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(54) Title: MACHINE TOOL WINDOW

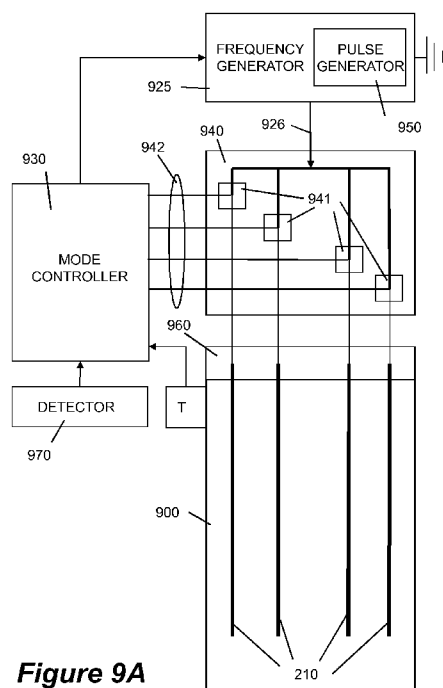


Figure 9A

(57) Abstract: A machine tool window is provided with an apparatus for ultrasonically clearing droplets of cutting fluid from the window. The apparatus comprises a one or more transducers (200, 210) coupled to the window. Each of the one or more transducers is operable to at any selected one of a plurality of different frequencies to generate respective wave-types. A frequency generator (925) is operable to provide ultrasonic drive signals (926) to the transducers for the plurality of different frequencies. A mode controller (930) controls the generator (925) and transducer (200) to apply to the window ultrasonic waves of any selected frequency and wave type from the plurality of different frequencies and wave-types.



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MACHINE TOOL WINDOW

The present invention relates to a window for use in a machine tool and to
5 a machine tool comprising the window.

BACKGROUND

A machine tool uses cutting fluid to lubricate and cool a cutting tool whilst it works on a metal work piece being shaped by the tool. The metal cut from the
10 piece, known as swarf, can be a danger to the operator of the machine and there is also a risk that the cutting tool will break and that too is a risk to the operator. To protect the operator, the whole machine tool, or at least the region around the cutting tool is enclosed in a housing. The housing has a window so the operator can see how the cutting operation is progressing. However, cutting fluid sprays
15 inside the housing and onto the window obscuring the operator's view. Cutting fluid may comprise water and various additives or oil and various additives.

It is known to provide a window in the form of a circular disk which is rotated by an electric motor; cutting fluid which falls onto the window is thrown off due to the rotation of the disc giving the operator a clearer view. In one example a
20 circular frame supports a motor to which the disc is fixed. The periphery of the disc is sealed to the frame to prevent leakage of cutting fluid. Such windows are small, heavy and complicated.

STATEMENT OF INVENTION

25 According to one aspect of the present invention, there is provided a system comprising a machine tool window and an apparatus for clearing droplets of cutting fluid from the machine tool window, the apparatus comprising: one or more transducers coupled to the window each of the one or more transducers being operable to generate ultrasonic waves in the window; and a generator for

providing ultrasonic drive signals to the one or more transducers; whereby, in operation of the system, droplets of cutting fluid are ultrasonically cleared from the window.

In an embodiment of the system each of the transducers is operable to
5 generate ultrasonic waves in the window at any selected one of a plurality of different frequencies and wave-types; and the generator is operable to provide ultrasonic drive signals to the transducer for the plurality of different frequencies; and the system further comprises a mode controller, for configuring the generator and transducer to generating ultrasonic waves of any selected frequency and
10 wave type from the plurality of different frequencies and wave-types.

The system may be configured to operate with one, two or more wave types which are applied to the window in succession.

The system of the present invention allows the use of a window bigger than the rotating disc and has no mechanically moving parts as in the apparatus using
15 the rotating window. The system of the present invention allows the window to be sealed to the machine tool housing more simply because the window is fixed (i.e. it does not rotate).

According to another aspect of the invention, there is provided a method of clearing cutting fluid from a window of a machine tool window, the method
20 comprising generating ultrasonic waves in the window using one or more ultrasonic transducers coupled to the window.

An example of the method uses the apparatus of the embodiment of the system and the method comprises selecting a wave type and corresponding frequency of an ultrasonic wave, causing the generator to generate a drive signal
25 of the selected frequency, and configuring each of the one or more transducers to operate at the selected frequency and produce the selected wave type.

BRIEF DESCRIPTION OF THE DRAWINGS

Various features and advantages of certain examples will be apparent from
30 the description which follows, taken in conjunction with the accompanying drawings, which together illustrate, by way of example only, a number of features, and wherein:

Figure 1 is a schematic diagram of a part of a housing for a machine tool;

Figure 2A is a schematic diagram of an example of a transducer;

Figure 2B is a schematic a side view of the transducer of figure 2A;

Figures 3A-C are schematic illustrations of a transducer emitting ultrasonic waves
5 towards a droplet of cutting fluid on a window;

Figure 4A is a schematic diagram of a side view of a transducer showing an
example of a configuration of electrodes;

Figure 4B is a schematic side view of a transducer showing another example of
a configuration of the electrodes of the transducer;

10 Figure 4C is a schematic illustration showing by way of example a transducer
emitting ultrasonic waves along a surface of a window towards a droplet on the
window for mode conversion;

Figure 4D is a schematic illustration showing by way of example a transducer
emitting ultrasonic waves along the surface of a window to clear a droplet of
15 cutting fluid from the surface of the window by atomization of the droplet;

Figure 4E is a schematic illustration showing by way of example a transducer
coupled to a laminated window;

Figures 5A-B are schematic diagrams of a side view of a transducer showing
other examples of configurations of the electrodes of the transducer;

20 Figure 5C is a schematic illustration showing by way of example a transducer
emitting ultrasonic waves through a droplet of cutting fluid on a window for mode
conversion;

Figure 5D is a schematic illustration showing by way of example a transducer
emitting ultrasonic waves through a droplet of cutting fluid on a window for mode
25 conversion to cause propulsion of the droplet along the window surface;

Figures 6A-B are schematic diagrams of a side view of a transducer showing
further examples of configurations of the electrodes of the transducer

Figure 6C is a schematic illustration showing a transducer emitting ultrasonic
waves towards a droplet on a window to cause the droplet to overcome surface
30 tension with the window surface and to leave the window surface according to an
example;

Figure 6D is a schematic illustration showing by way of example a transducer emitting ultrasonic waves towards a droplet of cutting fluid on a window to cause the droplet to leave the window surface;

Figure 7 is a flow chart of a method of clearing precipitation;

5 Figure 8 a dispersion graph;

Figures 9A-B are schematic diagrams of an example of a transducer and associated circuitry for controlling and operating the transducer;

Figure 10A is a schematic diagram of a machine tool incorporating an example of the present invention; and

10 Figure 10B is an example of a window of the machine tool of Figure 10A.

DETAILED DESCRIPTION

Figure 1 shows part XX of a housing for use with a machine tool to protect an operator of the machine tool. The housing has a window. The window is a
15 sheet of transparent material, which in the following examples is glass, in this example a sheet of toughened glass. The window allows the operator to inspect the cutting operation carried out by the machine tool. It is necessary to clear cutting fluid from the window. Clearing droplets of cutting fluid from the window in accordance with examples of the present invention involves one or more of
20 vibration, propulsion and/or atomization of the droplets from the surface of the window using ultrasonic waves. Illustrative apparatus for clearing droplets of cutting fluid from the window comprises one or more piezoelectric transducers fixed to the glass window and circuitry for operating the transducers to apply ultrasonic waves to the window. The following description describes various
25 modes of operation of the transducer(s). One or more of the modes may be used. In some examples of use of the clearing apparatus only one of the modes is used.

Although the machine tool window of Figure 1 is of toughened glass, alternatively, the window may comprise a laminate layer wherein the laminate
30 layer is sandwiched between a top and bottom layer of glass. For example, the laminate layer may be a polyvinyl butyral (PVB) lamination that is compressed between two layers of annealed glass.

The term “ultrasonic” or “ultrasonically” is used to refer to waves having an ultrasonic frequency. An ultrasonic frequency is considered to have a frequency approximately within the range of 100 kiloHertz (kHz) to 50 MegaHertz (MHz) or higher. The ultrasonic waves are emitted from a transducer coupled to a signal generator. The generator may be a signal generator configured to provide an electrical signal of ultrasonic frequency to the transducer. The transducer is arranged to be driven for generating ultrasonic waves based on the ultrasonic signals from the generator.

In certain examples described herein, a transducer is configured such that it is capable of emitting frequencies within the frequency range of 100 kHz to 4 MHz, or higher frequencies. Clearing a window may be achieved using one or more transducers.

Each of the one or more transducers described herein comprises a plurality of electrodes. The electrodes of each transducer are configured such that each electrode may be operated individually from the other electrodes. As such, the transducer can be configured to operate at a frequency within the range of possible ultrasonic frequencies. The selection of a frequency is achieved by generating an electrical signal of that frequency at the signal generator and applying that signal to a “set” of one or more of the electrodes having a spacing selected to correspond approximately to that natural frequency. The term “a”, “one” or “single” frequency used throughout this description should be interpreted as relating to a central frequency or main frequency emitted from the transducer, since a band of frequencies will be emitted having a bandwidth around a central frequency.

The wave-type of the ultrasonic waves may be selected. The combination of frequency and wave type is referred to as a mode of operation. Examples of different wave-types include surface acoustic waves, Rayleigh waves, Lamb waves and plate waves. Certain ranges of frequencies may have a preferred wave-type, and vice versa. For example, Rayleigh waves may be generated at higher frequencies above approximately 2.5 MHz; Lamb waves may be generated at medium frequencies at approximately 1 MHz to 2.5 MHz; and plate waves may be generated at the lower frequencies below approximately 1 MHz.

The one or more transducers described herein provide the ability to select the frequency and/or wave-type of the ultrasonic waves emitted from the one or more transducers. The operating mode of each transducer may be dynamically selected. The mode of operation relates to the combination of frequency of
5 transducer operation and the wave type. Hence, each transducer is a “multimode” transducer.

