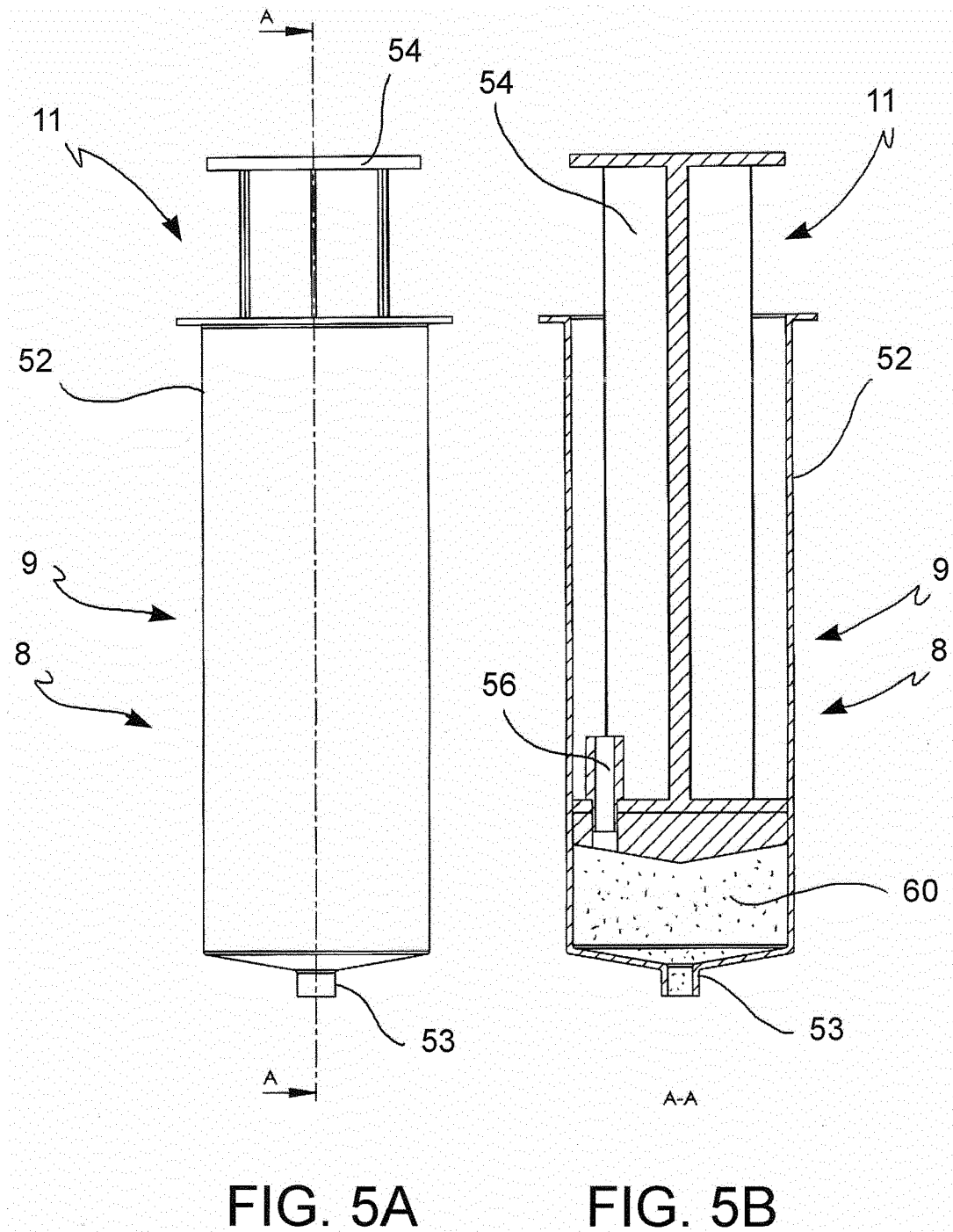


FIG. 4



