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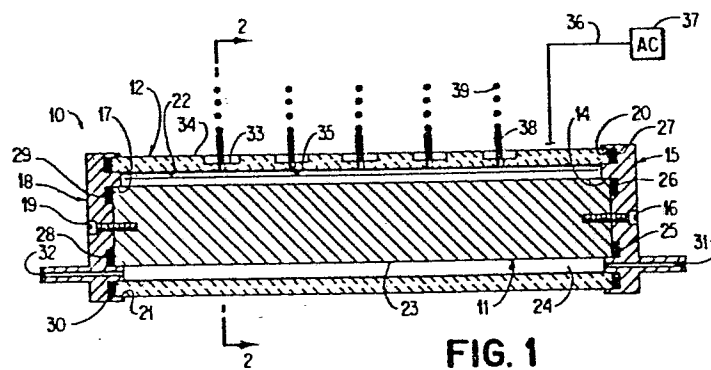
(54) Liquid droplet forming apparatus.

(57) An ink jet head 10 has coaxially disposed inner and outer cylindrical tube 11, 12 with the outer cylindrical surface 23 of the inner cylindrical tube spaced from the inner cylindrical surface 22 of the outer cylindrical tube to form an ink cavity 24 therebetween from which ink is supplied through one or more arrays of ink jet nozzles 35. Only the outer tube is a piezoelectric material so that the outer tube vibrates radially when electrically excited to produce vibrations in the ink in the ink cavity whereby a stream of ink droplets is supplied from each of the ink jet nozzles. In embodiments having only multiple arrays of ink jet nozzles, if desired, only the inner cylindrical tube or both the inner and outer cylindrical tubes can be formed of a piezoelectric material. If both of the tubes are formed of a piezoelectric material, the operating frequencies, which are preferably resonant, of the two tubes must then be matched.

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LIQUID DROPLET FORMING APPARATUS

The invention relates to apparatus for forming liquid droplets and is more particularly concerned with such apparatus for producing a plurality of similar streams of liquid droplets. Such apparatus is used in ink jet printers.

When a plurality of ink jet nozzles is connected to an ink cavity, it is desired that the ink droplets produced from the streams passing through each of the nozzles have substantially the same break-off point, have substantially uniform spacing between the droplets, and be satellite free. This ensures that the quality of the print from each of the nozzles will be substantially the same.

To obtain this uniform between the droplets of the various streams, it is necessary that the perturbations applied to each of the ink streams of the nozzles be substantially uniform and that the nozzles be of uniform quality. Furthermore, for the production of the droplets to be satellite free, the perturbations must be sufficiently large. It also is a requisite for the perturbations to not only be substantially uniform but to be reproducible through-
out the time that the droplets are being produced.

It is also necessary that the transducer or driver, which produces the vibrations to create the perturbations in the ink streams, be capable of producing the droplets at the desired frequency. This is determined by the overall requirements of the ink jet system including the size of the droplets, the spacing between the droplets on the medium on which the droplets are impinged, the rate at which the droplets can be charged, and the rate of relative movement between the medium and the nozzles. Thus, the transducer or driver must be capable of operating at a specific frequency.

The invention provides apparatus for producing a plurality of similar streams of liquid droplets, said apparatus comprising an elongated chamber formed between two elongated, similar shaped, opposed surfaces on two component parts, said chamber being filled with liquid, in use, one of said component parts having an aperture or apertures there-through providing or communicating with an elongated array of liquid jet nozzles, each nozzle having its axis perpendicular to the length of the chamber, said one or the other or both of the component parts being formed of piezoelectric material, means through which liquid under pressure can be supplied in use from a pressure liquid source to the nozzles to cause liquid jets to issue therefrom, and electrically energisable means effective when energized to subject the piezoelectric material to an electric field having a periodically fluctuating magnitude such that the separation of the said two surfaces fluctuates periodically in a direction perpendicular to the length of the chamber thereby causing periodic pressure waves in the liquid in the chamber and causing the jets to break up into similar streams of liquid droplets.

The invention also provides apparatus for producing a plurality of similar streams of ink droplets including an ink jet head comprising outer means having an inner cylindrical surface; an inner cylindrical tube disposed within the inner cylindrical surface of said outer means and having its outer cylindrical surface spaced from the inner cylindrical surface of said outer means, said inner cylindrical tube having its longitudinal axis substantially parallel to the longitudinal axis of the inner cylindrical surface of said outer means or coaxial therewith; an ink cavity formed between the outer cylindrical surface of said inner cylindrical tube and the inner cylindrical surface of said outer means and having pressurized ink therein; a plurality

of arrays of ink jet nozzles communicating through said outer means with said ink cavity and from which the streams of ink droplets are supplied, said plurality of arrays of ink jet nozzles being spaced from each other about the periphery of said outer means; each of said ink jet nozzles having its axis substantially perpendicular to the longitudinal axis of said inner cylindrical tube; and at least one of said inner cylindrical tube and said outer means being formed of a piezoelectric material and vibrating radially when electrically excited to produce vibrations within the ink in said ink cavity so that a stream of ink droplets is supplied from each of said ink jet nozzles.

The invention further provides apparatus for producing a plurality of similar streams of ink droplets including an ink jet head comprising outer means having an inner cylindrical surface; an inner cylindrical tube disposed within the inner cylindrical surface of said outer means and having its outer cylindrical surface spaced from the inner cylindrical surface of said outer means, said inner cylindrical tube having its longitudinal axis substantially parallel to the longitudinal axis of the inner cylindrical surface of said outer means or coaxial therewith; an ink cavity formed between the outer cylindrical surface of said inner cylindrical tube and the inner cylindrical surface of said outer means and having pressurized ink therein; a plurality of ink jet nozzles communicating through said outer means with said ink cavity and from which the streams of ink droplets are produced; each of said ink jet nozzles having its axis substantially perpendicular to the longitudinal axis of said inner cylindrical tube; and only said outer means being formed of a piezoelectric material and vibrating radially when electrically excited to produce vibrations within the ink in the ink cavity so that a stream of ink droplets is supplied from any of said ink jet nozzles.

The invention furthermore provides apparatus for producing a plurality of similar streams of ink droplets including an ink jet head comprising: inner means and outer means spaced from each other, said inner means and said outer means having adjacent walls spaced from each other at a substantially constant distance; an ink cavity formed between the adjacent walls of said inner means and said outer means, said ink cavity having pressurized ink therein; a plurality of ink jet nozzles communicating through said outer means with said ink cavity and from which the streams of droplets are produced; and only said outer means being formed of a piezoelectric material and vibrating when electrically excited to produce vibrations within the ink in said ink cavity so that a stream of ink droplets is supplied from any of said ink jet nozzles.

The invention also further provides apparatus for producing a plurality of similar streams of ink droplets including an ink jet head comprising outer component means having longitudinal passage therethrough providing an inner surface; an inner component means disposed within said longitudinal passage in said outer component means, said inner component means having its outer surface of substantially the same shape as the inner surface of said outer component means, said inner component means having its outer surface spaced uniformly from the inner surface of said outer component means, said inner component means having the longitudinal axis of its outer surface substantially parallel to the longitudinal axis of the inner surface of said outer component means or coaxial therewith; an ink cavity formed between the outer surface of said inner component means and the inner surface of said outer component means and having pressurized ink supplied thereto in use; a plurality of arrays of ink jet nozzles communicating through said outer

component means with said ink cavity and from which the streams of ink droplets are supplied, said plurality of arrays being spaced from each other about the periphery of said outer component means; each of said ink jet nozzles having its axis substantially perpendicular to the longitudinal axis of the outer surface of said inner component means; and one of said inner component means and said outer component means being formed of a piezoelectric material and vibrating radially when electrically excited to produce vibrations in the ink within said ink cavity so that a stream of ink droplets is supplied from each of said ink jet nozzles.

Various examples of apparatus for producing a plurality of similar streams of liquid droplets will now be described with reference to the accompanying drawings. Each apparatus is an ink jet printer and each example comprises an ink jet printer head. In the drawings:-

FIG. 1 is a longitudinal sectional view of a first ink jet head embodying the present invention in which an outer cylindrical tube, which forms the outer wall of the ink cavity, is formed of a piezoelectric material with the ink ~~cavity having no ink therein for clarity purposes~~ and taken along line 1-1 of FIG. 2.

FIG. 2 is a sectional view of the ink jet head of FIG. 1 taken along line 2-2 of FIG. 1.

FIG. 3 is an end elevational view of the ink jet head of FIG. 1.

FIG. 4 is a sectional view, taken along the position of line 2-2 of FIG. 1, of a modification of the ink jet head of FIG. 1 in which two offset arrays of nozzles are provided in a nozzle plate on the outer cylindrical tube.

FIG. 5 is a sectional view, taken along the position of line 2-2 of FIG. 1, of a further modification of the ink jet head of FIG. 1, the ink jet head having two arrays of nozzles in the outer cylindrical tube and spaced 180° from each other.

FIG. 6 is a sectional view, taken along the position line 2-2 of FIG. 1, of another modification of the ink jet head of FIG. 1, in which two sets of arrays of nozzles are provided in two nozzle plates one on each side of the outer cylindrical tube.

FIG. 7 is a longitudinal sectional view of a second ink jet head embodying the present invention in which each of inner and outer cylindrical tubes, which form the walls of the ink cavity, is formed of a piezoelectric material with the ink cavity having no ink therein for clarity purposes and taken along line 7-7 of FIG. 8.

FIG. 8 is a sectional view of the ink jet head of FIG. 7 taken along line 8-8 of FIG. 7.

FIG. 9 is an ~~end elevational view of the ink jet head~~ of FIG. 7.

FIG. 10 is a sectional view, taken along the position of line 8-8 of FIG. 7, of a modification of the ink jet head of FIG. 7, the modified ink jet head having two arrays of ink jet nozzles spaced 180° from each other with each array being in a nozzle plate on the outer cylindrical tube.

FIG. 11 is a sectional view, taken along the position of line 8-8 of FIG. 7, of a further modification of the ink jet head of FIG. 7, the further modified ink jet head having two offset arrays of ink jet nozzles on each side of the outer cylindrical tube.

FIG. 12 is a longitudinal sectional view of a third ink jet head embodying the present invention in which an inner cylindrical tube, which forms the inner wall of the ink cavity, is formed of a piezoelectric material with the ink cavity having no ink therein for clarity purposes and taken along line 12-12 of FIG. 13.

FIG. 13 is a sectional view of the ink jet head of FIG. 12 taken along line 13-13 of FIG. 12.

FIG. 14 is a sectional view, taken along the position of line 13-13 of FIG. 12 of a modification of the ink jet head of FIG. 12, the modified ink jet head having two arrays of ink jet nozzles in the outer cylindrical tube and spaced 180° from each other.

FIG. 15 is a sectional view, taken along the position of the line 13-13 of FIG. 12, of a further modification of the ink jet head of FIG. 12, the further modified ink jet head having two offset arrays of ink jet nozzles on each side of the outer cylindrical tube.

FIG. 16 is a longitudinal sectional view of a fourth ink jet head embodying the present invention in which an inner semi-cylindrical element of piezoelectric material forms the inner wall of the ink cavity with the ink cavity having no ink therein for clarity purposes and taken along line 16-16 of FIG. 17.

FIG. 17 is a sectional view of the ink jet head of FIG. 16 taken along line 17-17 of FIG. 16.

FIG. 18 is a longitudinal sectional view of a fifth ink jet head embodying the present invention in which the ink

cavity has an outer planar wall formed of a piezoelectric material with the ink cavity having no ink therein for clarity purposes.

FIG. 19 is a side elevational view of a sixth ink jet head embodying the present invention having a single array of ink jet nozzles.

FIG. 20 is a longitudinal sectional view of the ink jet head of FIG. 1 and taken along line 20-20 of FIG. 19.

FIG. 21 is a sectional view of the ink jet head of FIG. 1 and taken along line 21-21 of FIG. 19.

FIG. 22 is a sectional view of one of the end plates of the ink jet head of FIG. 19.

FIG. 23 is a sectional view of the other of the end plates of the ink jet head of FIG. 19.

FIG. 24 is an end elevational view of one of the end plugs of the ink jet head of FIG. 19.

FIG. 25 is an end elevational view of the other of the end plugs of the ink jet head of FIG. 19.

FIG. 26 is a fragmentary side elevational view of another form of the transducer for use with the ink jet head of the present invention.