Certain examples will now be described with reference to the Figures. Use of the same reference numeral in a set of Figures for a particular feature relates to the same feature.

10 Each electrode of the transducer may be individually connected to the signal generator for independent operation of each electrode. The independent selection of the electrodes to be connected and powered gives the ability to dynamically control the selected frequency or operating frequency of the transducer. For example, the electrodes may be connected individually, or in
15 groups, and some electrodes may not be connected at all. For example, every other electrode along the transducer may be connected to the signal generator wherein alternate electrodes are operated (active) and the remaining electrodes are not operated (inactive). A desired operating frequency of the transducer may therefore be achieved based on selection of the mode of transducer operation,
20 i.e. based on the sets of electrodes selected for operation and the frequency of operation of the frequency generator. The window is cleared by the ultrasonic waves emitted from the transducer for the selected mode of operation, i.e. with the desired frequency or frequencies and/or wave-types at that mode of operation.

25 Figure 2A shows a transducer 200 having a plurality of electrodes 210. Each electrode has its own connector which provides electrical connection a frequency generator and switching circuit as will be described later with reference to Figures 9A and 9B. A shielding strip 230 electrically isolates the electrodes 210 from a ground plane 250. The piezoelectric layer 240 of the
30 transducer may be of a lead zirconate titanate (PZT) material or any other suitable piezo-electric material, for example quartz crystal. The electrodes 210 may have the physical appearance of electrode “fingers” running along the

piezoelectric layer. A further electrode on the opposite side of the piezoelectric layer, from the electrode fingers, is electrically connected to ground 250.

Figure 2B shows a side view of the transducer described with reference to Figure 2A. The further electrode 260 is shown electrically connected to ground 250. When the transducer is operated the signal generator applies a signal of the required frequency to a set of electrodes chosen for that frequency and the coupling of the electrodes to the piezoelectric layer causes the transducer to emit ultrasonic waves. The ultrasonic waves are emitted in a direction that is perpendicular to the electrode fingers, for example in the direction indicated by the arrow 270.

The transducer is coupled to the window by attaching the transducer to a surface of the window. In the example of the machine to window of Figure 1, the transducer(s) are attached to the window on the inside of the housing; i.e. on the side of the window which is wetted by cutting fluid. Attaching the transducer to the window surface may be achieved by chemical bonding, or physical fixing, of the transducer to the window surface. Suitable bonding agents may be commercially available, for example this may include epoxy resin. In use the bonding agent forms a bonding layer between the transducer and window surface. This bonding layer may be thin, have a uniform thickness and be free from gas bubbles, for example being prepared under vacuum conditions. The transducer may be attached to a window with its electrodes facing the window surface, or alternatively attached such that its electrodes face away from the window surface. Having electrodes facing the window increases the wave energy applied to the window but also increases the difficulty of providing electrical connections to the electrodes.

Examples of the mode of operation of the transducer will now be described. In examples described herein the transducer may be configured to operate at any one frequency selected from the range of frequencies from 200 kHz to 4 MHz or higher. The frequency is selectable based on the selected frequency of the electrical signal produced by the signal generator and the selection of particular sets of electrodes of the transducer. For example, in certain examples the sets of electrodes may be configured for a frequency to be selected from any

one frequency around 220 kHz, 570 kHz, 1.39 MHz, 2 MHz or 3.1 MHz. Frequencies around those values may be used; for example 220 kHz +/- 50kHz, 570 kHz +/- 50kHz, 1.39 MHz +/- 100kHz, 2 MHz +/- 100kHz or 3.1 MHz +/- 100kHz .

5 The selection of each of these example frequencies will be described later with reference to Figures 4A/B, 5A/B and 6A/B. It should be noted that the frequencies that may be selected based on using different sets of electrodes described herein should in no way be considered limiting, since it is envisioned that any frequency may be selectable. The selection of any one frequency within
10 the range of frequencies should be possible based on a transducer that is fabricated and configured for the predetermined frequency selection. The operating frequency is then selectable based on the methods described herein by operation of different sets of electrodes. However, the invention is not limited to only the selectable frequencies described herein.

15 Figures 3A-C show examples of the different wave-types that may be ultrasonically emitted from the one or more transducers during operation.

 In the example of Figure 3A, a transducer 300 is bonded to the surface of the window 310 by a bonding layer 320, for example epoxy resin. A droplet of cutting fluid 330 may be present on the surface of the window. The transducer
20 is capable of being driven to emit ultrasonic waves that propagate only through the surface of the window. The ultrasonic waves in this example are surface acoustic waves, such as Rayleigh waves 340. The Rayleigh waves emitted from the transducer may be generated at higher frequencies above approximately 2.5 MHz. The Rayleigh waves propagate along the surface of the window towards
25 the droplet of cutting fluid. Since the ultrasonic waves are coupled to the surface of the window when they arrive at the droplet(s) of cutting fluid the ultrasonic waves "see" the droplet of cutting fluid and energy is transferred from the ultrasonic waves to the droplet of cutting fluid to clear the droplet of cutting fluid from the window surface. High frequency ultrasonic waves possess more energy
30 than low frequency ultrasonic waves. Atomisation of the droplet(s) of cutting fluid on the surface of the window is achieved by efficient transference of the higher energies of the ultrasonic waves, with higher frequencies, to the droplet(s) of

cutting fluid. In this example, the droplet of cutting fluid may be cleared by the process of atomisation or propulsion. The droplet of cutting fluid may be atomized to completely or partially remove it from the surface of the window. If partially atomized the remaining droplet of cutting fluid may be cleared by the further process of propulsion or vibration. For example, the droplet of cutting fluid may be propelled along the surface of the window to move the droplet of cutting fluid away from obstructing a clear view through the window. The foregoing description of Figures 3A and 3B assumes for ease of explanation that Rayleigh and Lamb waves exist at different frequencies. However they coexist; Rayleigh waves being predominant at higher frequencies and Lamb waves at lower frequencies. As frequency increases from low frequency, the wave-type progressively changes from Lamb waves to Rayleigh waves.

In the example of Figure 3B, the ultrasonic waves emitted from the transducer are Lamb waves. The Lamb waves propagate along a surface of the window. The Lamb waves emitted from the transducer in this example may have a frequency between approximately 1 MHz to 2.5 MHz. The Lamb waves propagating along the window surface to which the transducer is coupled may have a larger amplitude than the Lamb waves propagating along the opposite surface of the window. The Lamb waves propagating at both window surfaces may be in phase or out of phase, for example the Lamb waves may be symmetric or anti-symmetric waves. More energy is delivered to the Lamb waves at the transducer surface than is delivered to the Lamb waves on the opposite window surface. Therefore, most of the ultrasonic wave energy emitted from the transducer propagates through the surface of the window upon which droplets of cutting fluid may be present. In this example, the droplets of cutting fluid may be removed by propulsion of the droplets of cutting fluid along the surface of the window. If enough energy is transferred from the Lamb waves to the droplets of cutting fluid it may be possible to clear the droplets of cutting fluid by atomisation of the droplets.

In the example of Figure 3C, the ultrasonic waves emitted from the transducer are plate waves. The frequency of the plate waves emitted from the transducer in this example may have a relatively low frequency below

approximately 1 MHz. The plate waves travel mainly through the body of the window. The plate waves having lower frequencies possess less energy than the high frequency ultrasonic waves and therefore plate waves may only vibrate droplets of cutting fluid on the surface of the window. The vibration of the droplets of cutting fluid on the window surface may cause separate droplets of the cutting fluid to merge and be combined to form relatively larger droplets.

The machine tool window of Figure 1 is mounted vertically or inclined at a small angle to the vertical. Thus propulsion and vibration of droplets is configured to act downwardly aided by gravity in examples of the invention. Propulsion alone or vibration alone or a combination of propulsion and vibration may be sufficient to clear droplets from the window without atomisation.

The examples of Figures 3A-C show only one transducer coupled to the window surface, however any number of transducer may be coupled to the window surface. The one or more transducers may be coupled near the edge of the window or in a peripheral region of the window.

It should be understood that there will be a cut-off frequency above which atomisation is achievable due to the higher energies of the ultrasonic waves above the cut-off frequency. Below the cut-off frequency the ultrasonic waves may not possess enough energy for atomisation, however they may possess enough energy for propulsion of the droplet of cutting fluid (s) along the window surface. Further there will be a further cut-off frequency below which propulsion of the droplet(s) of cutting fluid is not achievable, however vibration of the droplet(s) of cutting fluid is possible. The cut-off frequency for atomisation, propulsion or vibration may depend upon the size and/or composition of the droplet(s) of cutting fluid. By way of example, consider droplets of cutting fluid on the surface of the window: smaller droplets will have a larger surface area to volume ratio (in comparison to larger droplets which have a smaller surface area to volume ratio), hence the smaller droplets have a larger surface tension. Therefore smaller droplets require larger amounts of energy (from higher ultrasonic frequencies) to overcome surface tension before propulsion or atomisation may be achieved, i.e. higher ultrasonic frequencies may be required

to atomize and remove smaller droplets in comparison to larger droplets which may require less energy for atomisation to occur.

The surface of the window may be treated, for example by applying an optional coating that modifies the surface tension between the liquid deposit and the window surface. Preferably the machine tool window is coated with a coating
5 which tends to repel the cutting fluid. For example the coating reduces surface tension. For water based cutting fluid a hydrophobic coating may be used. The coating is preferably resistant to abrasion. Such a coating which tends to repel cutting fluid and is resistant to abrasion is known.

10 As described, the electrodes of each transducer are configured such that each electrode may be operated independently from the other electrodes. The selection of a frequency and/or wave-type is achieved by operation of different “sets” of the electrodes. For example, different combinations of the electrodes may be selectively operated and some of the electrodes may optionally not
15 operate. If an electrode is chosen for operation then a signal from the frequency generator is applied between the chosen electrode and ground; the remaining electrodes may electrically float. By way of example, if only half of the electrodes are operated, then the “set” will include only half of the total available electrodes of which are operating. As will be discussed below, the electrodes which would
20 otherwise float may receive the signal from the frequency generator shifted by 180 degrees in phase.