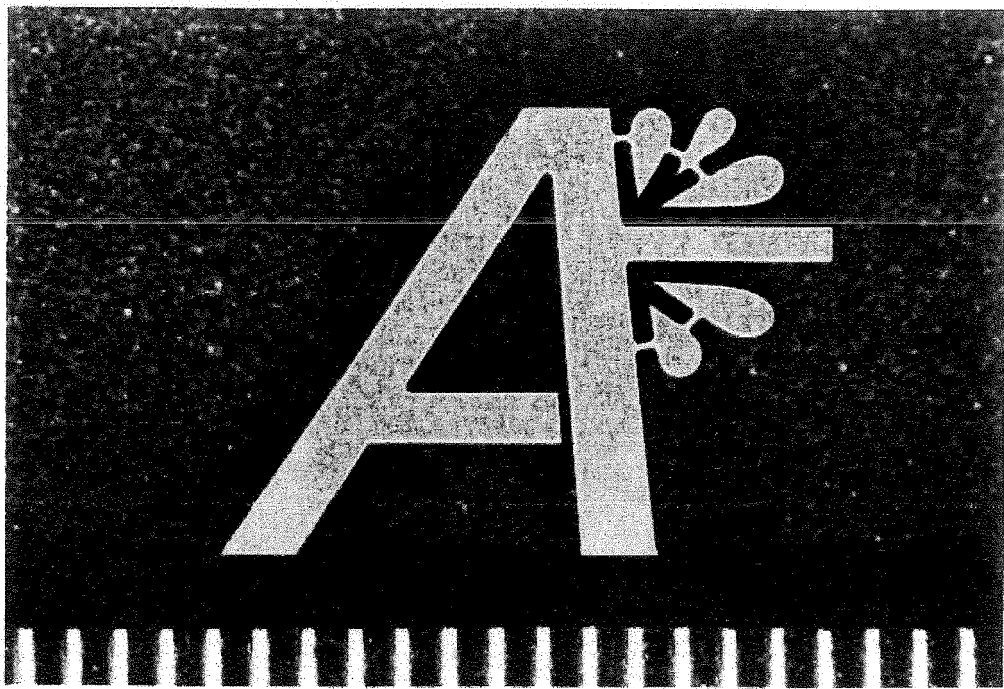
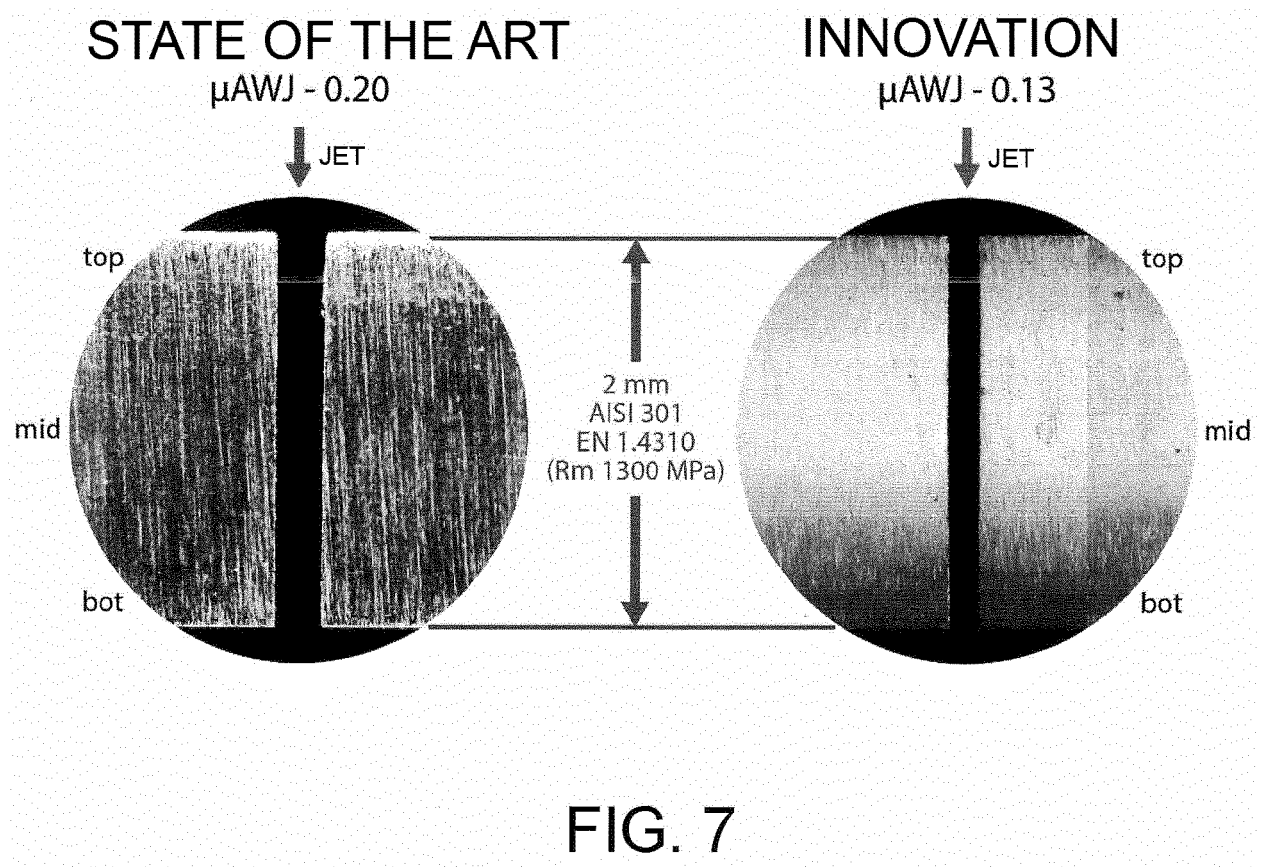