FIG. 27 is a side elevational view of a seventh ink jet head embodying the present invention in which the ink jet head has a plurality of arrays of ink jet nozzles.

FIG. 28 is a longitudinal sectional view of the ink jet head of FIG. 27 and taken along line 28-28 of FIG. 27.

FIG. 29 is a sectional view of the ink jet head of FIG. 27 and taken along line 29-29 of FIG. 25.

FIG. 30 is an end elevational view of the ink jet head of FIG. 27 and taken along line 30-30 of FIG. 28.

FIG. 31 is a perspective view of the main body of the ink jet head of FIG. 27.

FIG. 32 is a longitudinal sectional view of the body of FIG. 31 and taken along line 32-32 of FIG. 31.

FIG. 33 is a fragmentary longitudinal sectional view of an eighth ink jet head embodying the present invention and taken along line 33-33 of FIG. 34.

FIG. 34 is a sectional view of the ink jet head of FIG. 33 and taken along line 34-34 of FIG. 33.

Referring to the drawings and particularly FIGS. 1-3, there is shown an ink jet head 10 of the present invention. The ink jet head 10 includes an inner cylindrical element 11, which is formed of metal, for example, and an outer cylindrical tube 12, which is formed of a piezoelectric material, disposed in surrounding relation to the inner cylindrical element 11 and spaced therefrom. One end of the element 11 is disposed within a circular recess 14 in an entry end plate 15, which is circular. A mounting screw 16 secures the entry end plate 15 to the adjacent end of the inner cylindrical element 11.

The other end of the element 11 is disposed within a circular recess 17 in an exit end plate 18, which is circular. A mounting screw 19 secures the exit end plate 18 to the adjacent end of the inner cylindrical element 11.

The outer cylindrical tube 12 has one end disposed within an annular groove 20 in the entry end plate 15 and its other end disposed within an annular groove 21 in the exit end plate 18. Thus, the outer cylindrical tube 12 is retained between the end plates 15 and 18 when they are secured to the inner cylindrical element 11.

Accordingly, the outer cylindrical tube 12 has its inner cylindrical surface 22 spaced the same distance from outer cylindrical surface 23 of the inner cylindrical element 11 throughout the length and around the entire circumference. Thus, an annular ink cavity 24 is formed between the inner cylindrical surface 22 of the outer cylindrical tube 12 and the outer cylindrical surface 23 of the inner cylindrical element 11.

The circular recess 14 in the entry end plate 15 has an annular groove 25 adjacent its circumference to receive an O-ring 26 to form a seal between one end of the inner cylindrical element 11 and the entry end plate 15. The entry end plate 15 has a second O-ring 27, which is disposed within the annular groove 20, engaging the end of the outer cylindrical tube 12 in the annular groove 20 to form a seal therebetween. Accordingly, the O-rings 26 and 27 cooperate to seal the ink cavity 24 relative to the entry end plate 15.

The circular recess 17 in the exit end plate 18 has an annular groove 28 adjacent its circumference to receive an O-ring 29 to form a seal between the end of the inner

cylindrical element 11 and the exit end plate 18. The exit end plate 18 has a second O-ring 30, which is disposed within the annular groove 21, bearing against the end of the outer cylindrical tube 12 disposed therein to form a seal therebetween. Accordingly, the O-rings 29 and 30 cooperate to seal the ink cavity 24 relative to the exit end plate 18.

The ink cavity 24 has pressurized, conductive ink supplied thereto from a pressurized source such as a pump, for example, through a passage 31 in the entry end plate 15. Whenever it is desired to flush the ink cavity 24 the pressurized ink flows from the ink cavity 24 through a passage 32 in the exit end plate 18 to an ink reservoir or the like connected to the suction side of the pump. This flow path from the ink cavity 24 is normally blocked.

The ink is grounded in any suitable manner. If the entry end plate 15 is formed of metal, it could be grounded to ground the ink in the cavity 24. If the entry end plate 15 is formed of a plastic such as an acetal plastic sold under the trademark Delrin, for example, then the ink must be grounded in some other suitable manner.

The outer cylindrical tube 12 has a plurality of longitudinal spaced flat portions 33 in its outer surface 34. Each of the flat portions 33 has an orifice 35, which functions as a nozzle, formed therein and extending through the outer cylindrical tube 12 to provide communication from the ink cavity 24 to the exterior of the outer cylindrical tube 12. Thus, the row of the orifices 35 forms an array of nozzles.

The axis of each of the orifices 35 is disposed substantially perpendicular to the longitudinal axis of the inner cylindrical element 11 and the longitudinal axis of

of the inner cylindrical element 11 and the longitudinal axis of the outer cylindrical tube 12. The longitudinal axis of the outer cylindrical tube 12 is preferably coaxial with the longitudinal axis of the inner cylindrical element 11 although they could be parallel.

As previously mentioned, the outer cylindrical tube 12 is formed of a piezoelectric material. It is polarized so that it vibrates in a radial direction when a voltage is applied thereto. The operating frequency at which the outer cylindrical tube 12 is electrically excited is preferably at or below its resonant frequency but it could be electrically excited above its resonant frequency in certain instances.

The outer cylindrical tube 12 has its outer surface 34 metallized so that the outer cylindrical tube 12 can be electrically connected through a lead 36 to an AC source 37 of power. Accordingly, when the AC source 37 of power is energized at a frequency, which is preferably equal to or below the resonant frequency of the outer cylindrical tube 12, the outer cylindrical tube 12 vibrates radially. This causes each ink stream 38 passing through one of the orifices 35 to be broken up into droplets 39 at a uniform break-off point with the droplets 39 being of substantially uniform size and having substantially uniform spacing therebetween.

Referring to FIG. 4, there is shown another form of the ink jet head 10 in which the outer cylindrical tube 12 is replaced by an outer cylindrical tube 45, which is formed of a piezoelectric material. The remainder of the structure of the ink jet head 10 of FIG. 4 is the same as shown in FIGS. 1-3.

The outer cylindrical tube 45 is similar to the outer cylindrical tube 12 except that it has a single continuous flat portion 46 formed in its outer surface 47 so as to have a nozzle plate 48, which is preferably silicon, mounted thereon. It should be understood that the flat portion 46 extends for substantially the same length as the distance between the extreme edges of the outermost of the flat portions 33 in the outer surface 34 of the outer cylindrical tube 12 as shown in FIG. 1.

The nozzle plate 48 has two offset arrays of ink jet nozzles 49 and 50. Each of the longitudinally spaced nozzles 49 is aligned with an orifice 51 extending through the outer cylindrical tube 45 to the ink cavity 24 to provide communication therewith. Each of the longitudinally spaced nozzles 50 is aligned with an orifice 52, which extends through the outer cylindrical tube 45 to provide communication with the ink cavity 24.

Accordingly, when the outer cylindrical tube 45 is vibrated in the same manner as the outer cylindrical tube 12, the droplets 39 are produced in the same manner as discussed with respect to FIG. 1. Thus, a first plurality of the streams 38 passes through the nozzles 49 in the nozzle plate 48 with each of the streams 38 being broken up into the droplets 39. Similarly, a second plurality of the streams 38 passes through the nozzles 50 with each of the streams 38 being broken up into the droplets 39. Accordingly, two offset rows of the droplets 39 are produced.

Referring to FIG. 5, there is shown an outer cylindrical tube 55, which is formed of a piezoelectric material, used in place of the outer cylindrical tube 12. The remainder of the structure of the ink jet head 10 of FIG. 5 is the same as shown in FIGS. 1-3.

The outer cylindrical tube 55 has a plurality of longitudinally spaced flat portions 56 formed in its outer surface 57 in the same manner as the flat portions 33 are formed in the outer surface 34 of the outer cylindrical tube 12. The outer cylindrical tube 55 has longitudinally spaced flat portions 58, which are diametrically disposed to the flat portions 56 formed in the same manner as the flat portions 33 are formed in the outer surface 34 of the outer cylindrical tube 12.

Each of the flat portions 56 has an orifice 59 formed therein and extending through the outer cylindrical tube 55 to provide communication from the ink cavity 24 to the exterior of the outer cylindrical tube 55. Similarly, each of the flat portions 58 has an orifice 60 formed therein and extending through the outer cylindrical tube 55 to communicate with the ink cavity 24.

Accordingly, when the outer cylindrical tube 55 is vibrated in the same manner as the outer cylindrical tube 12, the ink stream 38 flows from each of the orifices 59 and each of the orifices 60 and breaks up into the droplets 39. Thus, the droplets 39 from each of the orifices 59 can be utilized with a first recording medium and the droplets 39 from each of the orifices 60 can be employed with a second recording medium so that the ink jet head 10 functions as a double print head.

Referring to FIG. 6, there is shown an outer cylindrical tube 65, which is formed of a piezoelectric material, being used in the ink jet head 10 in place of the outer cylindrical tube 12. The remainder of the structure is the same as that shown in FIG. 1.

The outer cylindrical tube 65 has a first flat portion 66 formed in its outer surface 67 and a second flat portion

68, which is diametrically disposed to the first flat portion 66, formed in its outer surface 67. Each of the flat portions 66 and 68 extends for the same distance, which is preferably the same as that from the extreme edges of the outermost flat portions 33 in the outer surface 34 of the outer cylindrical tube 12 as shown in FIG. 1.

The flat portions 66 and 68 have nozzle plates 69 and 70, respectively, mounted thereon. The nozzle plate 69, which is preferably silicon, has a first array of longitudinally spaced nozzles 71 and a second array of longitudinally spaced nozzles 72 offset from the array of nozzles 71. The nozzles 71 communicate with the ink cavity 24 through orifices 73, which extend through the outer cylindrical tube 65 to the ink cavity 24. The nozzles 72 communicate with the ink cavity 24 through orifices 74, which extend through the outer cylindrical tube 65 to the ink cavity 24. The nozzle plate 70 is similarly formed as the nozzle plate 69.

Accordingly, when the outer cylindrical tube 65 vibrates in the manner previously described for the outer cylindrical tube 12, the droplets 39 are produced in two rows from each of the opposite sides of the outer cylindrical tube 65. Thus, two separate recording mediums may be utilized with each receiving two rows of the droplets 39.

It should be understood that the outer cylindrical tube 12 of FIGS. 1-3 could be formed in a manner similar to the outer cylindrical tube 45 of FIG. 4 so as to have a single row of the nozzles formed in a nozzle plate. Similarly, the outer cylindrical tube 55 of FIG. 5 could have each of the flat portions 56 and 58 continuous with a nozzle plate mounted thereon in the same manner as shown in FIG. 6.

It also should be understood that the outer cylindrical tube 45 of FIG. 4 could have a plurality of longitudinally spaced flat portions rather than the single flat portion 46 in the same manner as the flat portions 33 of FIG. 1 are formed in the outer cylindrical tube 12 and be utilized without the nozzle plate 48. Likewise, the nozzle plates 69 and 70 of FIG. 6 could be omitted from the outer cylindrical tube 65 and each of the flat portions 66 and 68 be a plurality of separate, longitudinally spaced flat portions like the flat portions 33 of FIG. 1 rather than a single continuous flat portion.

Referring to FIGS. 7-9, there is shown an ink jet head 80, which includes an inner cylindrical tube 81 and an outer cylindrical tube 82. Each of the inner cylindrical tube 81 and the outer cylindrical tube 82 is formed of a piezo-electric material. The outer cylindrical tube 82 is disposed in surrounding relation to the inner cylindrical tube 81 and spaced therefrom to form an ink cavity 83 therebetween.

The inner cylindrical tube 81 has one end disposed within an annular groove 84 in an entry end plate 85 and its other end disposed in an annular groove 86 in an exit end plate 87. The outer cylindrical tube 82 has one end disposed in an annular groove 88 in the entry end plate 85 and its other end disposed in an annular groove 89 in the exit end plate 87.

A cylindrical connecting element 90 extends between the inner surfaces of the entry end plate 85 and the exit end plate 87 and abuts against each. A mounting screw 91 secures the entry end plate 85 to one end of the connecting element 90, and a mounting screw 92 attaches the exit end plate 87 to the other end of the connecting element 90.

Accordingly, the outer cylindrical tube 82 has its inner cylindrical surface 93 spaced the same distance from outer cylindrical surface 94 of the inner cylindrical tube 81 throughout the length and around the entire circumference. Thus, the annular ink cavity 83 has the same spacing between its walls at any point.