Figures 4A-B show example modes of operation or configurations of electrode sets in a transducer, for achieving atomisation of a droplet of cutting fluid on a window surface. In these examples, the configurations cause the
25 transducer to emit surface acoustic waves or Rayleigh waves. The ultrasonic waves emitted from the transducer for these electrode configurations may have a frequency above approximately 2.5 MHz.

In the example of Figure 4A, the transducer 400 comprises a plurality of electrodes 405, 410. The electrodes are adjacent to a piezoelectric layer 415, for example PZT material. On the opposite side of the piezoelectric layer to the
30 electrodes 405, 410 is a further electrode 420 electrically connected to ground 425. In operation, some electrodes 405 are connected to the signal generator,

whilst other electrodes 410 may not be connected to the signal generator. The set of electrodes 410 that are connected may be operated to generate ultrasonic waves with a frequency above 2.5 MHz.

Certain physical parameters within the transducer may be selectively manufactured or fabricated to have predetermined properties. For example, the electrodes may be designed for the transducer to operate at predetermined or selected frequencies. For example, the width of each electrode and the gap or spacing between consecutive electrodes are design parameters upon which a particular frequency may depend. The transducer electrodes may be designed such that operation of different sets of electrodes causes the transducer to emit ultrasonic waves at predetermined frequencies. For example, the transducer shown in Figure 4A comprises twenty-eight independent electrodes. Each of the twenty-eight electrodes 405, 410 shown in Figure 4A may have a width of 0.4 millimeters (mm) with an electrode gap or spacing between the electrodes of 0.1 mm. For generating a wave having a frequency of around 3.1 MHz, a set of 14 alternate ones of the 28 electrodes 410 are connected to the signal generator to receive a signal having a frequency of around 3.1 MHz.

Figure 4B shows a transducer 400 (as similarly described in Figure 4A), in which the electrodes 410 receive a signal of a first frequency and phase and the intervening electrodes 405 receive a signal of the same frequency but with a 180 degree phase shift compared to electrodes 410. This configuration allows for an electrical field 430 to be set up between adjacent electrodes 410, 405. This allows for the additional electric field to cause the piezoelectric layer of the transducer to become more active resulting in higher displacements of the transducer, i.e. higher amplitude ultrasonic waves to be emitted. This configuration may improve the operating efficiency of the transducer and/or increase the energy transferred to droplets of cutting fluid on a window surface.

The examples of Figures 4C-E correspond to the example described with reference to Figure 3A. A transducer 400 is bonded by a bonding layer 435 to the surface of a window 440. The transducer may be the transducer described in Figures 4A-B and emit ultrasonic waves having a frequency above 2.5 MHz. The ultrasonic waves emitted from the transducer during operation in the

examples shown in Figures 4C-EF are surface acoustic waves or Rayleigh waves. The ultrasonic waves 445 emitted from the transducer are coupled to the window and propagate along the surface of the window. A droplet of cutting fluid 450 present on the window surface may be encountered by the ultrasonic waves propagating along the window surface. On meeting the droplet, energy from the ultrasonic waves is then transferred to the droplet. This energy transfer may be based on mode conversion. The mode conversion may be stronger for higher frequencies than for lower frequencies. Mode conversion is an energy transfer process in which a mechanical wave such as an ultrasonic wave is coupled into a substance, for example a droplet of cutting fluid on the window surface, and longitudinal waves 455 are transmitted into the substance. As such, the amplitude of the ultrasonic waves incident on the droplet of cutting fluid will decrease as energy is transferred. The longitudinal waves transmitted into the substance have the effect of exerting pressure 460 on the inner surface of the substance such that it may cause the substance to be propelled along the surface on which it sits or cause the substance to be atomized.

Figure 4D shows an example in which the droplet of cutting fluid on the surface of the window is completely atomized 465. Therefore, the window is cleared. The window is cleared by atomisation of the droplet of cutting fluid.

The machine tool window may be laminated, although that is not essential to the present invention. Figure 4E shows an example in which the transducer is coupled to a laminated window. The transducer may be coupled to the window in a peripheral region or edge of the window. The transducer may be hidden from view beneath a rubber seal surrounding the window. The laminated window may comprise a laminate layer 470 sandwiched between a top 440 and bottom 475 layer of glass. During operation of the one or more transducers attached to the surface of the window, may be configured to emit ultrasonic waves that propagate only through the surface 480 of the top layer of glass 440. In this example, since the ultrasonic waves propagate substantially only through the top layer of glass, the ultrasonic waves do not propagate through the laminate layer. This is beneficial because no ultrasonic wave energy is "lost" into the laminate layer which can otherwise cause strong absorption of the ultrasonic

waves. Configuring the transducer to emit only surface acoustic waves has the advantage of improving the efficiency of clearing the window because attenuations in the laminate layer are avoided.

Figures 4C-E above have been described in relation to a transducer capable of emitting frequencies above approximately 2.5 MHz. The higher frequencies emitted may generate surface acoustic waves such as Rayleigh waves for clearing the window by atomisation of droplets of cutting fluid on the window surface. The following section will describe other example modes of operation for the transducer, for different electrode configurations.

Figures 5A-B show example modes of operation or configurations of electrode sets in a transducer, for achieving propulsion of a droplet of cutting fluid on a window surface. In these examples, the electrode configurations may cause the transducer to emit waves that may have a frequency in the range of approximately 1 MHz to 2.5 MHz. The ultrasonic waves emitted from the transducer may be Lamb waves.

Figures 5A-B show different example modes of operation for the transducer 500. Each of the Figures 5A-B relate to different electrode configurations. The transducer 500 comprises a plurality of electrodes 505, 510. The electrodes are on a piezoelectric layer 515. On the opposite side of the piezoelectric layer to the electrodes 505, 510 is a ground electrode. In operation, some electrodes 505 may not be connected to the signal generator, whilst other electrodes 510 are connected to the signal generator to receive a signal of selected frequency. The set of electrodes 510 that are connected are operated receive a signal of, and to generate ultrasonic waves with, a frequency in the range of approximately 1 MHz to 2.5 MHz. The electrodes of set of electrodes 510 of Figure 5A and in 5B are spaced to have a natural frequency in that range.

The transducer shown in the examples of Figures 5A-B comprises twenty-eight independent electrodes. Each of the twenty-eight electrodes 505, 510 may have a width of 0.4 millimeters (mm) with an electrode gap or spacing between the electrodes of 0.1 mm. In the example of Figure 5A, the set of electrodes 510 connected to the signal generator comprises ten electrodes, such that pairs of remaining electrodes are left unconnected in between each of the connected

electrodes. This electrode configuration or mode of operation can be used to generate ultrasonic waves having a frequency of around 2 MHz. The transducer shown in the example of Figure 5B similarly comprises twenty-eight independent electrodes. The electrodes shown are generally connected to the signal generator in consecutive pairs along the piezoelectric layer (apart from the electrodes either end of the piezoelectric layer). This electrode configuration or mode of operation can be used to generate ultrasonic waves having a frequency of around 1.39 MHz. The electrodes which float in Figures 5A and 5B may alternatively receive a signal of the selected frequency but shifted in phase by 180 degrees relative to the electrodes 510.

The examples of Figures 5C-D correspond to the example described with reference to Figure 3B. A transducer 500 is bonded by a bonding layer 530 to the surface of a window 535. The transducer may be the transducer described in Figures 5A-B and emit ultrasonic waves having a frequency in the range of approximately 1 MHz to 2.5 MHz. The ultrasonic waves emitted from the transducer during operation in the examples shown in Figures 5C-D are mainly Lamb waves. The ultrasonic waves 540, 545 emitted from the transducer propagate along the surfaces of the window. The ultrasonic waves are coupled to the window surfaces. A droplet of cutting fluid 550 present on the window surface may be encountered by the ultrasonic waves propagating along the window surface to which the transducer is attached. Figure 5C shows ultrasonic waves propagating through the droplet of cutting fluid in which energy from the ultrasonic waves is transferred to the droplet of cutting fluid, for example by mode conversion. Longitudinal waves 555 are transmitted into the droplet of cutting fluid. The longitudinal waves transmitted into the substance have the effect of exerting pressure 560 on the inner surface of the substance.

Figure 5D shows the effect of the ultrasonic waves incident on the droplet of cutting fluid. The ultrasonic waves incident on the droplet of cutting fluid cause the substance to be propelled along the window surface. The direction of propulsion 565 may be in the same direction as the ultrasonic wave propagation. When the droplet of cutting fluid is propelled along the window surface the shape of the droplet of cutting fluid may change. For example, the droplet of cutting

fluid may have a trailing end 570 and a leading edge 575 that may have different contact angles with the window surface. For example, the trailing end 570 may have a larger contact angle with the window surface in comparison to the leading edge 575. The ability to propel the droplet of cutting fluid along the window surface allows the window to be cleared 580.

Once the droplet of cutting fluid is propelled along the surface, a change in the contact angle of the trailing end with the window surface may change the coupling efficiency of the ultrasonic waves into the droplet of cutting fluid. Hence, once propulsion begins it may be necessary to alter the mode of operation of the transducer to modify the frequency of the ultrasonic waves emitted to maintain propulsion of the droplet of cutting fluid.

The following section will describe other example modes of operation for the transducer, for different electrode configurations.

Figures 6A-B show example modes of operation or configurations of electrode sets in a transducer, for achieving vibration of a droplet of cutting fluid on a window surface. In these examples, the electrode configurations may cause the transducer to emit waves which have a frequency below approximately 1 MHz or between 200kHz and 1MHz. The ultrasonic waves emitted from the transducer for these electrode configurations may be mainly plate waves or vibrational waves.