FIG. 6



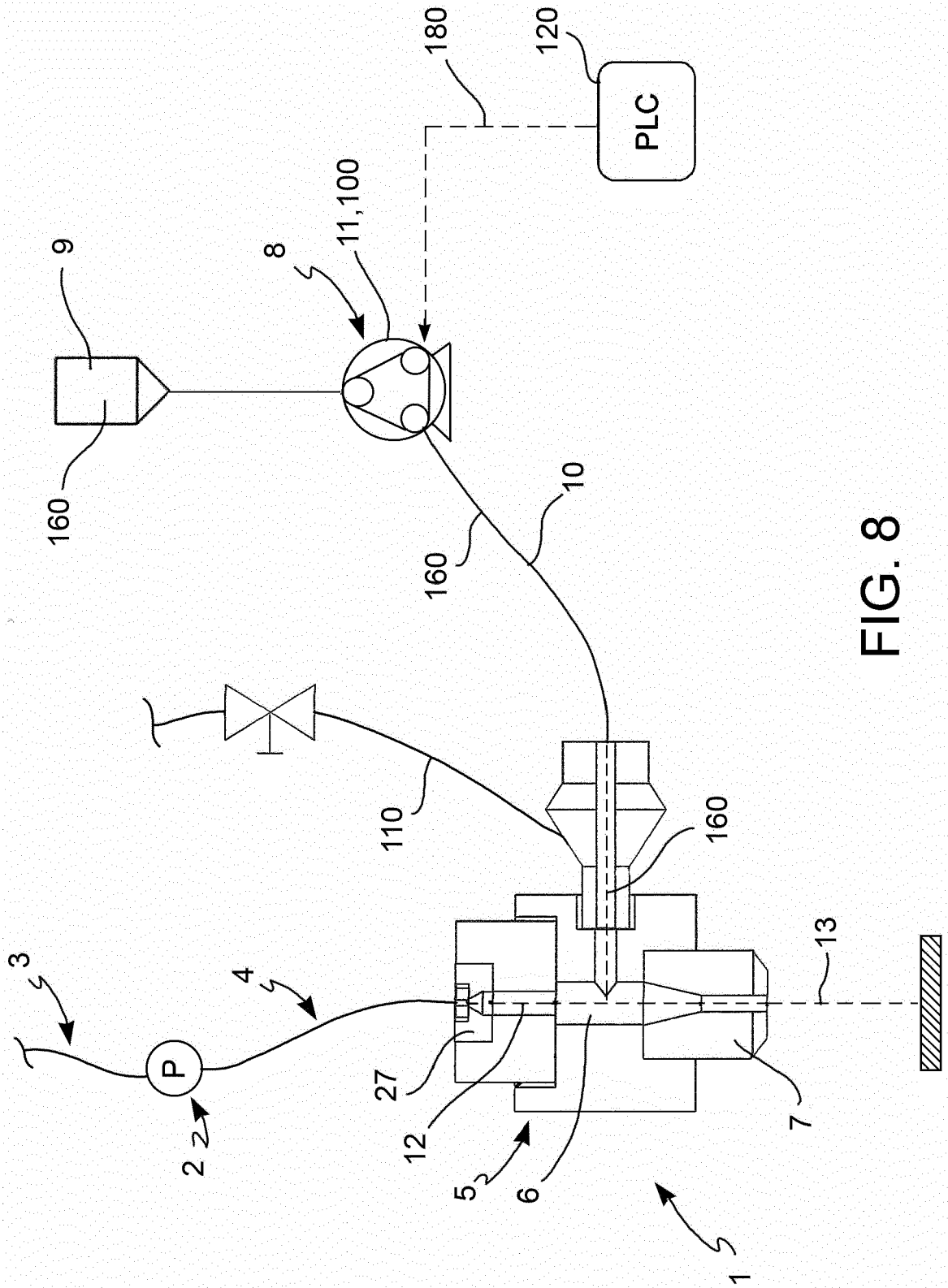