The entry end plate 85 has a first O-ring 95, which is disposed within the annular groove 84, engaging the end of the inner cylindrical tube 81 in the annular groove 84 to form a seal therebetween. The entry end plate 85 has a second O-ring 96, which is disposed within the annular groove 88, abutting the end of the outer cylindrical tube 82 in the annular groove 88 to form a seal therebetween. Accordingly, the O-rings 95 and 96 cooperate to seal the ink cavity 83 relative to the entry end plate 85.

The exit end plate 87 has a first O-ring 97, which is disposed within the annular groove 86, engaging the end of the inner cylindrical tube 81 in the annular groove 86 to form a seal therebetween. The exit end plate 87 has a second O-ring 98, which is disposed within the annular groove 89, abutting the end of the outer cylindrical tube 82 in the annular groove 89 to form a seal therebetween. Accordingly, the O-rings 97 and 98 cooperate to seal the ink cavity 83 relative to the exit end plate 87.

The ink cavity 83 has pressurized, conductive ink supplied thereto through a passage 99 in the entry end plate 85 in the same manner as described for the ink jet head 10 of FIG. 1. Flushing can occur in the same manner as described for the ink jet head 10 through utilization of a passage 100 in the exit end plate 87. The ink is grounded in any suitable manner.

The outer cylindrical tube 82 has a plurality of longitudinally spaced flat portions 101 in its outer surface 102. Each of the flat portions 101 has a first orifice 103 and a second orifice 104 formed therein. Each of the orifices 103 and 104 extends through the outer cylindrical tube 82 to provide communication from the ink cavity 83 to the exterior of the outer cylindrical tube 82 and functions as a nozzle. Thus, there are two offset arrays of nozzles formed in the outer cylindrical tube 82 with the row of the orifices 103 forming one of the arrays of nozzles and the row of the orifices 104 forming the other of the arrays of nozzles.

The axis of each of the orifices 103 and of each of the orifices 104 is disposed substantially perpendicular to the longitudinal axis of the inner cylindrical tube 81 and the longitudinal axis of the outer cylindrical tube 82. The longitudinal axis of the outer cylindrical tube 82 is preferably coaxial with the longitudinal axis of the inner cylindrical tube 81 although they could be parallel.

As previously mentioned, each of the inner cylindrical tube 81 and the outer cylindrical tube 82 is formed of a piezoelectric material. In order for the resonant operating frequencies of the inner cylindrical tube 81 and the outer cylindrical tube 82 to be matched, it is necessary that they be formed of different piezoelectric materials.

Each of the inner cylindrical tube 81 and the outer cylindrical tube 82 is polarized to vibrate in a radial direction when a voltage is applied thereto. The operating frequency at which the inner cylindrical tube 81 and the outer cylindrical tube 82 is electrically excited is preferably the matched resonant frequency but any matched operating frequency below the matched resonant frequency also could be employed. It should be understood that one of the tubes 81

and 82 could be electrically excited at its resonant frequency and the other of the tubes 81 and 82 having its operating frequency matched therewith.

The outer cylindrical tube 82 has its outer surface 102 metallized so that the outer cylindrical tube 82 can be electrically connected through a lead 105 to an AC source 106 of power. The inner cylindrical tube 81 has its inner cylindrical surface 107 metallized so that the inner cylindrical tube 81 can be electrically connected through a lead 108 and a phase inverter 109 to the AC source 106 of power. The lead 108 passes through a passage 110 in the entry end plate 85.

Accordingly, when the AC source 106 of power is energized at a frequency, which is preferably equal to or below the matched resonant frequency of the inner cylindrical tube 81 and the outer cylindrical tube 82, each of the inner cylindrical tube 81 and the outer cylindrical tube 82 vibrates radially with one expanding while the other is contracting. This causes the ink streams 38 passing through each of the orifices 103 and each of the orifices 104 to be broken up into the droplets 39.

Referring to FIG. 10, there is shown another form of the ink jet head 80 in which the outer cylindrical tube 82 is replaced by an outer cylindrical tube 115, which is formed of a piezoelectric material. The remainder of the structure of the ink jet head 80 of FIG. 10 is the same as shown in FIGS. 7-9.

The outer cylindrical tube 115 has first flat portion 116 formed in its outer cylindrical surface 117 and extending for substantially the same length as the distance between the extreme edges of the outermost flat portions 101 of FIG.

7. The outer cylindrical tube 115 has a second flat portion 118, which is diametrically disposed to the first flat portion 116, formed in its outer cylindrical surface 117. The second flat portion 118 extends for the same length as the first flat portion 116.

A nozzle plate 119, which is preferably silicon, is mounted on the first flat portion 116, and a nozzle plate 120, which is preferably silicon, is mounted on the second flat portion 118. The nozzle plate 119 has a plurality of longitudinally spaced nozzles 121 therein with each of the nozzles 121 communicating with the ink cavity 83 through an orifice 122 in the outer cylindrical tube 115. Each of the orifices 122 extends through the outer cylindrical tube 115 to the ink cavity 83.

The nozzles plate 120 has a plurality of longitudinally spaced nozzles 123 therein with each of the nozzles 123 communicating with the ink cavity 83 through an orifice 124 in the outer cylindrical tube 115. Each of the orifices 124 extends through the outer cylindrical tube 115 to the ink cavity 83.

Accordingly, each of the nozzles 121 has one of the streams 38 pass therethrough, and each of the nozzles 123 has one of the streams 38 pass therethrough. Therefore, when the inner cylindrical tube 81 and the outer cylindrical tube 115 vibrate radially in the same manner as described for the inner cylindrical tube 81 and the outer cylindrical tube 82 of FIG. 7, the streams 38 are broken up into the droplets 39 and applied to two separate recording mediums.

Referring to FIG. 11, there is shown another form of the ink jet head 80 in which the outer cylindrical tube 82

is replaced by an outer cylindrical tube 125, which is formed of a piezoelectric material. The remainder of the structure of the ink jet head 80 of FIG. 11 is the same as shown in FIGS. 7-9.

The outer cylindrical tube 125 has a plurality of first flat portions 126 formed in its outer surface 127 in the same manner as the flat portions 101 on the outer cylindrical tube 82 of FIG. 7. A plurality of second flat portions 128 is formed in the outer cylindrical surface 127 of the outer cylindrical tube 125 and diametrically opposite to the first flat portions 126. Each of the second flat portions 128 is formed at the same longitudinal position as one of the diametrically disposed first flat portions 126.

Each of the first flat portions 126 has a first orifice 129 and a second orifice 130 formed therein with each of the orifices 129 and 130 providing communication from the ink cavity 83 to the exterior of the outer cylindrical tube 125. Thus, the orifices 129 form a first array of nozzles, and the orifices 130 form a second array of nozzles.

Each of the second flat portions 128 has a first orifice 131 and a second orifice 132 formed therein with each of the orifices 131 and 132 extending through the outer cylindrical tube 125 to provide communication from the ink cavity 83 to the exterior of the outer cylindrical tube 125. The orifices 131 forms a first array of nozzles on the opposite side of the outer cylindrical tube 125 from the orifices 129 and 130. The orifices 132 form a second array of nozzles, which is offset from the first array of nozzles formed by the orifices 131. Accordingly, this arrangement can be utilized with two separate recording mediums with two rows of the ink droplets 39 being applied to each of the recording mediums.

It should be understood that the outer cylindrical tube 82 of FIGS. 7-9 could be formed with the flat portions 101 as a continuous flat portion in a manner similar to the formation of the first flat portion 116 on the outer cylindrical tube 115 of FIG. 10 so as to have a nozzle plate with a single row of nozzles mounted thereon. Similarly, the outer cylindrical tube 125 of FIG. 11 could have each of the longitudinally spaced flat portions 126 and 128 continuous so as to have a nozzle plate mounted on each in the same manner as shown in FIG. 10. It also should be understood that the outer cylindrical tube 115 of FIG. 10 could have a plurality of longitudinally spaced flat portions rather than the single flat portion 116 and a plurality of longitudinally spaced flat portions rather than the single flat portions 118 in the same manner as the flat portions 101 are formed in the outer cylindrical tube 82 of FIGS. 7-9 and be utilized without the nozzle plates 119 and 120.

Referring to FIGS. 12 and 13, there is shown an ink jet head 140, which has a similar construction to that of the ink jet head 80 except that the outer cylindrical tube 82 of piezoelectric material is replaced by an outer cylindrical tube 141, which is not formed of piezoelectric material but of metal, for example. The outer cylindrical tube 141 has a nozzle plate 142, which is preferably silicon, mounted thereon through forming a flat portion 143 in outer cylindrical surface 144 of the outer cylindrical tube 141.

The nozzle plate 142 has a first row of longitudinally spaced nozzles 145 forming a first array of nozzles and a second row of longitudinally spaced nozzles 146 forming a second array of nozzles. Thus, the two arrays of the nozzles in the nozzle plate 142 are offset from each other.

Each of the nozzles 145 in the nozzle plate 142 communicates through an orifice 147, which extends through the outer cylindrical tube 141, with the ink cavity 83. Each of the nozzles 146 communicates through an orifice 148, which extends through the outer cylindrical tube 141, with the ink cavity 83.

In the same manner as in FIG. 7, the inner cylindrical tube 81 has its inner surface 107 metallized and connected by the lead 106 to an AC source 149 of power. Accordingly, when the AC source 149 of power is energized at a frequency, which is preferably equal to or below the resonant frequency of the inner cylindrical tube 81, the inner cylindrical tube 81 vibrates radially. This causes each of the ink streams 38 passing through the nozzles 145 and 146 to be broken up into the droplets 39 to provide two rows of the droplets 39 for application to a recording medium.

Referring to FIG. 14, there is shown another arrangement of the ink jet head 140 in which the outer cylindrical tube 141 is replaced by an outer cylindrical tube 150, which is formed of metal. The remainder of the structure of the ink jet head 140 of FIG. 14 is the same as shown in FIGS. 12 and 13.

The outer cylindrical tube 150 has a first row of longitudinally spaced orifices 151, which function as nozzles, extending therethrough to provide communication from the ink cavity 83 to the exterior of the outer cylindrical tube 150. The outer cylindrical tube 150 has a second row of longitudinally spaced orifices 152, which are diametrically disposed to the orifices 151 and function as nozzles, extending through the outer cylindrical tube 150 to provide communication from the ink cavity 83 to the exterior of the outer cylindrical tube 150.

When the inner cylindrical tube 81 is electrically excited from the AC source 149 of power, the streams 38 passing through the orifices 151 break up into the droplets 39 and the streams 38 exiting through the orifices 152 break up into the droplets. Thus, the ink jet head 140 of FIG. 14 can be utilized with two separate recording mediums with one of the recording medium receiving the droplets 39 from the orifices 151 and the other of the recording mediums receiving the droplets 39 from the orifices 152.

Referring to FIG. 15, there is shown another arrangement of the ink jet head 140 in which an outer cylindrical tube 155 of metal is utilized in place of the outer cylindrical tube 141. The remainder of the structure of the ink jet head 140 of FIG. 15 is the same as shown in FIGS. 12 and 13.

The outer cylindrical tube 155 has a plurality of first flat portions 156, which are longitudinally spaced, formed in its outer cylindrical surface 157 in the same manner as the flat portions 101 are formed in the outer cylindrical tube 82 in FIG. 7. Each of the first flat portions 156 has a first orifice 158, which extends through the outer cylindrical tube 155 to the ink cavity 83, providing communication from the ink cavity 83 to the exterior of the outer cylindrical tube 155. Each of the first flat portions 156 has a second orifice 159, which extends through the outer cylindrical tube 155 to the ink cavity 83, to provide communication from the ink cavity 83 to the exterior of the outer cylindrical tube 155. Thus, the first orifices 158 form a first array of nozzles and the second orifices 159 form a second array of nozzles with the two arrays of nozzles being offset from each other.

The outer cylindrical tube 155 has a plurality of second flat portions 160, which are longitudinally spaced, formed

therein and diametrically disposed to the first flat portions 156. Each of the second flat portions 160 has a first orifice 161, which extends through the outer cylindrical tube 155 to provide communication from the ink cavity 83 to the exterior of the outer cylindrical tube 155, and a second orifice 162, which extends through the outer cylindrical tube 155 to provide communication from the ink cavity 83 to the exterior of the outer cylindrical tube 155. Thus, the row of the first orifices 161 forms a first array of nozzles and the row of the second orifices 162 forms a second array of nozzles with the two arrays being offset from each other.