Figures 6A-B show different example modes of operation for the transducer 600. Each of the Figures 6A-B relate to different electrode configurations. The transducer 600 comprises a plurality of electrodes 605, 610. The electrodes sit adjacent to a piezoelectric layer 615. On the opposite side of the piezoelectric layer to the electrodes 605, 610 is a ground electrode 620 that is electrically connected to ground 625. In operation, some electrodes 605 may not be connected to the signal generator, whilst other electrodes 610 may be connected to the signal generator. The set of electrodes 610 are connected to receive a signal of, and to generate ultrasonic waves with, a frequency in the range 200 kHz to approximately 1 MHz. The electrodes of set of electrodes 510 of Figure 5A and in 5B are spaced to have a natural frequency in that range.

The transducer shown in the examples of Figures 6A-B comprises twenty-eight independent electrodes. Each of the twenty-eight electrodes 605, 610 may have a width of 0.4 millimeters (mm) with an electrode gap or spacing between the electrodes of 0.1 mm. In the example of Figure 6A, the set of electrodes 610 connected to the signal generator comprises eighteen electrodes, these are connected in electrode groups of “connect 4/miss 4/connect 5/miss 2/connect 5/miss 4/connect 4” electrodes as indicated 630, 635, 640, 645, 650, 655, 660 respectively. This electrode configuration or mode of operation can be used to generate ultrasonic waves having a frequency of around 570 kHz. The transducer shown in the example of Figure 5B similarly comprises twenty-eight independent electrodes with the set of electrodes 610 connected to the signal generator comprising eighteen electrodes. The electrodes shown are connected in electrode groups of “connect 8/miss 12/connect 8” electrodes along the piezoelectric layer as shown 665, 670, 675 respectively. This electrode configuration or mode of operation can be used to generate ultrasonic waves having a frequency of around 220 kHz.

The examples of Figures 6C-D correspond to the example described with reference to Figure 3C. A transducer 600 is bonded by a bonding layer to the surface of a window. The transducer may be the transducer described in Figures 6A-B and driven to emit ultrasonic waves having a frequency below approximately 1 MHz. The ultrasonic waves emitted from the transducer during operation in the examples shown in Figures 6C-D are plate waves. The ultrasonic waves 680 emitted from the transducer propagate through the body of the window. This could be related to a resonant condition of the window. This causes the window to vibrate.

In the example of Figure 6C, a droplet of cutting fluid 685 is shown to be present on the window surface. Vibration of the window allows for the surface tension between the droplet of cutting fluid and the window surface to be overcome. The droplet of cutting fluid on the vibrating window surface may therefore be “kicked” or “ejected” 690 off the window surface. Therefore the droplet(s) of cutting fluid leave the window surface and the ultrasonic waves clear the window. Further, an air flow 695 over the surface of the window may

assist in the clearing of the window. This may be achieved by moving the droplet(s) of cutting fluid further away from the window surface therefore reducing the chances that the droplet(s) of cutting fluid may land back onto the vibrating surface.

5 The example modes of operation described in Figures 4-6 can be used to control the frequencies and wave-types of the ultrasonic waves emitted from the transducer(s), based on different configurations of the electrodes which are electrically connected to the signal generator and on different frequencies of signals produced by the generator. An example method for clearing a window
10 using one or more modes of operation for the transducer will now be described.

Figure 7 is an example flow chart outlining a method 750 for clearing a window using one or more selected modes of transducer operation. At block 710 a mode or sequence of modes of operation is selected. It is possible to select either one mode of operation or a sequence of more than one mode of operation
15 for clearing the window. Since the mode of operation of a transducer is based on the configuration of electrodes in the transducer that are actively connected to the signal generator, in examples of the system only one mode of operation may be operated at any one time for a single transducer. Hence, if more than one mode of operation is required for clearing (780) the window, the modes of
20 operation must be sequentially selected.

For example, if a droplet of cutting fluid is to be cleared from the window surface using two modes of operation, then the first mode of operation selected may be such that the transducer is configured for emitting ultrasonic waves having a frequency at approximately 3.1 MHz, and a second mode of operation
25 selected for configuring the transducer to emit ultrasonic waves having a frequency at approximately 2 MHz. In this example, the two modes of operation for the transducer may be alternated for configuring the transducer to first emit ultrasonic waves at approximately 3.1 MHz and to second emit ultrasonic waves at approximately 2 MHz. Other example frequencies may be used to initiate
30 vibration of the droplets with lower frequencies and then to propel or atomize the droplets with higher frequencies.

The method for clearing the window described in Figure 7 allows for the frequency and wave type (i.e. a mode) of the ultrasonic waves emitted from the transducer to be dynamically controlled or selected. The dynamic selection of the operating frequency of the transducer allows for different frequencies of ultrasonic waves to be emitted from the transducer in a controlled manner to propagate across the window surface, or optionally through the body of the window. A plurality of different modes of operation may be available for a single transducer based on the large number of different combinations of electrode configurations as described hereinabove.

The modes of operation may be selected sequentially using a set time delay in between selections of each mode of operation. For example, the time delay between successive modes of operation may be 5 microseconds, i.e. the frequency of ultrasonic waves emitted from the transducer(s) and the sets of electrodes may be changed every 5 microseconds. The time delay of 5 microseconds is only an example; other time delays could be used for example a few microseconds in the range 1 to 10 microseconds. The delay may be chosen to ensure that the result of one mode on a droplet is still active when the next mode is applied to it.

The detection 760 and selection 710 of the mode(s) of operation may be manual or automatic. For example, an operator of the machine tool may manually select the mode of transducer operation based on visual observations of the droplets of cutting fluid on the window surface. Alternatively, a detection system may be configured to detect the presence of droplets automatically. If detection is automatic at least two transducers are required: a first transducer to act as a transmitter, and a second transducer to act as a receiver. The signal generator and one or more of the transducers used for clearing droplet may be used as the transmitter or an additional, separate, transducer may be used with the clearance signal generator or with an additional signal generator. Detection of droplet may be based on the transmitter emitting ultrasonic waves that are detected at the receiver wherein the ultrasonic waves have a "default" amplitude or signal strength which corresponds to zero droplet on the window surface. If the strength of the signal received at the second transducer varies from the

default signal strength, this may indicate a presence of droplets on the window surface. Where droplets are present on the window surface, energy may be transferred from the propagating ultrasonic waves to the droplets. As such, the ultrasonic waves may undergo attenuation and when the ultrasonic waves reach the receiver at the second transducer, the signal strength will be lower than the default value. Hence, the presence of droplet on the window surface is detected. The level of attenuation may indicate the amount of droplets of cutting fluid on the window surface, or the type of droplets. The amount of droplets detected may be used to automatically select a mode of operation for clearing the window as described.

Figure 8 is a graph 800 modelling dispersion 810 as a function of phase velocity 820 for ultrasonic waves on a glass substrate (i.e. a window). This information is useful for determining the effect that each wave-type will have on a droplet of cutting fluid sitting on the surface of a window. The vertical axis represents phase velocity in meters per second (m/s) and the horizontal axis represents frequency in MHz for glass 3mm thick equivalent to dispersion ($\text{Hz} \times 10^6$) i.e. frequency for a glass substrate 3 mm thick.

In the example of Figure 8, the ultrasonic waves modelled are Lamb waves but the graph may be approximately applied to other wave-types such as plate and Rayleigh waves. The glass substrate modelled is 3 mm thick, which is roughly the thickness of a vehicle window, or top layer of glass in a laminated windscreen. The phase velocity of ultrasonic waves propagating through bulk glass for anti-symmetric Lamb waves is 5654 m/s and for symmetric Lamb waves is 3391 m/s. For a thin sheet of glass or glass substrate, such as for a window the waves may behave differently than for bulk glass and may exhibit surface coupling or plate-wave behavior. The graph represents how the phase velocity or speed of the ultrasonic waves changes with frequency whilst propagating through the glass substrate.

Figure 8 shows that the ultrasonic waves emitted may be first-order waves (first-mode) 830, 835, second-order waves (second-mode) 840, 845, third-order waves (third-mode) 850, 855 or higher-order waves. As shown in Figure 8, the ultrasonic waves are Lamb waves and may be anti-symmetric or symmetric

waves, i.e. out of phase or in phase respectively. The phase velocity for the anti-symmetric waves are shown by 830, 840 and 850. The phase velocity for the symmetric waves are shown by 835, 845 and 855. The frequencies of ultrasonic waves emitted for different configurations of the transducer(s) described herein are indicated on the phase velocity-dispersion relationship for the first-order mode of anti-symmetric waves (830) by 860A, 865A, 870 and 875. The phase velocity of the 570 kHz "plate" waves are shown by 860A; the approximately 1.5 MHz Lamb waves by 865A; and higher frequency "Rayleigh" waves by 870 and 875. There is higher displacement of the transducer for lower values of dispersion, i.e. for plate waves, since the ultrasonic waves emitted for lower dispersion values have longer wavelengths. The wavelengths (λ) of the ultrasonic waves emitted that cross the dotted lines 880, 885, 890, 895 on the graph are: $\lambda = 10$ mm; $\lambda = 4.9$ mm; $\lambda = 2.16$ mm; $\lambda = 1.55$ mm respectively.

For example, the "plate" waves at 570 kHz for the first-mode anti-symmetric waves 860A have a wavelength of 10 mm, and the second-order anti-symmetric waves 860B (at a slightly higher shifted frequency) also have a wavelength of 10 mm. It can be seen that the first-order waves 860A have a slower phase velocity around 2000 m/s compared to the second-order waves which have a faster phase velocity around 8000 m/s.

By way of example, the higher frequency ultrasonic waves 870, 875 that have shorter wavelengths at 2.16 mm and 1.55 mm respectively have a wavelength close to the diameter of a typical water droplet (a few mm). Therefore, these waves are more suitable for atomizing droplets due to strong mode conversion. In contrast, the lower frequency ultrasonic waves 860A that have longer wavelengths at 10 mm will have very weak mode conversion (if any) and not be suitable for atomizing the droplet but may be suitable for simply vibrating the droplets. Of course, there will be a "medium" set of frequencies somewhere in between atomization and vibration that will give rise to a level of mode conversion somewhere between the very weak mode conversion of lower frequencies and strong mode conversion of higher frequencies. This graph helps to pinpoint the frequencies best suited for clearing the window of water droplets or cutting fluid.