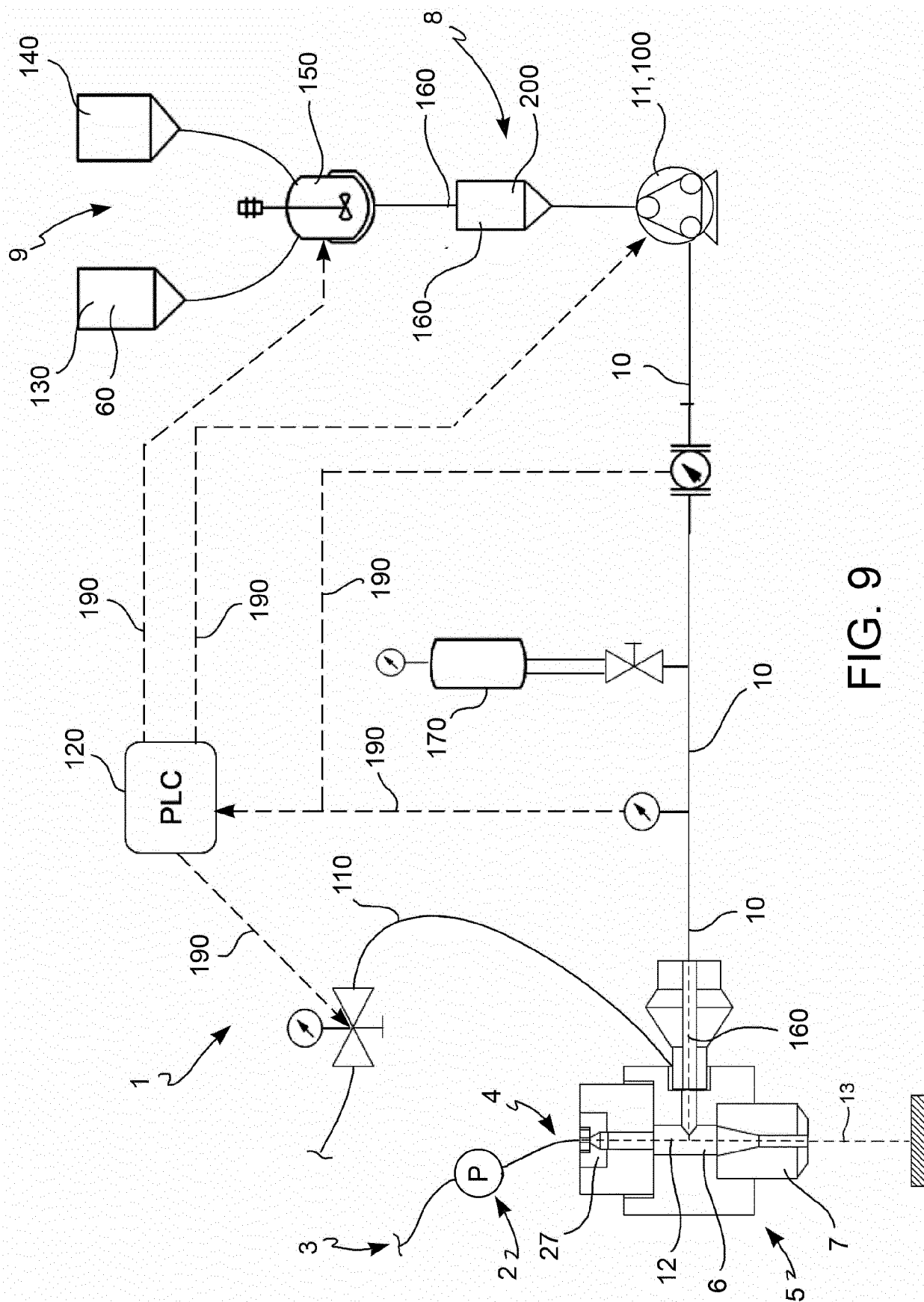