Furthermore, the two arrays of nozzles in the first flat portions 156 are used with a first recording medium and the two arrays of nozzles in the second flat portions 160 are used with a second recording medium. Thus, each of the recording mediums has two offset rows of the droplets 39 directed thereto when the inner cylindrical tube 81 is vibrated radially.

It should be understood that the outer cylindrical tube 141 of FIGS. 12 and 13 could have a plurality of longitudinally spaced flat portions rather than the single continuous flat portion 143 in the same manner as the flat portions 156 are longitudinally spaced in the outer cylindrical tube 155 and be utilized without the nozzle plate 142. It also should be understood that the outer cylindrical tube 150 of FIG. 14 could be formed with a continuous flat portion on each side so as to have a nozzle plate mounted on each flat portion in the same manner as shown in FIG. 13. Likewise, each of the longitudinally spaced flat portions 156 and 160 in the outer cylindrical tube 155 of FIG. 15 could be continuous so as to have a nozzle plate mounted thereon in the same manner as shown in FIG. 13.



Referring to FIGS. 16 and 17, there is shown an ink jet head 170, which includes a semi-cylindrical element 171 of a piezoelectric material. The element 171 has its inner semi-cylindrical surface 172 resting on a semi-cylindrical portion 173 of a support 174, which is formed of a suitable electrically insulating material such as plastic, for example.

A body 175, which is formed of metal or plastic, for example, is supported on the support 174 and secured thereto by mounting screws 176. The body 175 has a semi-cylindrical recess 177 to receive the semi-cylindrical element 171 and the semi-cylindrical portion 173 of the support 174 therein with the element 171 having its outer surface 178 spaced from the wall of the recess 177 when the body 175 is secured to the support 174 by the mounting screws 176. Accordingly, the spacing of the outer surface 178 of the semi-cylindrical element 171 the same distance from the wall of the recess 177 provides an ink cavity 179 therebetween with the ink cavity 179 having the same thickness at any position.

The body 175 has an O-ring 180 mounted in a groove 181 therein. The groove 181 surrounds the recess 177 of the body 175 and forms a seal with the support 174 to seal the ink cavity 179.

The ink cavity 179 has pressurized, conductive ink supplied thereto through a passage 182 in a plug 183 and a passage 184 in the support 174 from a pressurized source in the manner previously described relative to the ink jet head 10 of FIG. 1. When flushing is desired, the ink flows from the ink cavity 179 through a passage (not shown) in the support 174 and a passage (not shown) in a connecting plug 187 in the manner described relative to the ink jet head 10. The ink is grounded in any suitable manner.

The body 175 has a nozzle plate 188, which is preferably formed of silicon bonded thereto. The nozzle plate 188 has a first row of longitudinally spaced nozzles 189 therein to form a first array of nozzles and a second row of longitudinally spaced nozzles 190 therein to form a second array of nozzles offset from the first array of nozzles.

Each of the nozzles 189 communicates with the ink cavity 179 through an orifice 191, which extends through the body 175 to the ink cavity 179, in the body 175. Each of the nozzles 190 communicates with the ink cavity 179 through an orifice 192, which extends through the body 175 to the ink cavity 179. The axis of each of the orifices 191 and 192 is disposed substantially perpendicular to the longitudinal axis of the semi-cylindrical element 171.

As previously mentioned, the semi-cylindrical element 171 is formed of a piezoelectric material. It is polarized so that it vibrates in a radial direction when a voltage is applied thereto. The operating frequency at which the semi-cylindrical element 171 is electrically excited is preferably below its resonant frequency but it could be at its resonant frequency.

The semi-cylindrical element 171 has the inner semi-cylindrical surface 172 metallized so that the semi-cylindrical element 171 can be connected through a lead 193, which extends through a passage 194 in the support 174, to an AC source 195 of power. Accordingly, when the AC source 195 of power is energized at a frequency, which is preferably equal to or below the resonant frequency of the semi-cylindrical element 171, the semi-cylindrical element 171 vibrates radially. This causes each of the streams 38 passing through one of the nozzles 189 and 190 to be broken up into the droplets 39.

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Referring to FIG. 18, there is shown an ink jet head 200. The ink jet head 200 includes an outer planar element 201, which is formed of a piezoelectric material, and an inner block 202, which can be formed of metal, for example. The outer element 201 is secured to the inner block 202 by any suitable means such as bonding, for example.

An ink cavity 203 is formed between the outer element 201 and the inner block 202 within the inner block 202. The distance between an inner surface 204 of the outer element 201 and an inner surface 205 of the inner block 202 is substantially constant throughout the length of the ink cavity 203.

The ink cavity 203 has pressurized, conductive ink supplied thereto through a passage 206 in the inner block 202 from a suitable pressurized source in the same manner as discussed with respect to the ink jet head 10. Whenever it is desired to flush the ink cavity 203, the ink flows from the ink cavity 203 through a passage 207 in the inner block 202 to an ink reservoir or the like as discussed with respect to the ink jet head 10. The ink is grounded in any suitable manner.

The outer element 201 has a plurality of longitudinally spaced flat portions 210 in its outer surface 211. Each of the flat portions 210 has an orifice 212, which functions as a nozzle, formed therein and extending through the outer element 201 to provide communication from the ink cavity 203 to the exterior of the outer element 201. The axis of each of the orifices 212 is substantially perpendicular to the longitudinal axis of the outer element 201.

As previously mentioned, the outer element 201 is formed of a piezoelectric material. It is polarized so that

it vibrates in a direction substantially parallel to the axis of each of the orifices 212 when a voltage is applied thereto. The operating frequency at which the outer element 201 is electrically excited is preferably below its resonant frequency but it could be at its resonant frequency.

The outer element 201 has its outer surface 211 metallized so that the outer element 201 can be connected through a lead 213 to an AC source 214 of power. Accordingly, when the AC source 214 of power is energized at a frequency, which is preferably equal to or below the resonant frequency of the outer element 201, the outer element 201 vibrates in and out relative to its thickness and substantially parallel to the axes of the orifices 212. This causes each of the ink streams 38 passing through the orifices 212 to break up into the droplets 39 in the manner previously described relative to the ink jet head 10.

Referring now to FIGS. 19 and 20, there is shown an ink jet head 210 of the present invention. The head 210 includes a nozzle mounting plate 211 and a back plate 212 with a gasket 213 therebetween. The nozzle mounting plate 211, the back plate 212, and the gasket 213 are held together by screws 214.

An entry end plate 215 is secured to one end of the nozzle mounting plate 211 and the back plate 212 by suitable means such as screws (not shown), for example. An exit end plate 217, which is formed of an electrically insulating material, is secured to the other end of each of the nozzle mounting plate 11 and the back plate 212 by suitable means such as screws (not shown), for example.

A right circular cylindrical tube 219 is disposed within an ink cavity 220, which is a longitudinal passage, in the nozzle mounting plate 211 and the back plate 212. The tube 219 has one end supported within an entry end plug 222 and its other end supported within an exit end plug 223, which is formed of an electrically insulating material. Each of the plugs 222 and 223 is supported between the nozzle mounting plate 11 and the back plate 212.

The tube 219 fits within a circular recess 226 (see FIG. 25) in a spherical end surface of the plug 222 and a circular recess 227 (see FIG. 24) in a spherical end surface of the plug 223. A rubber boot or gasket 228 (see FIG. 20) holds one end of the tube 219 within the recess 226 in the plug 222, and a rubber boot or gasket 229 holds the other end of the tube 219 within the recess 227 in the plug 223.

The tube 219 is formed of a piezoelectric material and polarized so that it vibrates in a radial direction when a voltage is applied thereto. The operating frequency at which the tube 219 is electrically excited is the frequency at which the droplets are to be produced.

An electrode 230 extends through a passage 231 in the end plate 217 and a passage 232 in the plug 223. The electrode 230 is electrically connected to the inner cylindrical surface of the tube 219 so that the tube 219 is electrically connected to an AC source 233 of power.

The ink cavity 220 has pressurized, conductive ink supplied thereto from a pressurized source through a connecting plug 234 (see FIG. 19) and a passage 235 (see FIG. 23) in the end plate 215 to an annular passage or cavity 236, which communicates with a plurality of passages 237 (see FIG. 20)

in the plug 222. As shown in FIG. 25, there are four of the passages 237 equally angularly spaced about the circumference of the plug 222. Thus, the pressurized ink is easily supplied to the ink cavity 220.

Whenever it is desired to flush the ink cavity 220, the pressurized ink flows from the ink cavity 220 through a plurality of passages 238 in the plug 223. As shown in FIG. 24 there are four of the passages 238 equally angularly spaced about the circumference of the plug 223.

The passages 238 communicate with an annular passage or cavity 239 in the end plate 217. The annular passage or cavity 239 communicates through a passage 240 (see FIG. 22) in the end plate 217 and a connecting plug 241 to an ink reservoir or the like connected to the suction side of the pump. This flow path from the ink cavity 220 (see FIG. 20) is normally blocked.

An O-ring 242 is mounted in an annular groove in the entry end plate 215 and in surrounding relation to the annular passage or cavity 236. This prevents leakage.

The exit end plate 217 has a first O-ring 243 disposed in an annular groove therein and in surrounding relation to the annular passage or cavity 239 in the same manner as the O-ring 242 in the entry end plate 215 surrounds the annular passage or cavity 236. The exit end plate 217 has a second O-ring 244 mounted in an annular groove therein and in surrounding relation to the passage 231 in which the electrode 230 is disposed. Each of the O-rings 243 and 244 prevents leakage.

The nozzle mounting plate 211 has a focusing cavity 245 (see FIG. 21) therein communicating with the ink cavity 220. The focusing cavity 245 increases the efficiency.

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The nozzle mounting plate 211 has a relatively thin wall 246 (see FIG. 20) at the end of the focusing cavity 245 with a plurality of passages 247 formed therein. Each of the passages 247 is aligned with a nozzle 248 in a very thin nozzle plate 249, which is secured to the nozzle mounting plate 211 by suitable means such as an epoxy, for example. Thus, an array of the nozzles 248 is formed with each of the nozzles 248 having its axis aligned with the axis of one of the passages 247.

It should be understood that the wall 246 is substantially thicker than the nozzle plate 249 but is not so shown in the drawings for clarity purposes. As an example, the wall 246 could have a thickness of twenty mils and the nozzle plate 249 could have a thickness of one mil.

The axis of each of the nozzles 248 is disposed substantially perpendicular to the longitudinal axis of the tube 219 and the longitudinal axis of the ink cavity 220. The longitudinal axis of the ink cavity 220 is preferably coaxial with the longitudinal axis of the tube 219 although they could be parallel.

Accordingly, when the AC source 233 of power is energized at the operating frequency of the tube 219, the tube 219 vibrates radially. This causes each of the ink streams passing through the nozzles 248 to be broken up into droplets at a uniform break-off point, the droplets to be of substantially uniform size, and the droplets to have substantially uniform spacing therebetween.

The ink cavity 220 is preferably formed so that the liquid cavity resonance is at the desired frequency at which the tube 219 is to be operated. This is the operating frequency of the AC source 233 of power applied to the tube

219. Therefore, it is necessary for the spacing between outer surface 250 of the tube 219 and inner surface 251 of the ink cavity 220 to be selected so that the ink cavity 220 is at the resonant frequency at which the tube 219 is vibrated.

The focusing cavity 245 can be tuned to the same resonant frequency as the ink cavity 220. This is accomplished by varying the angle for the focusing cavity 245 and especially its depth.

It is well known that the length of perturbations in a liquid in an annular cavity is described by Bessel functions. If the presence of the focusing cavity 245 is ignored, a good approximation for the resonant modes of the annular ink cavity 220 is that the difference between the inner and outer radii of the cavity 220 is a multiple of a half wave length of the perturbation at a resonant frequency so that $dr = n(w/2)$ where dr is the difference between the inner and outer radii of the annular ink cavity 220, n is the resonant frequency mode, and w is the wave length of the perturbation or pressure wave in the cavity. The wave length w is related to the resonant frequency, f , and the velocity of sound in the material, c , by $c = fw$. When $n = 1$, the lowest resonant frequency mode occurs within the annular ink cavity 220.

As an example, $f = 100$ kHz and $c = 6 \times 10^4$ in/sec (1.524×10^5 cm/sec) when the liquid in the cavity is water (Ink has substantially the same properties as water.). Thus, if $n = 1$ for the lowest mode, the cavity will resonate $dr = dr = w/2 = c/2f = 6 \times \frac{10^4}{2 \times 10^5} = 0.3"$ (0.762 cm). Therefore, a difference of 0.3" (0.762 cm) between the inner and outer radii of the annular ink cavity 220 will enable resonance to occur at a frequency of 100 kHz.