22

Example implementations of the multimode transducer(s) and associated circuitry are described herein with reference to Figures 9A and 9B.

Referring to Figure 9A, a transducer, which may be one of many comprises a plurality of electrodes 210 on a piezo-electric substrate as shown in Figure 2
5 for example. Each electrode 210 is connected by a connector 960 to a respective one of a plurality of binary switches 941 of a switch circuit 940. All of the switches are connected to the output 926 of a frequency generator 925. A mode controller 930 controls the frequency generator and the switch circuit. The mode controller controls the frequency of the output signal applied to the
10 switches 941. The mode controller also selects which of the switches are conductive and which are non-conductive thereby selecting the set of electrodes 210 which receive the output signal. The mode controller controls the switches by for example applying binary signals to their control inputs 942. The combination of frequency and set of electrodes selected to receive the output
15 signal defines the selected mode of operation of the transducer as described above.

Figure 9B differs from Figure 9A in that the electrodes 211 which float in Figure 9A receive the output signal 926 of the frequency generator shifted in phase by 180 degrees. For that purpose the frequency generator has a further
20 output 926+180 and an additional switch circuit 940- which selects the other electrodes 211 under the control of the mode controller 930 which has an additional control port 943 for controlling the additional switch circuit 940-. Thus the system of Figure 9B can select any electrode of the transducer to receive the signal 926 or the signal 926 shifted by 180 degrees.

25 The frequency generator may additionally include a pulse generator which pulses the output signal 926 on and off with a desired mark-space ratio to reduce heating of the transducer. The pulsing of the output signal 926 may be controlled by the controller 930. The pulsing may be controlled in dependence on the temperature of the transducer as measured by a sensor T.

30 The selection of the mode may be done manually by an operator, for example the operator of a machine tool, as described above with reference to Figure 7.

The selection of the mode may be done automatically using a detector 970 which detects the amount of cutting fluid on the window, as described above with reference to Figure 7.

Figures 10A and 10B schematically illustrates the clearing apparatus of the present invention installed on a machine tool.

The example of Figure 10A shows a machine tool 1000 having protective housing H containing a machine tool window 1030. Figure 10B shows a plurality of transducers 1010 attached to a peripheral region of the window on the inside of the housing. The transducers are driven to emit ultrasonic waves 1020 that are coupled to the window surface and propagate across the window surface. The direction of propagation in this example is in a direction that is perpendicular to the transducer electrodes. Droplets 10140 on the surface of the window may be cleared according to methods described herein, for example by vibration, propulsion and/or atomisation. The transducers may be arranged along the edge of the window in a linear fashion such that ultrasonic waves may propagate across the entire window surface. The location of attachment of the transducers allow droplets to be cleared from any region of the window surface. The transducers are attached to the window to permit an unobstructed view through the window for the operator of the machine tool. In the example shown the transducers are attached at the top of the window. They may be elsewhere on the periphery of the window.

Figure 10B shows by way of example, one or more of the plurality of transducers 1010 attached to the window acting as transmitters and one or more further transducers 1070 acting as receivers. Ultrasonic waves 1080 propagating across the window are transmitted and received by the transducer(s) 1070. The presence of cutting fluid may thus be detected. Droplets are then automatically cleared from the window as previously described hereinabove. The examples described herein above provide a robust method of clearing droplet of cutting fluid(s) from a window surface. The combination of a transducer having many electrodes and the selection of different combinations of electrodes and frequencies of operation allow a wide selection of modes of operation. The modes may be selected automatically. In the examples described herein, a single

transducer may be dynamically configured to emit ultrasonic waves separately at five different frequencies. However, it is to be understood that many more frequencies may additionally or alternatively be selected.

5 The selection of the modes of operation allows selection of modes in which most of the ultrasonic wave energy emitted from the transducer propagates through the surface of the window upon which droplets of cutting fluid may be present. This allows efficient removal of the droplets for clearing the window surface.

10 The examples of the present invention described above allow the use of a window which is much larger than the rotating disc. The examples have no mechanically moving parts, unlike the rotating disc.

The examples of the present invention described above allow the window to be sealed to the machine tool housing more simply because the window is fixed (i.e. it does not rotate).

15 The window may be of any suitable shape.

The apparatus may be set up to operate with only a single mode of operation for example, vibration or propulsion. Alternatively, the apparatus may be set up to operate with two modes of operation, for example vibration and propulsion which are used in succession.

20 The preceding description has been presented to illustrate and describe examples of the principles described. This description is not intended to be exhaustive or to limit these principles to any precise form disclosed. Many modifications and variations are possible in light of the above teaching.

CLAIMS

1. A system comprising a machine tool window and an apparatus for clearing
5 droplets of cutting fluid from the machine tool window, the apparatus
comprising:

one or more transducers coupled to the window each of the one or more
transducers being operable to generate ultrasonic waves in the window; and

a generator for providing ultrasonic drive signals to the one or more
10 transducers;

whereby, in operation of the system, droplets of cutting fluid are ultrasonically
cleared from the window.

2. A system according to claim 1, wherein

15 each of the transducers is operable to generate ultrasonic waves in the window
at any selected one of a plurality of different frequencies and wave-types; and

the generator is operable to provide ultrasonic drive signals to the transducer
for the plurality of different frequencies; and

further comprising a mode controller, for configuring the generator and
20 transducer to generating ultrasonic waves of any selected frequency and wave
type from the plurality of different frequencies and wave-types.

3. A system according to claim 2, wherein the plurality of different
frequencies are within the frequency range of 200 kHz to 4 MHz.

4. A system according to claim 2 or 3, wherein the or each transducer has a plurality of electrodes and the mode controller is operable to select different sets of electrodes of the transducer for generating ultrasonic waves of different frequencies and wave types.

5

5. An apparatus according to claim 4, wherein the frequency generator is configured to generate in-phase signals of different frequencies and signals of the same frequencies shifted in phase by 180 degrees, and the mode controller is operable to configure the generator to produce a signal of a selected

10 frequency and the same signal shifted in phase by 180 degrees and is operable to configure the electrodes of the transducer such that one set of electrodes receive the signal shifted in phase by 180 degrees and another set receive the in-phase signal.

15 6. A system according to claim 4 or 5, wherein the mode controller comprises a mode selector for selecting a frequency and wave type and a switching circuit for selecting the different sets of electrodes.

7. A system according to claim 4 5 or 6, wherein the mode controller is
20 operable to select different sets of electrodes of the transducer for generating ultrasonic waves at a) a selected frequency in the range 220 kHz +/- 50kHz, b) a selected frequency in the range 570 kHz +/- 50kHz, c) a selected frequency in the range 1.39 MHz +/- 100kHz, d) a selected frequency in the range 2MHz +/- 100kHz, and e) a selected frequency in the range 3.1 MHz +/- 100kHz.

25

8. An apparatus according to claim 3, 4, 5, 6 or 7, wherein the mode controller is arranged to configure the transducer to operate at a particular

27

frequency by selecting a set of electrodes which are spaced part by a distance dependent on the wavelength of a wave of that frequency.

9. A system according to any one of claims 2 to 8, wherein said wave-types
5 comprise surface acoustic waves, Rayleigh waves, Lamb waves and plate waves.

10. A system according to claim 9, wherein the mode controller is operable to
10 configure the generator and transducer to produce waves with frequencies in the range of 2.5 MHz or more.

11. A system according to claim 9 or 10, wherein the mode controller is
operable to configure the generator and transducer to produce waves with
frequencies in the range of 1 MHz to 2.5 MHz.

15

12. A system according to claim 9. 10 or 11, wherein the mode controller is
operable to configure the generator and transducer to produce waves with
frequencies in the range of 100 kHz to 1 MHz.

20 13. A system according to any one of claims 2 to 12, wherein the mode controller is operable to configure the transducer and generator to successively operate at different ones of a plurality of the selected frequencies and wave types.

25 14. A system according to claim 13, wherein the mode controller is operable to change from one configuration of the generator and transducer(s) to another with a time delay between the configurations.

15. A system according to claim 14, wherein the time delay is in the range 1 to 10 microseconds.

5 16. A system according to any preceding claim, wherein the generator is arranged to apply ultrasonic drive signals to the transducer(s) in pulses.

17. A system according to any one of claims 2 to 16, further comprising:

a control system, having a detector arranged to sense ultrasonic waves emitted
10 by one or more of the said transducers for detecting the amount of wave attenuation on the window,

wherein the mode selector is responsive to the detector for selecting the configuration of the generator and transducer in dependence on the detected amount of attenuation.

15

18. A system according to any preceding claim, wherein the, or each, transducer has twenty-eight electrodes each having an electrode width of 0.4 millimeters and a gap between each of the electrodes of 0.1 millimeters.

20 19. A system according to any preceding claim, wherein the one or more transducers are fixed to the surface of the window which, in operation, is inside the machine tool.

20. A system according to any preceding claim, wherein the window is of
25 toughened glass.

29

21. A system according to any preceding claim, wherein the one or more transducers are fixed to a peripheral region of a surface of the window.

22. A system according to claim 21 wherein the plurality of transducers are
5 fixed to the window in a strip along a peripheral region of the window.

23. A system according to any one of claims 19 to 22, wherein the window is coated on the surface which, in operation, is inside the machine tool with a coating which tends to repel cutting fluid.

10

24. A system according to claim 23, wherein the coating is resistant to abrasion.

25. A system according to any preceding claim comprising a plurality of the transducers.

15

26. A machine tool comprising a system according to any one of claims 1 to 25.

27. A method of clearing cutting fluid from a window of a machine tool window, the method comprising generating ultrasonic waves in the window using one or
20 more ultrasonic transducers coupled to the window.

28. A method according to claim 27 of clearing cutting fluid from a window of a machine tool using the apparatus of claim 2 or any one of claims 3 to 21 when dependent on claim 2, the method comprising:

25 selecting a wave type and corresponding frequency of an ultrasonic wave,

30

causing the generator to generate a drive signal of the selected frequency, and configuring each of the one or more transducers to operate at the selected frequency and produce the selected wave type.