FIG. 8



**FIG. 9**

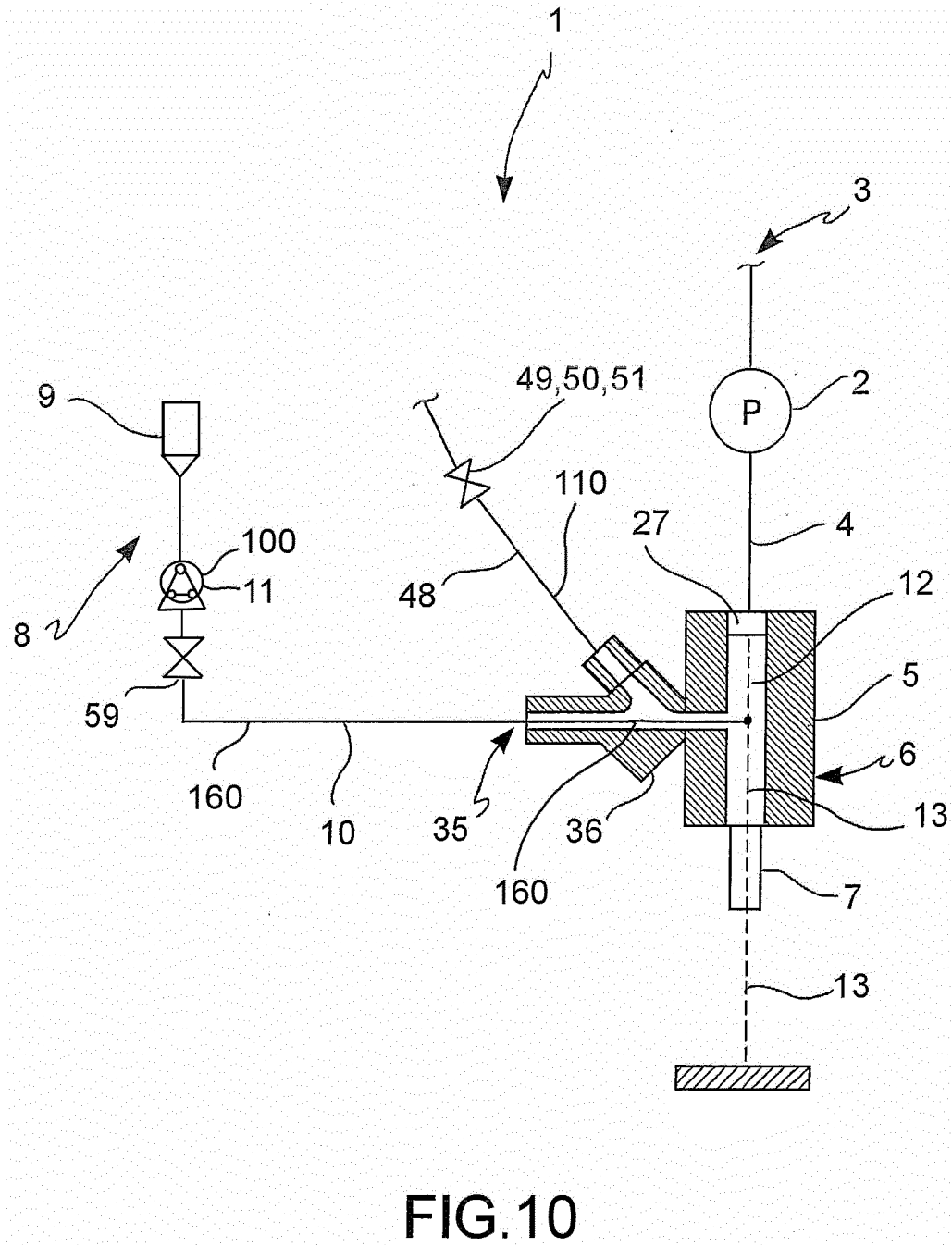


FIG.10



## EUROPEAN SEARCH REPORT

Application Number  
EP 21 16 1182

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| DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                             |                                                   |                                                       |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|-------------------------------------------------------|
| Category                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Citation of document with indication, where appropriate, of relevant passages                                                                               | Relevant to claim                                 | CLASSIFICATION OF THE APPLICATION (IPC)               |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | US 2019/210188 A1 (PASTORI GIANCARLO [IT])<br>11 July 2019 (2019-07-11)<br>* paragraphs [0018], [0053], [0081], [0085], [0090], [0093] - [0096]; figure 1 * | 1-14                                              | INV.<br>B24C1/04<br>B24C7/00<br>B24C5/04<br>B24C11/00 |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | US 2003/092364 A1 (ERICKSON KARL ROBERT [US] ET AL) 15 May 2003 (2003-05-15)<br>* paragraphs [0038], [0040]; figure 1 *                                     | 1-14                                              |                                                       |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | US 2015/031270 A1 (MILLER DONALD [GB])<br>29 January 2015 (2015-01-29)<br>* paragraphs [0012], [0164], [0228] *                                             | 2,8,12                                            |                                                       |
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