Thus, with knowledge of the desired frequency of vibrations to be applied to the ink stream, the difference between the radius of the outer surface 250 of the tube 219 and the radius of the inner surface 251 of the cavity 220 can be selected. Therefore, the ink cavity 220 will resonate at the desired frequency, and this is the frequency at which the AC source 233 of power is operating.

In the formation of the vibrations in the radial mode, vibrations also are created along the length of the tube 219. These are caused by Poisson's ratio, which is due to the fact that a volume tends to be conserved for a solid so that compensation of volume requires shrinkage in one dimension when another dimension expands. If the vibrations of the tube 219 in its longitudinal or axial direction are coupled into the ink cavity 220, the desired uniform perturbations will not be produced at each of the nozzles 248.

One way of preventing propagation of longitudinal waves in the ink cavity 220 due to the vibrations of the tube 219 in the longitudinal or axial direction is to form each of the plugs 222 and 223 with a spherical end surface. This spherical end surface can destroy the uniform phase of any reflected wave in this longitudinal or axial direction to prevent propagation thereof. Instead of forming the plugs 222 and 223 with spherical end surfaces, the plugs 222 and 223 could be formed with an absorbing surface.

Another means of preventing the vibrations in the longitudinal direction within the ink cavity 220 is to prevent the production of such vibrations by the tube 219. This can be accomplished by forming the tube 219 with a length much smaller than the mean diameter of the tube 219. This will cause the fundamental and all harmonics of the

frequency along the length of the tube 219 to be substantially greater than the operating frequency of the tube 219 in its radial mode.

To obtain this reduction in length relative to the mean diameter of the tube 219 while still having the vibrations produced over the desired length of the ink cavity 220, the tube 219 could be replaced by a right circular cylindrical tube 255 (see FIG. 26), which is formed of a plurality of right circular cylindrical segments 256 of a piezoelectric material with a very thin rubber washer 257 between each pair of the segments 256. For example, each of the segments 256 could have a length of fifty mils, and each of the rubber washers 257 could have a length of five to ten mils. This relative thinness of each of the rubber washers 257 with respect to the segments 256 results in the washers 257 not affecting uniform break up because the nozzles 248 are too far away from the tube 255.

Referring to FIGS. 27-32, there is shown an ink jet head 260 having a main body 261. The body 261 has a hollow cylindrical recess or cavity 262, which is a longitudinal passage, extending therethrough with four converging passages 263, 264, 265, and 266 (see FIG. 29) extending from the recess or cavity 262 to the exterior of the body 261.

An entry end plate 267 (see FIGS. 27 and 28) is secured to one end of the body 261, and an exit end plate 268, which is formed of an electrically insulating material, is secured to the other end of the body 261. The end plates 267 and 268 are secured to the body 261 by suitable means such as screws (not shown), for example.

The tube 219 is disposed within the recess or cavity 262 in the body 261. The tube 219 has one end supported within

in conical shaped plug 275 and its other end supported within a conical shaped plug 276, which is formed of an electrically insulating material. Each of the plugs 275 and 276 is supported within the recess or cavity 262 in the body 261.

The tube 219 fits within a circular recess 277 in the plug 275 and a circular recess 278 in the plug 276. A rubber boot or gasket 279 holds one end of the tube 219 within the recess 277 in the plug 275, and a rubber boot or gasket 280 holds the other end of the tube 219 within the recess 278 in the plug 276.

The electrode 230 extends through a passage 282 in the end plate 268 and a passage 283 in the plug 276. The electrode 230 is electrically connected to the inner cylindrical surface of the tube 219 so that the tube 219 is electrically connected to the AC source 233 of power.

Each of the passages 263 (see FIG. 29), 264, 265, and 266 in the body 261 has its smaller end blocked by a membrane 285, 286, 287, and 288 respectively. The membrane 285 is held against the side of the body 261 by a block 289, which is secured to the body 261 by suitable means such as screws 290, for example. The screws 290 also extend through the membrane 285. The block 289 has a focusing cavity 291 therein and prevented from having liquid communication with the passage 263 and the recess or cavity 262 by the membrane 285.

The block 289 has a relatively thin wall 292 (see FIG. 28) at the end of the focusing cavity 291 with a plurality of passages 293 formed therein. Each of the passages 293 is aligned with a nozzle 294 in a very thin nozzle plate 295,

which is secured to the block 289 by suitable means such as an epoxy, for example. Thus, an array of the nozzles 294 is formed with each of the nozzles 294 having its axis aligned with the axis of one of the passages 293 in the thin wall 292 of the block 289.

It should be understood that the wall 292 is substantially thicker than the nozzle plate 295 but is not so shown in the drawings for clarity purposes. As an example, the wall 292 could have a thickness of twenty mils and the nozzle plate 295 could have a thickness of one mil.

The membranes 286-288 (see FIG. 29) are retained in a similar manner as the membrane 285. Additionally, a plurality of separate focusing cavities 96, 97, and 98 is formed in blocks 299, 300, and 301, respectively, in the same manner as the focusing cavity 291 is formed in the block 289.

The axis of each of the nozzles 294 is disposed substantially perpendicular to the longitudinal axis of the tube 219 and the longitudinal axis of the recess or cavity 262. The longitudinal axis of the recess or cavity 262 is preferably coaxial with the longitudinal axis of the tube 219 although they could be parallel. It should be understood that the nozzles in the nozzle plates 302, 303, and 304 communicating with each of the focusing cavities 296, 297, and 298, respectively, have their axes similarly arranged as the axis of each of the nozzles 294.

Ink is supplied under pressure to the focusing cavity 291 through a passage 305 (see FIG. 28) in the block 289. Whenever it is desired to flush the ink from the focusing cavity 291, the pressurized ink flows from the focusing cavity 291 through a passage 306 in the block 289. The

The passage 306 is blocked except when there is flushing of the focusing cavity 291.

Each of the other focusing cavities 296 (see FIG. 29), 297, and 298 is separately connected to the same or a different pressurized source of ink. Thus, each of the focusing cavities 291, 296, 297, and 298 could have a different colour ink therein.

While the membranes 285-288 prevent the recess or cavity 262 from having liquid communication with the focusing cavities 291, 296, 297, and 298, the material of the membranes 285-288 is selected so that pressure waves created within the recess or cavity 262 by the tube 219 are transmitted to the focusing cavities 291, 296, 297, and 298. Accordingly, membranes 285-288 could be positioned anywhere in the passages 263-266, respectively, or in the focusing cavities 291, 296, 297, 298, respectively, or in the cavity 262. One suitable example of the material of the membranes 285-288 is Mylar.

The recess or cavity 262 in the body 261 has a liquid trapped therein to be responsive to the vibrations produced by excitation of the tube 219. The liquid can be supplied through a connecting plug 307 (see FIG. 27) in the end plate 267 and a passage (not shown) in the end plate 267 and similar to the passage 235 (see FIG. 23) in the end plate 215 to an annular passage or cavity 308 (see FIG. 28) in the end plate 267.

The annular cavity 308 communicates with the recess or cavity 262 through a plurality of passages 309 in the plug 275. As shown in FIG. 28, there are four of the passages 309 angularly spaced about the plug 275. Thus, the liquid is easily supplied to the recess or cavity 262.

Whenever desired, the liquid in the recess or cavity 262 can flow therefrom through a plurality of passages (not shown) in the plug 276. There are four of the passages angularly spaced about the plug 276 in the same manner as the four passages 309 are spaced about the plug 275.

The passages (not shown) in the plug 276 communicate with an annular passage or cavity 311 in the end plate 268. The annular passage or cavity 311 communicates through a passage (not shown) in the end plate 268 and similar to the passage 240 (see FIG. 22) in the exit end plate 217 and a connecting plug 312 (see FIG. 27). The connecting plugs 307 and 312 are blocked except when flushing of the recess or cavity 262 is desired.

The entry end plate 267 has an O-ring 313 (see FIG. 28) disposed in an annular groove therein and in surrounding relation to the annular passage or cavity 308. This prevents leakage.

The exit end plate 268 has a first O-ring 314 disposed in an annular groove therein and in surrounding relation to the annular passage or cavity 311 in the end plate 268 in the same manner as the O-ring 313 in the end plate 267 surrounds the annular passage or cavity 308. The end plate 268 has a second O-ring 315 mounted in an annular groove therein and in surrounding relation to the passage 282 through which the electrode 230 extends. Each of the O-rings 314 and 315 prevents leakage.

As shown in FIG. 29, each of the passages 263-266 is formed to cooperate with the focusing cavities 291, 296, 297, and 298, respectively, as a continuation thereof so that the distance from inner cylindrical surface 316, which defines the recess or cavity 262, of the body 261 to the

nozzle plate 295 is $\frac{w}{2}$. Furthermore, the distance from the outer surface 250 of the tube 219 to the inner cylindrical surface 316 of the body 261 is $\frac{w}{2}$.

Accordingly, when the AC source 233 of power is energized at the operating frequency of the tube 219, the tube 219 vibrates radially in the same manner as described for the embodiment of FIG. 19. This causes each of the ink streams passing through the nozzles 294 (see FIG. 28) and each of the other arrays of nozzles to be broken up into droplets at a uniform break-off point, the droplets to be of substantially uniform size, and the droplets to have substantially uniform spacing therebetween.

The recess or cavity 262 is preferably formed so that the liquid cavity resonance is at the desired frequency at which the tube 219 is to be operated. This is the operating frequency of the AC source 233 of power applied to the tube 219. Therefore, it is necessary for the spacing between the outer surface 250 (see FIG. 29) of the tube 219 and the inner surface 316 of the body 261 to be selected so that the recess or cavity 262 is resonant at the frequency at which the tube 219 is vibrated.

Each of the focusing cavities 291, 296, 297, and 298, including the connecting passages 263, 264, 265, and 266, respectively, can be tuned to the same resonant frequency as the recess or cavity 262. This is accomplished by varying the angle for each of the focusing cavities and especially the depth of each of the focusing cavities.

It should be understood that the membranes 285-288 could be omitted if desired. This would occur where the ink from each of the arrays of the nozzles of the ink head 260 would be the same colour. In such an arrangement, the

passages 305 (see FIG. 28) and 306 in the block 289 and similar passages in the other blocks 299-301 (see FIG. 29) would be eliminated.

Thus, the ink would be supplied through the connecting plug 307 (see FIG. 27), the connecting passage (not shown) in the end plate 267, the annular passage or cavity 308 (see FIG. 28) in the end plate 267, and the passages 309 (see FIG. 28) in the plug 275 to the recess or cavity 262. The feeding from the connecting plug 307 (see FIG. 27) to the passages 309 (see FIG. 29) in the plug 275 would be in the same manner as described for supplying ink through the entry end plate 215 (see FIG. 20) in the ink jet head 210.

Whenever flushing of the recess or cavity 262 (see FIG. 28) is desired, the ink would be removed from the recess or cavity 262 through the passages (not shown) in the plug 276, the annular passage or cavity 311 in the end plate 268, the connecting passage (not shown) in the end plate 268, and the connecting plug 312 (see FIG. 28).

While the present invention has shown and described the tube 219 as being cylindrical, the inner surface 251 of the cavity 220 as being cylindrical, and the inner surface 316 of the body 261 as being cylindrical, it should be understood that such is not necessary for satisfactory operation. It is only necessary that the outer surface of the inner tube 219 and the cooperating inner surface of the outer means, which is defined by the nozzle mounting plate 271 and the back plate 212 or by the body 261, be of substantially the same shape. It is only necessary that the tube 219, when electrically excited, vibrate in a direction substantially perpendicular to the longitudinal axes of the tube 219 and the inner surface (the surface 251 or 316) of the outer means.

While only the tube 219 has been described as being piezoelectric, it should be understood that the outer means, which includes the nozzle mounting plate 211 and the back plate 212 in the embodiment of FIG. 17 and the body 261 of the modification of FIG. 27, could be formed as a hollow right circular cylindrical tube 320 (see FIGS. 33 and 34) and of a piezoelectric material.

In the modification of FIGS. 33 and 34, the outer tube 320 has a portion 321 of its outer cylindrical surface 322 flattened to form a relatively thin wall 323 in the outer tube 320. An annular ink cavity 324 is formed between the outer surface 250 of the tube 219 and inner cylindrical surface 325 of the outer tube 320.