- 5 29. A method according to claim 28, wherein each of the one or more transducers comprises a plurality of electrodes and configuring each of the one or more transducers to operate at the selected frequency with the selected wave type comprises selecting a set of the electrodes of the transducer and applying a drive signal of the selected frequency to the selected set.

10

30 A method according to claim 28 or 29, comprising vibrating droplets of cutting fluid on the surface of the window using one selected frequency and wave type, and/or propelling droplets across the surface of the window using another frequency and wave type, and/or atomize droplets on the surface of the
15 window using a further frequency and wave type.

31. A method according to claim 28, 29 or 30, wherein the ultrasonic drive signal is provided to each of the one or more transducers in pulses.

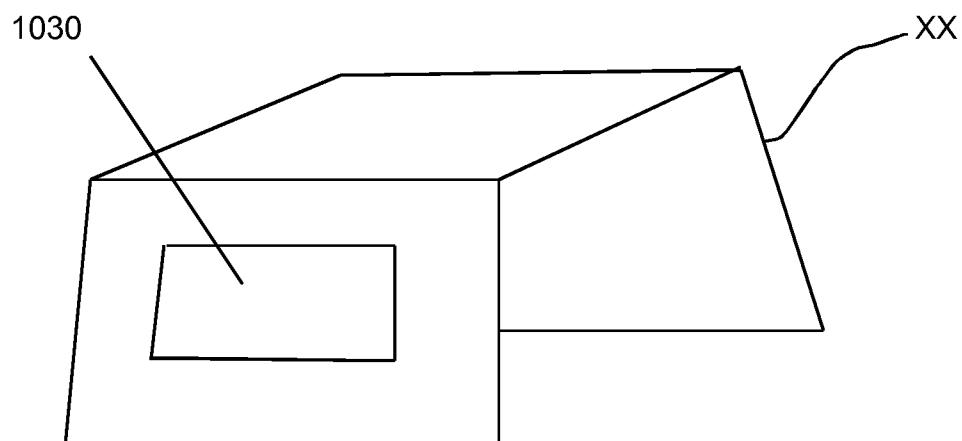
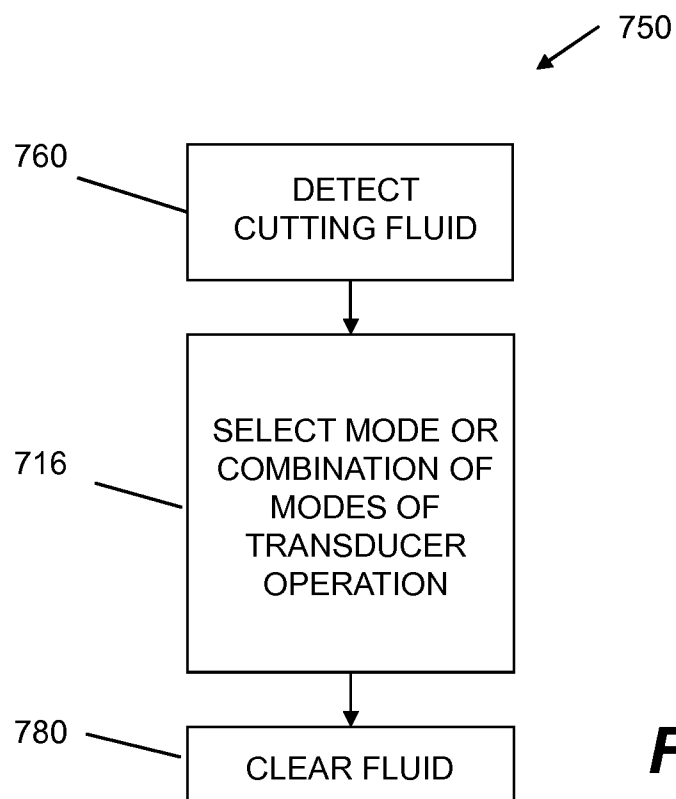
- 20 32. A method according to claim 28, 29 30 or 31, further comprising dynamically switching between different frequencies and wave types.

33 A method according to claim 32, comprising applying a time delay between switching frequencies of 1 to 10 microseconds.

25

34. A method according to any one of claims 28 to 33, wherein the ultrasonic waves propagate substantially only through a surface region of the window to a depth of less than 3 millimeters from the surface of the window.

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**Figure 1****Figure 7**

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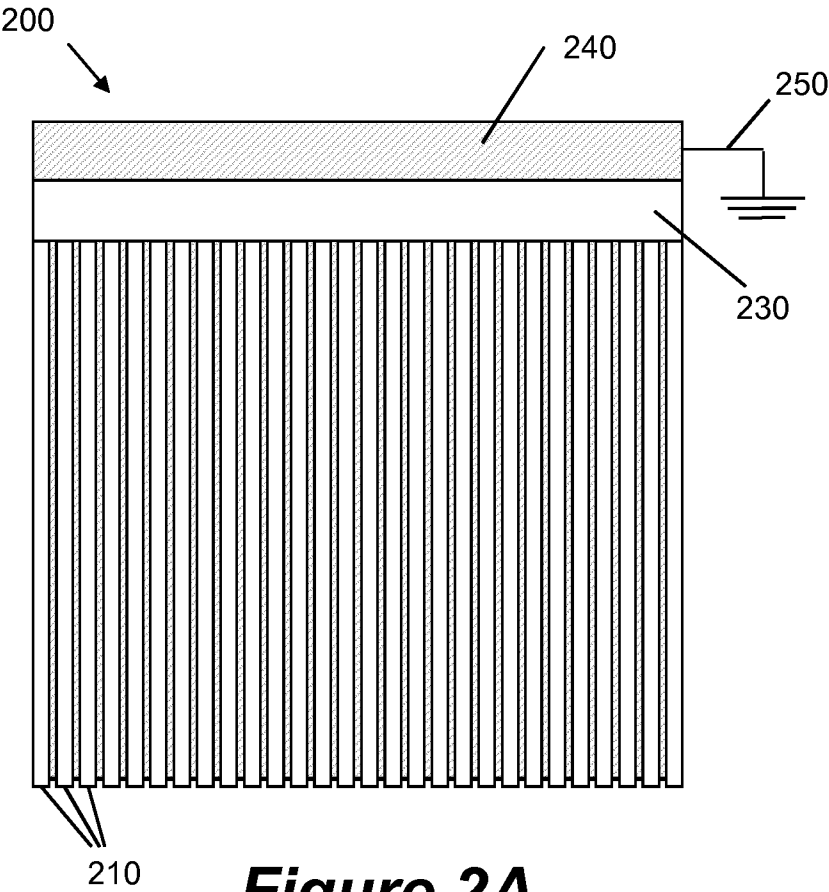


Figure 2A

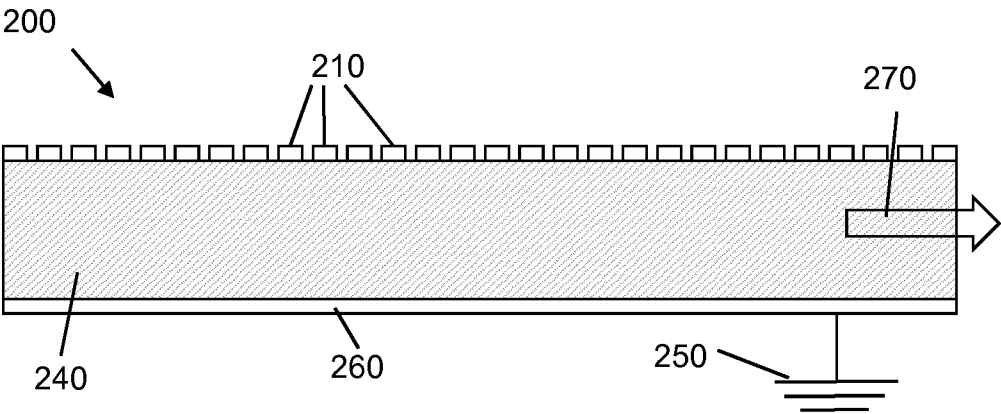


Figure 2B

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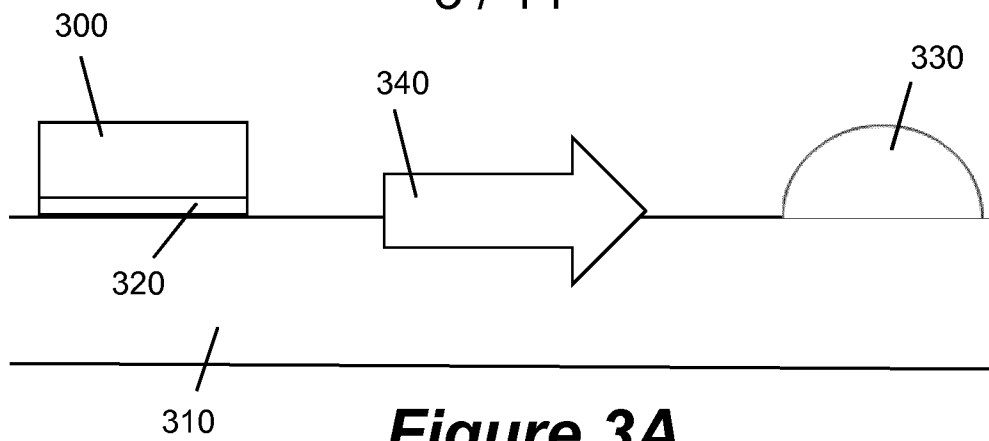


Figure 3A

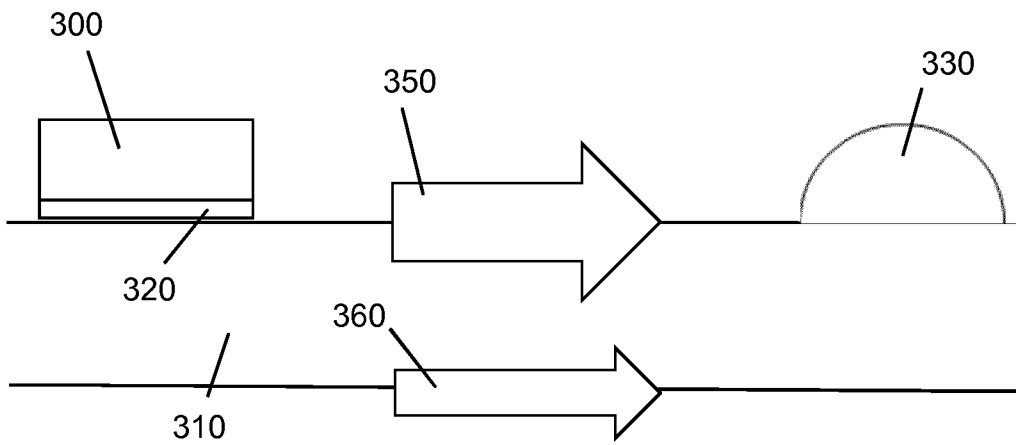


Figure 3B

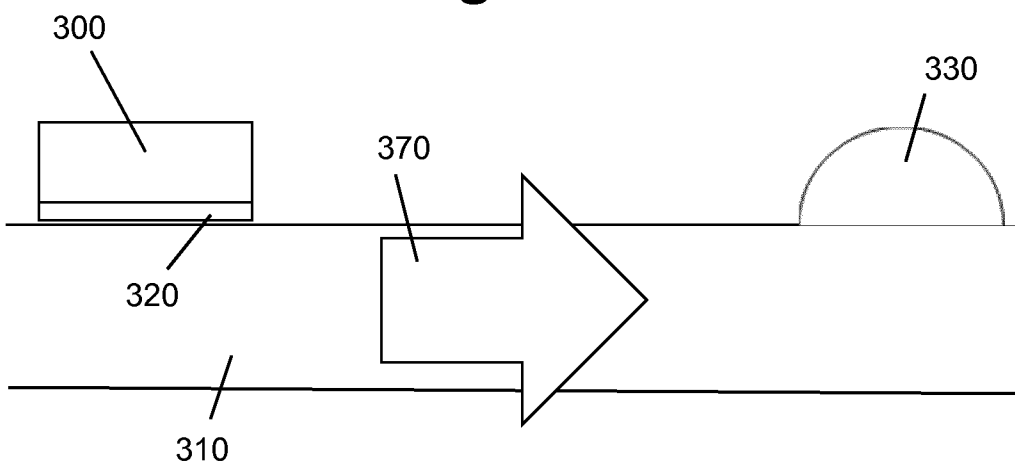


Figure 3C

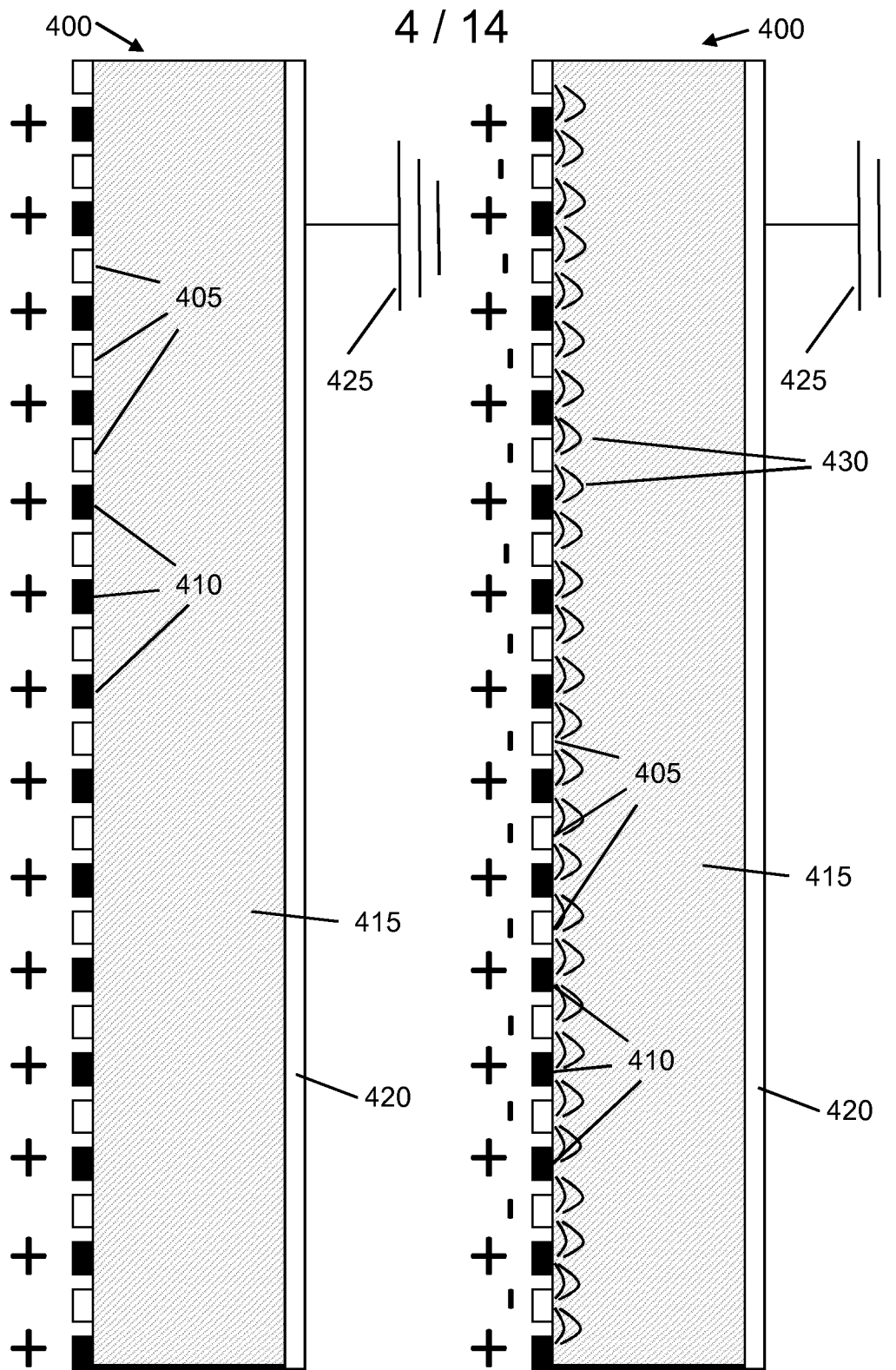


Figure 4A

Figure 4B

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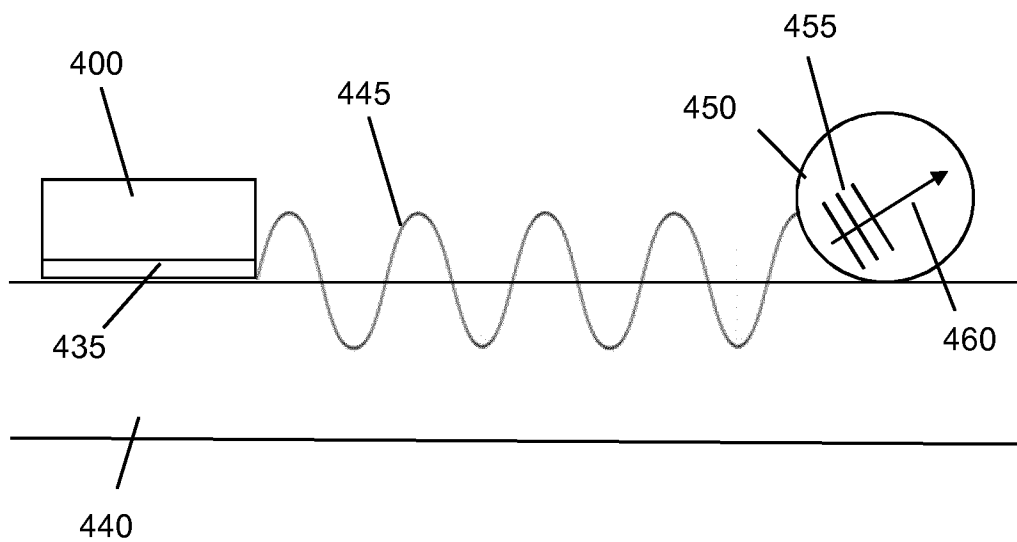