The relatively thin wall 323 has a plurality of passages 326 formed therein in the same manner as the relatively thin wall 246 (see FIG. 20) has the plurality of passages 247 formed therein. Each of the passages 3126 (see FIG. 33) is aligned with a nozzle 327 in a very thin nozzle plate 328, which is secured to the flattened portion 321 of the outer surface 322 of the outer tube 320 by suitable means such as an epoxy, for example. Thus, an array of the nozzles 327 is formed with each of the nozzles 327 having its axis aligned with the axis of one of the passages 326.

It should be understood that the wall 323 is substantially thicker than the nozzle plate 328 but is not so shown in the drawings for clarity purposes. As an example, the wall 323 could have a thickness of twenty mils and the nozzle plate 328 could have a thickness of one mil.

The axis of each of the nozzles 327 is disposed substantially perpendicular to the longitudinal axis of the

tube 219 and the longitudinal axis of the ink cavity 324. The longitudinal axis of the ink cavity 324 is preferably coaxial with the longitudinal axis of the tube 219 although they could be parallel.

In the same manner as the ink cavity 220 of the modification of FIGS. 19-26, the ink cavity 324 is preferably formed so that the liquid cavity resonance is at the desired frequency at which the tube 219 is operated. This also is the operating frequency of the outer tube 320.

The remainder of the structure of the modification of FIGS. 23 and 34 is the same as that shown for the embodiment of FIGS. 19-26 except that the end plates 215 and 217 are circular in cross section.

It should be understood that the outer surface 322 of the outer tube 320 could have a plurality of the flattened portions 321 formed therein in a plurality of positions around the circumference. Each of these flattened portions would have one of the nozzle plates 328 thereon.

While the present invention has shown and described the ink cavity 220, for example, to be resonant throughout the entire cross sectional area of the ink cavity 220, it should be understood that such is not a requisite for satisfactory operation.

If the ink cavity 220 or 262 is not resonant at the operating frequency, it should be understood that the tube 219 could operate at its resonant frequency. It should be understood that the resonant frequency of the tube 219 can be easily determined in accordance with its frequency constant and its mean diameter. With the frequency constant

varying in accordance with the piezoelectric material of the tube 219, selection of a specific piezoelectric material and a specific mean diameter of the tube 219 determines the frequency at which the AC source 233 of power is excited. This is the resonant operating frequency of the tube 219.

Additionally, if the ink cavity 324 is not resonant at the operating frequency, it should be understood that the tubes 219 and 320 could operate at the same resonant frequency. However, in order for the outer tube 320 to be resonant with the tube 219, it would have to be formed of a different piezoelectric material than the tube 219.

An advantage of this invention is that an efficient ink jet head is produced. Another advantage of this invention is that it can be fabricated without the use of adhesive within any cavity subjected to the ink. A further advantage of this invention is that it produces uniform generation of droplets from each of a plurality of arrays of nozzles at the same time. Still another advantage of this invention is that more than one color of ink can be supplied from a single ink jet head with all of the colors of ink having the same frequency.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein.

The present specification contains subject matter in common with European patent application No. , of even date, claiming priority from U.S. patent application Serial No. 958,916, filed 8 November 1978.

BAD ORIGINAL



CLAIMS

1. Apparatus for producing a plurality of similar streams of liquid droplets, said apparatus comprising an elongated chamber formed between two elongated, similar shaped, opposed surfaces on two component parts, said chamber being filled with liquid, in use, one of said component parts having an aperture or apertures therethrough providing or communicating with an elongated array of liquid jet nozzles, each nozzle having its axis perpendicular to the length of the chamber, said one or the other or both of the component parts being formed of piezoelectric material, means through which liquid under pressure can be supplied in use from a pressure liquid source to the nozzles to cause liquid jets to issue therefrom, and electrically energisable means effective when energised to subject the piezoelectric material to an electric field having a periodically fluctuating magnitude such that the separation of the said two surfaces fluctuates periodically in a direction perpendicular to the length of the chamber thereby causing periodic pressure waves in the liquid in the chamber and causing the jet to break-up into similar streams of liquid droplets.
2. Apparatus as claimed in claim 1, in which said other component part comprises an elongated tubular element mounted within a hollow housing providing or comprised in said one component part, said housing having a curved internal surface opposed to the outer surface of the tubular element so that said chamber is of annular or part annular cross-section.
3. Apparatus as claimed in claim 2, in which said tubular member is formed of piezoelectric material and the construction and arrangement is such that it undergoes its principle piezo-electric dimensional changes radially when subject to the electric field. .

4. Apparatus as claimed in claim 2 or 3, in which the housing comprises a cylindrical cavity within which the tubular member is mounted with its axis coincident with or parallel to the axis of the cavity, and in which the housing is formed of piezo-electric material, the construction and arrangement being such that the housing undergoes its principle piezoelectric dimensional changes radially of the cylindrical cavity.

5. Apparatus as claimed in claim 2, 3 or 4, in which the housing is provided by a cylindrical tube,

6. Apparatus as claimed in claim 2, 3 or 4, in which the housing comprises a hollow rectangular, parallelepiped shaped block, the four sides of the block being apertured and the four apertures being aligned with four nozzle plates, each plate having an array of nozzles therethrough.

7. Apparatus for producing a plurality of similar streams of ink droplets including an ink jet head comprising outer means having an inner cylindrical surface; an inner cylindrical tube disposed within the inner cylindrical surface of said outer means and having its outer cylindrical surface spaced from the inner cylindrical surface of said outer means, said inner cylindrical tube having its longitudinal axis substantially parallel to the longitudinal axis of the inner cylindrical surface of said outer means or coaxial therewith; an ink cavity formed between the outer cylindrical surface of said inner cylindrical tube and the inner cylindrical surface of said outer means and having pressurized ink therein; a plurality of arrays of ink jet nozzles communicating through said outer means with said ink cavity and from which the streams of ink droplets are supplied, said plurality of arrays of ink jet nozzles being spaced from each other about the periphery of said outer means; each of

said ink jet nozzles having its axis substantially perpendicular to the longitudinal axis of said inner cylindrical tube; and at least one of said inner cylindrical tube and said outer means being formed of a piezoelectric material and vibrating radially when electrically excited to produce vibrations within the ink in said ink cavity so that a stream of ink droplets is supplied from each of said ink jet nozzles.

8. Apparatus for producing a plurality of similar streams of ink droplets including an ink jet head comprising outer means having an inner cylindrical surface; an inner cylindrical tube disposed within the inner cylindrical surface of said outer means and having its outer cylindrical surface spaced from the inner cylindrical surface of said outer means, said inner cylindrical tube having its longitudinal axis substantially parallel to the longitudinal axis of the inner cylindrical surface of said outer means or coaxial therewith; an ink cavity formed between the outer cylindrical surface of said inner cylindrical tube and the inner cylindrical surface of said outer means and having pressurized ink therein; a plurality of ink jet nozzles communicating through said outer means with said ink cavity and from which the streams of ink droplets are produced; each of said ink jet nozzles having its axis substantially perpendicular to the longitudinal axis of said inner cylindrical tube; and only said outer means being formed of a piezoelectric material and vibrating radially when electrically excited to produce vibrations within the ink in the ink cavity so that a stream of ink droplets is supplied from any of said ink jet nozzles.

9. Apparatus for producing a plurality of similar streams of ink droplets including an ink jet head comprising: inner

means and outer means spaced from each other, said inner means and said outer means having adjacent walls spaced from each other at a substantially constant distance; an ink cavity formed between the adjacent walls of said inner means and said outer means, said ink cavity having pressurized ink therein; a plurality of ink jet nozzles communicating through said outer means with said ink cavity and from which the streams of droplets are produced; and only said outer means being formed of a piezoelectric material and vibrating when electrically excited to produce vibrations within the ink in said ink cavity so that a stream of ink droplets is supplied from any of said ink jet nozzles.

10. Apparatus for producing a plurality of similar streams of ink droplets including an ink jet head comprising outer component means having longitudinal passage therethrough providing an inner surface; an inner component-means disposed within said longitudinal passage in said outer component means, said inner component means having its outer surface of substantially the same shape as the inner surface of said outer component means, said inner component means having its outer surface spaced uniformly from the inner surface of said outer component means, said inner component means having the longitudinal axis of its outer surface substantially parallel to the longitudinal axis of the inner surface of said outer component means or coaxial therewith; an ink cavity formed between the outer surface of said inner component means and the inner surface of said outer component means and having pressurized ink supplied thereto in use; a plurality of arrays of ink jet nozzles communicating through said outer component means with said ink cavity and from which the streams of ink droplets are supplied, said plurality of arrays being spaced from each other about the periphery of said outer component means; each of said ink jet nozzles

having its axis substantially perpendicular to the longitudinal axis of the outer surface of said inner component means; and one of said inner component means and said outer component means being formed of a piezoelectric material and vibrating radially when electrically excited to produce vibrations in the ink within said ink cavity so that a stream of ink droplets is supplied from each of said ink jet nozzles.

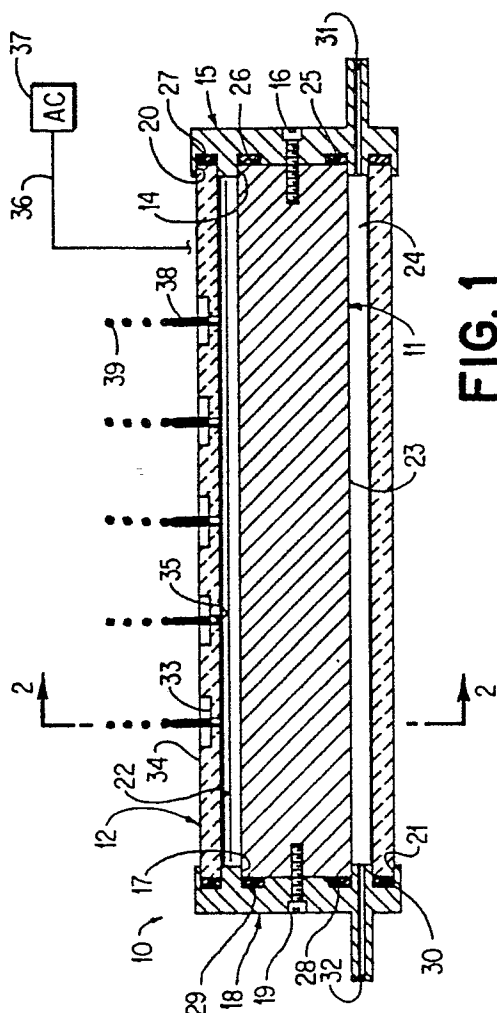


Fig. 1

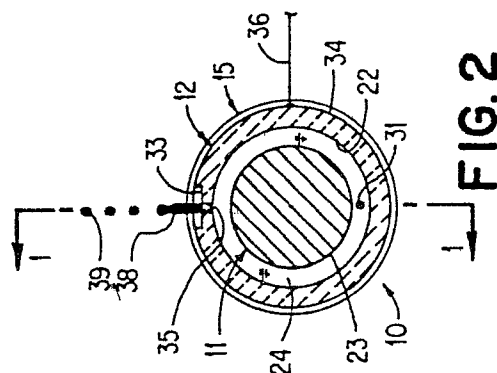


FIG. 2

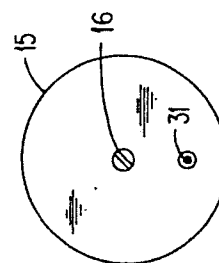


FIG. 3

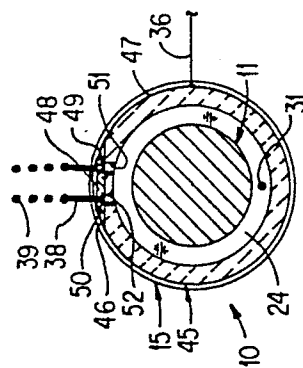
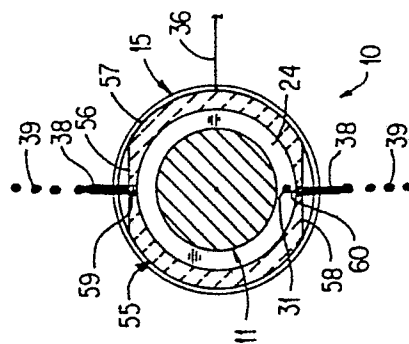


FIG. 4



FILE 5

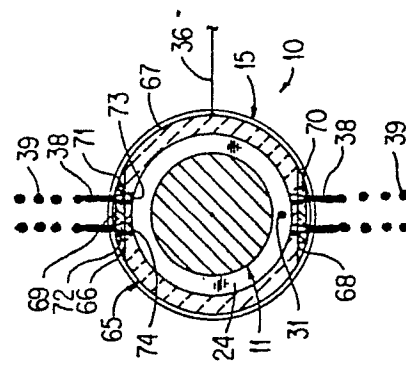
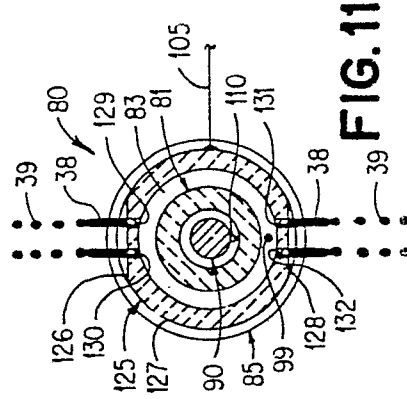
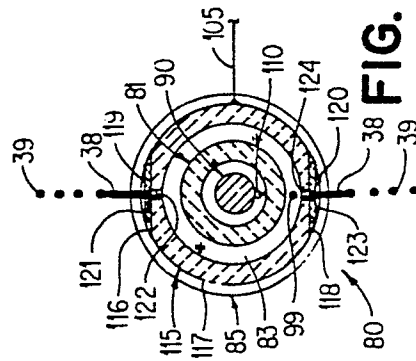
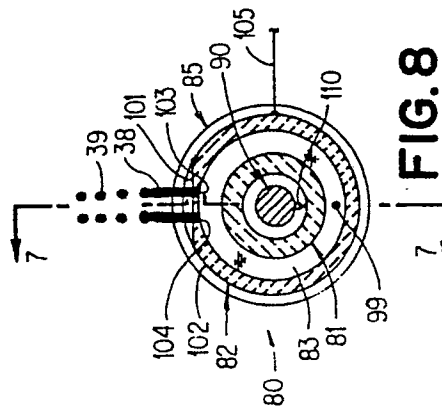
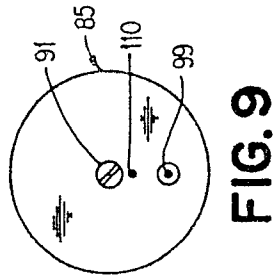
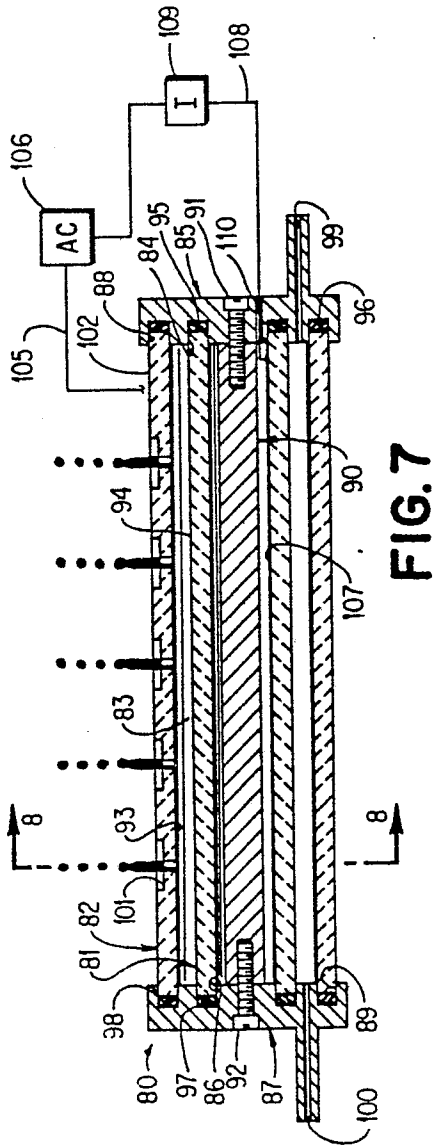
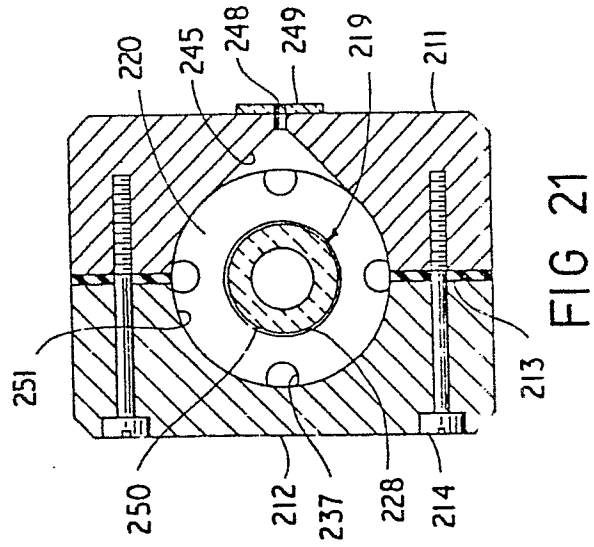
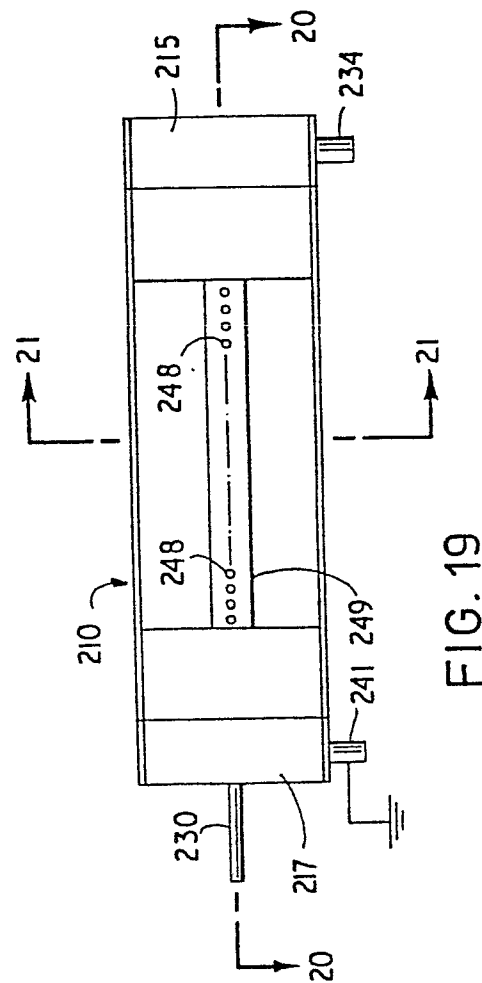
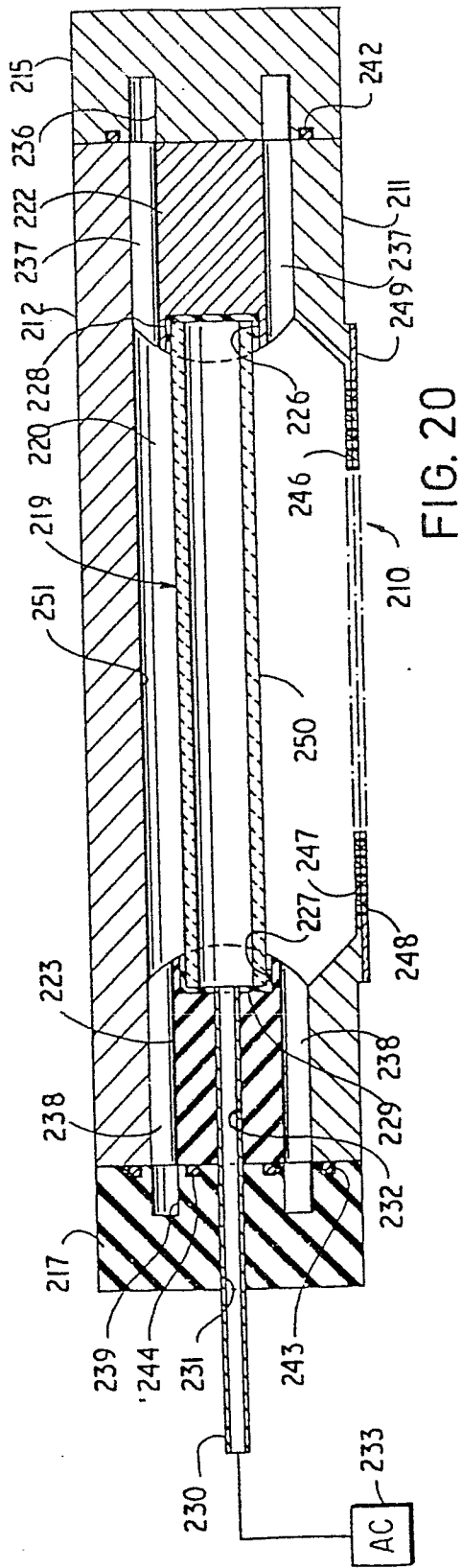


Fig. 6





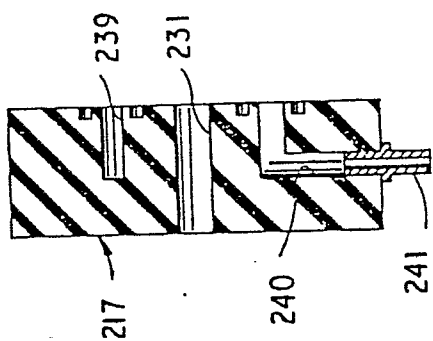


FIG. 22

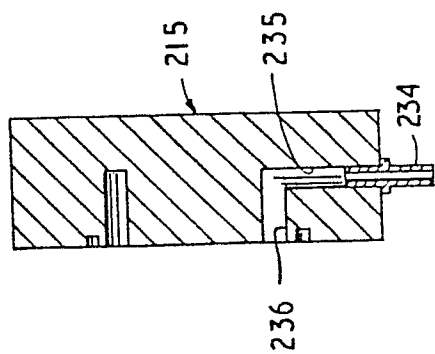


FIG. 23

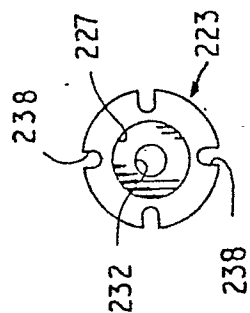


FIG. 24

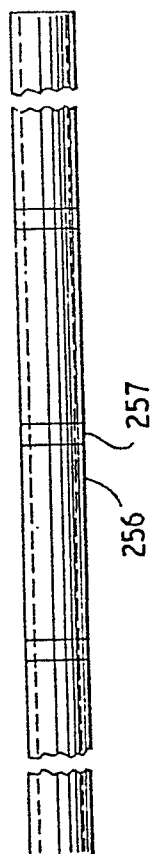


FIG. 25

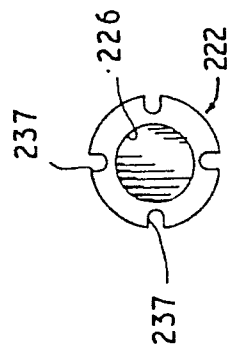


FIG. 26

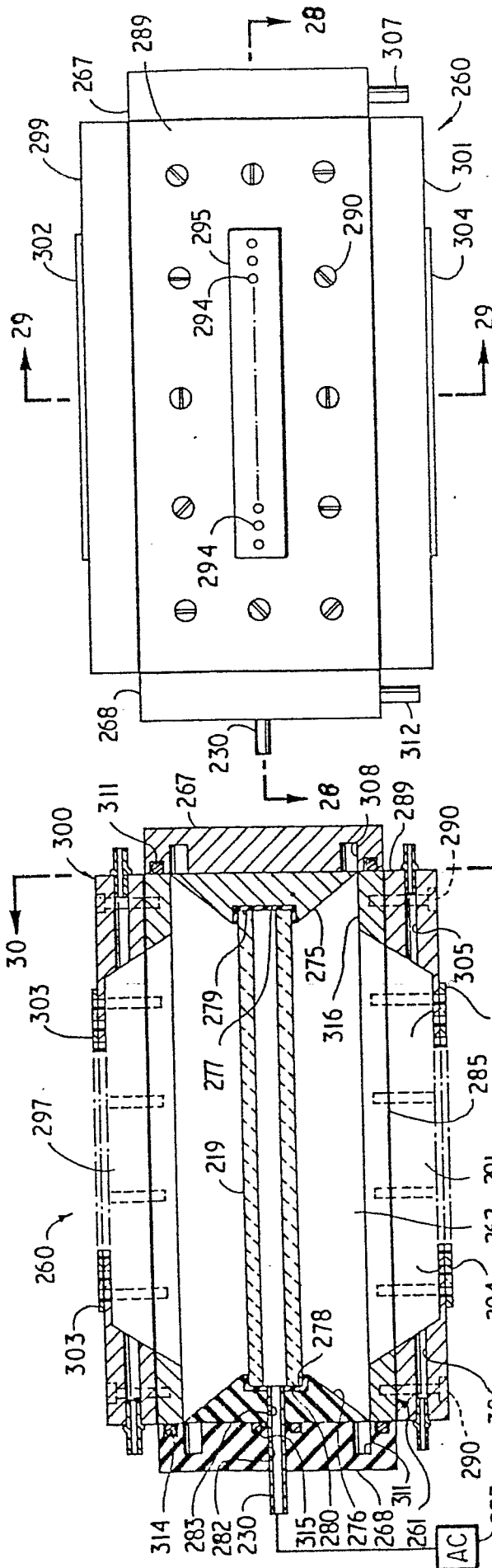


FIG. 27

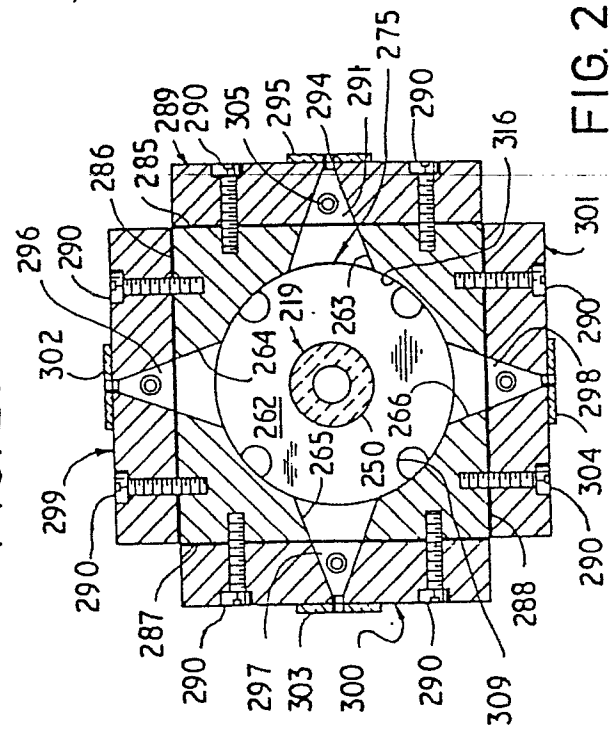


FIG. 29

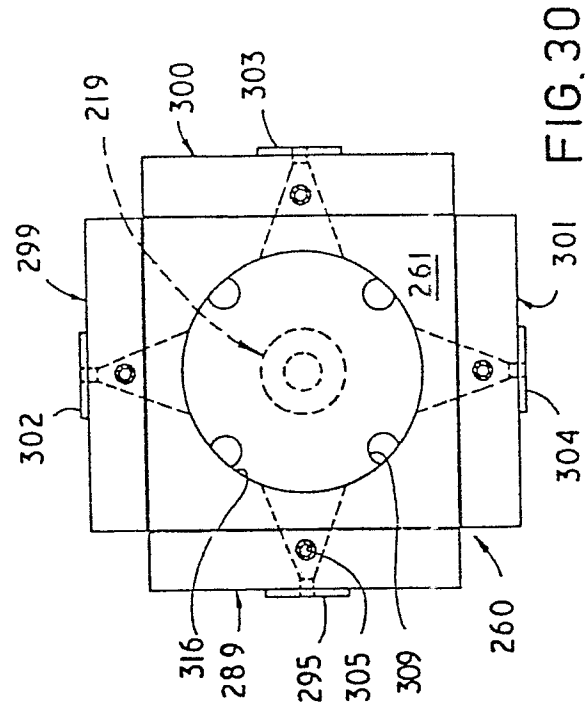
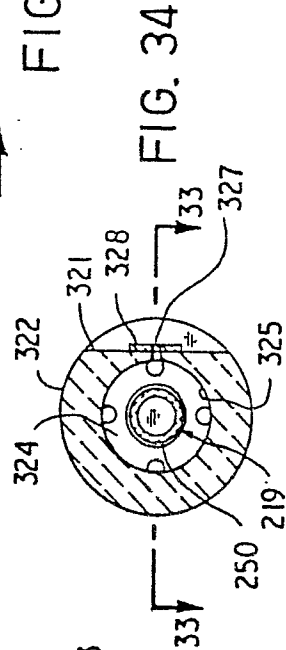
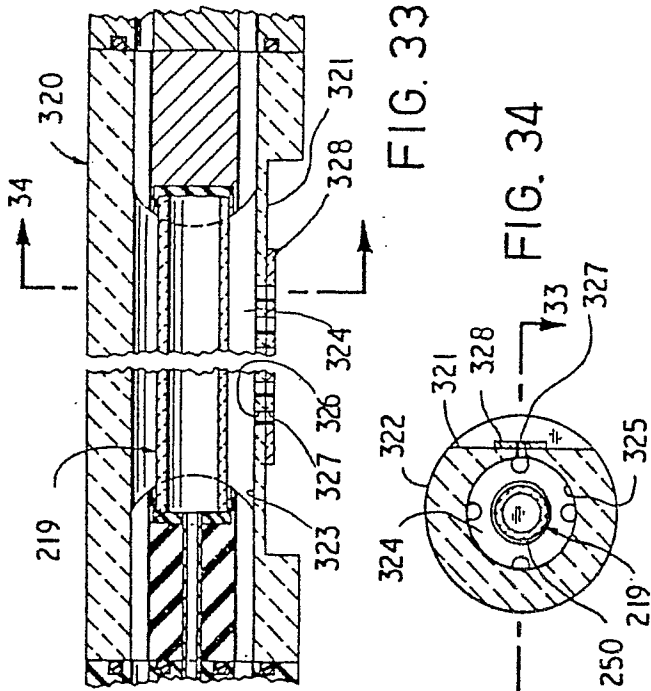
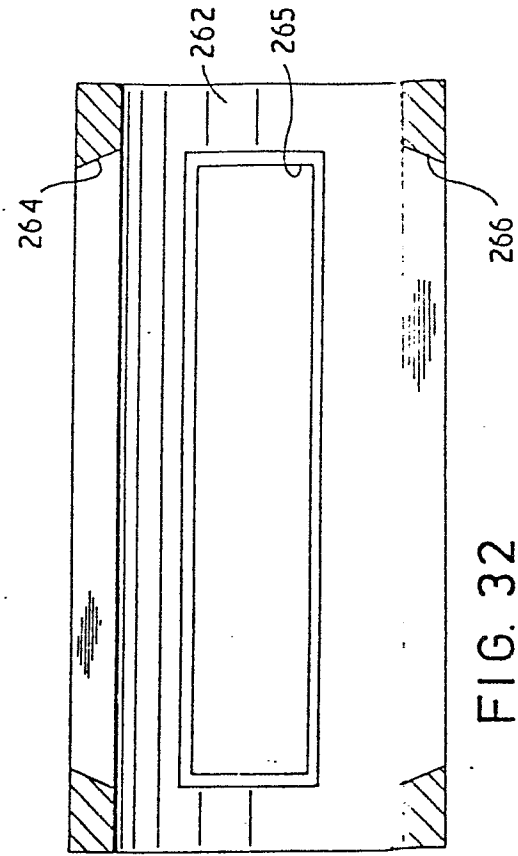
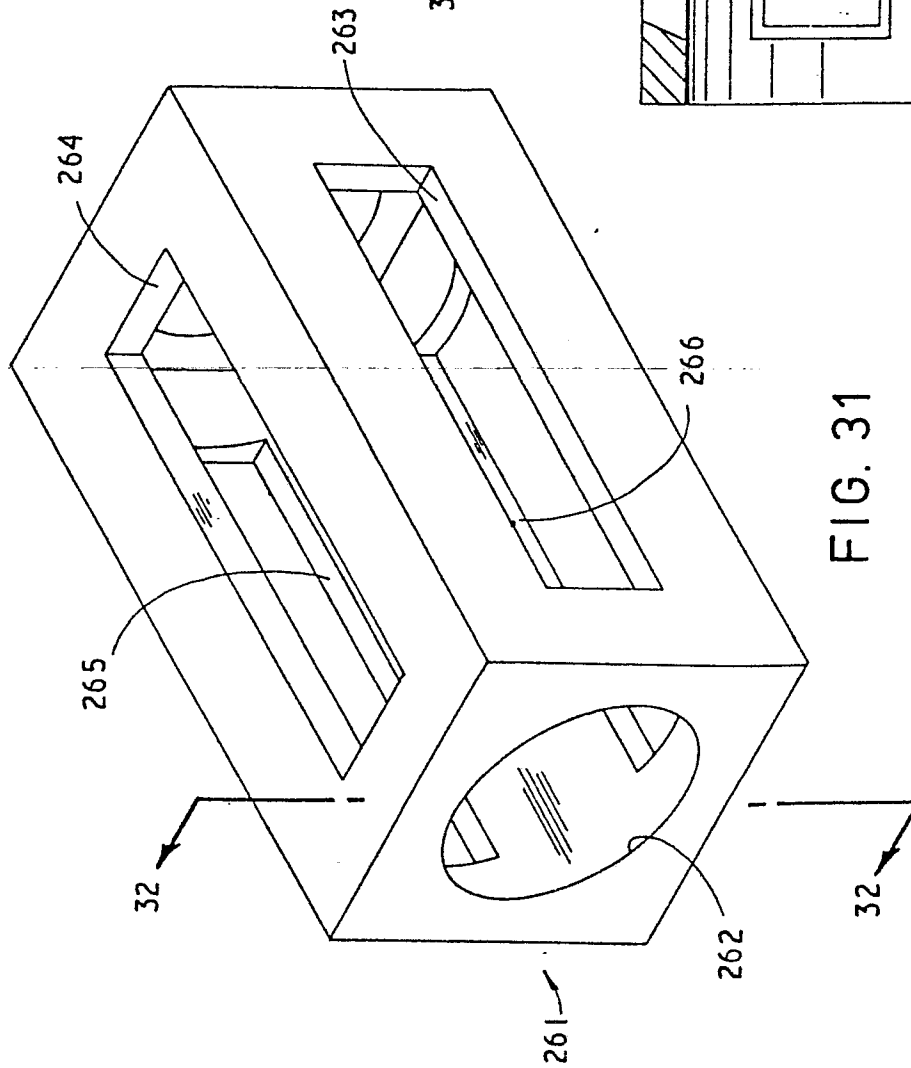


FIG. 30





European Patent
Office

EUROPEAN SEARCH REPORT

0011170

Application number

EP 79 10 4183

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
	IBM TECHNICAL DISCLOSURE BULLETIN, vol. 16, no. 6, November 1973, page 1833 Armonk, New York, U.S.A. J.H. MEIER: "Ink-Jet Head" * --	1,3,4, 5,7-10	B 41 J 3/04
	DE - A - 2 210 512 (OLYMPIA) * Page 3, last paragraph - page 6, paragraph 1; figures * --	1,2,7, 10	
	FR - A - 2 364 695 (RECOGNITION EQUIPMENT INCORPORATED) * Page 5, line 25 - page 6, line 15; page 15, lines 9-24; figures 1,11 * --	1,3,10	TECHNICAL FIELDS SEARCHED (Int.Cl. 3) B 41 J G 01 D
	PATENTS ABSTRACTS OF JAPAN, vol. 2, no. 64, 17th May 1978, page 2042E78 T. HIRATA: "Blast Head for Ink Jet" * Whole abstract * --	9	
A	US - A - 3 750 564 (OLYMPIA) * Whole document * --		CATEGORY OF CITED DOCUMENTS X: particularly relevant A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: conflicting application D: document cited in the application L: citation for other reasons
A	FR - A - 2 312 377 (I.B.M.) * Whole document * ----		
☒ The present search report has been drawn up for all claims			&: member of the same patent family, corresponding document
Place of search The Hague		Date of completion of the search 30-01-1980	Examiner DEBAY