Figure 4C

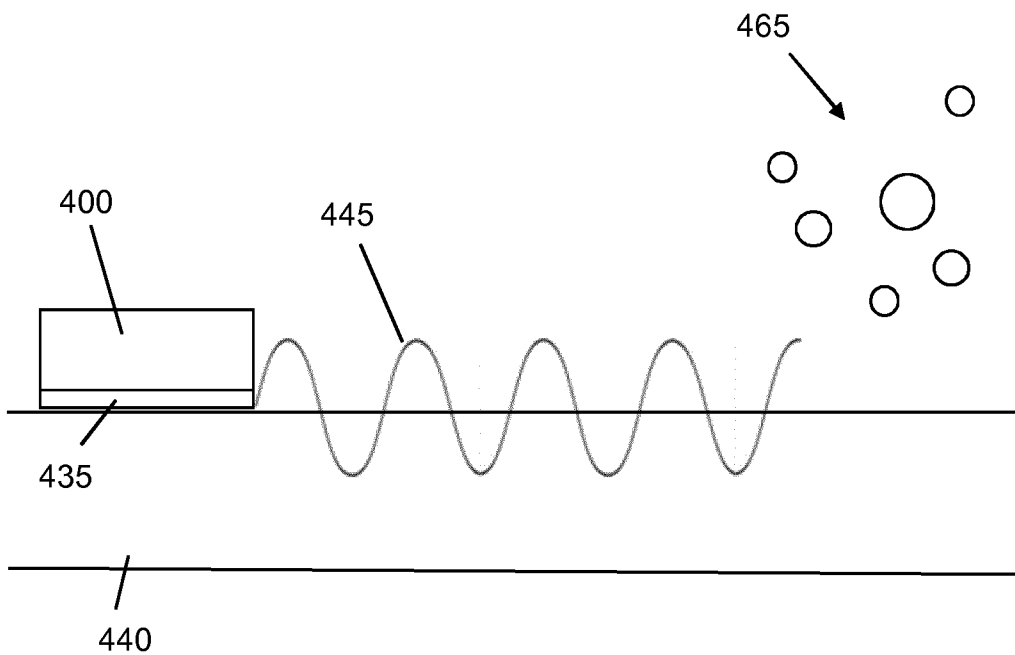
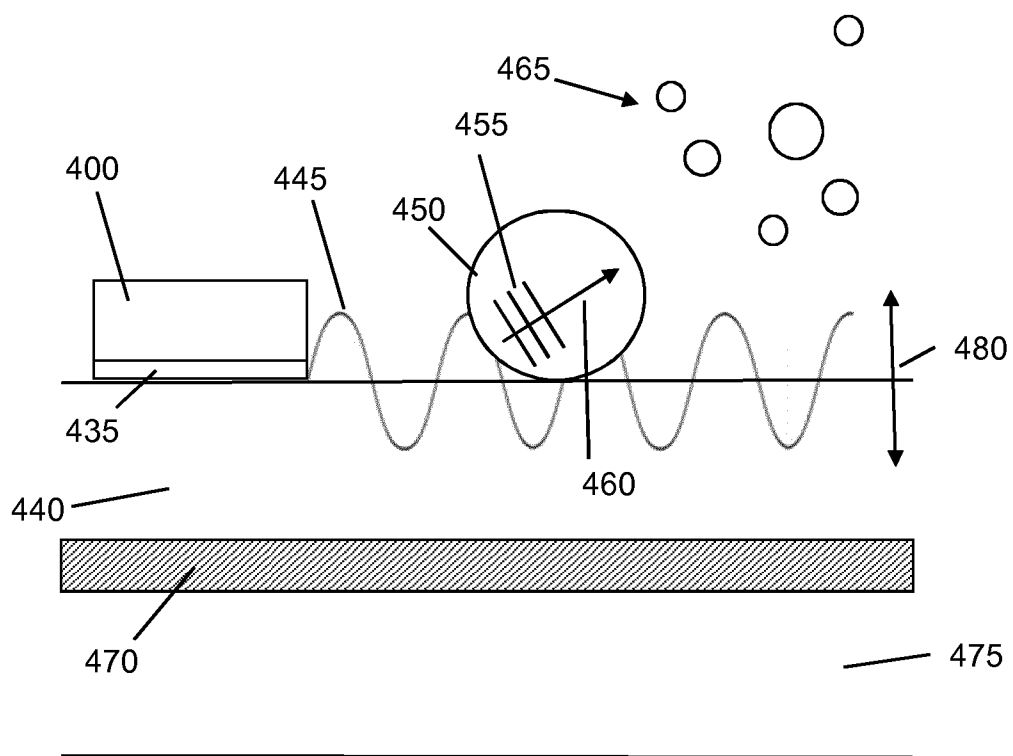


Figure 4D

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**Figure 4E**

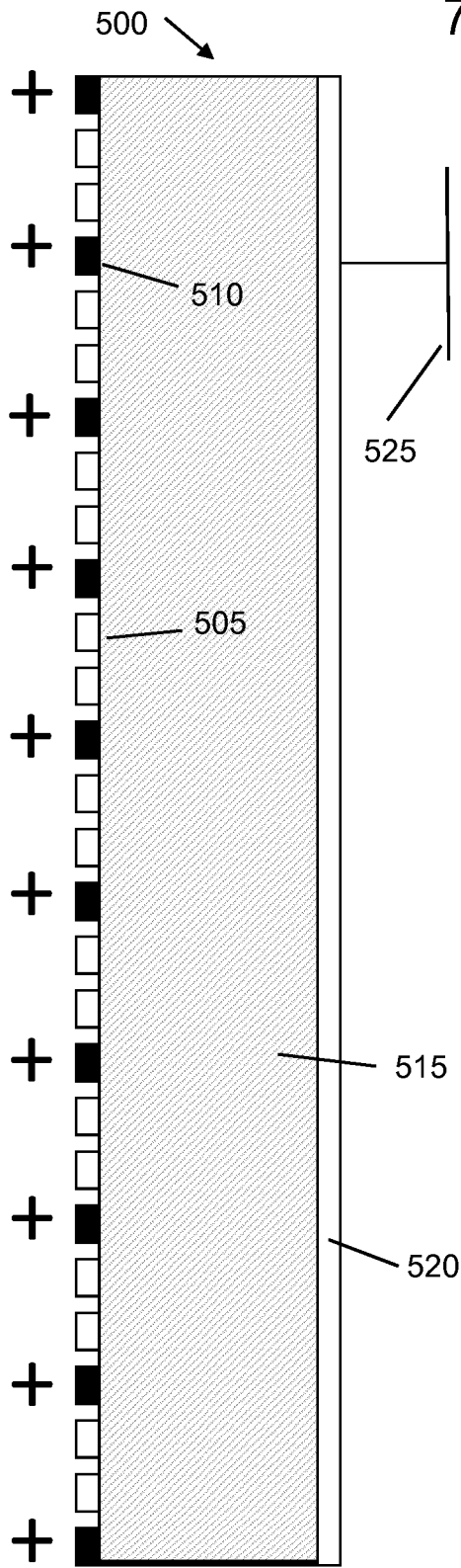


Figure 5A

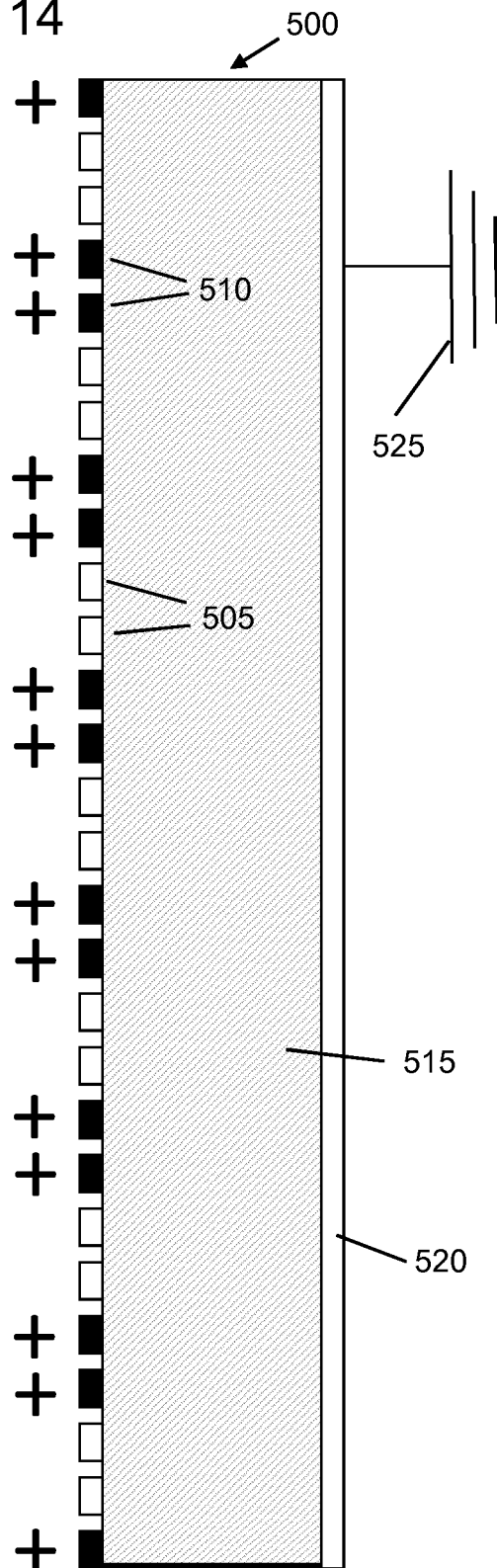


Figure 5B

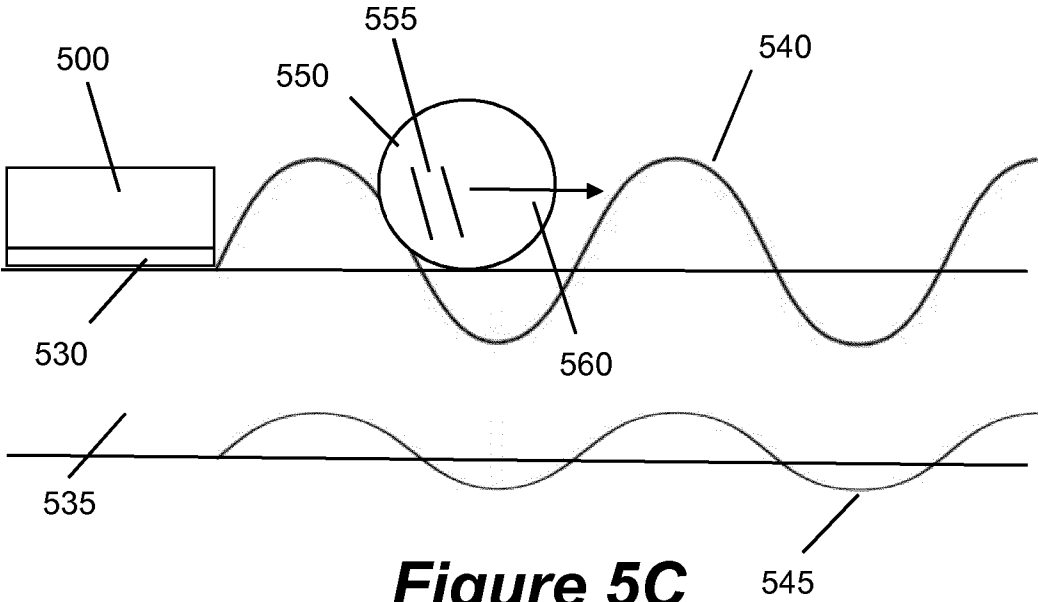


Figure 5C

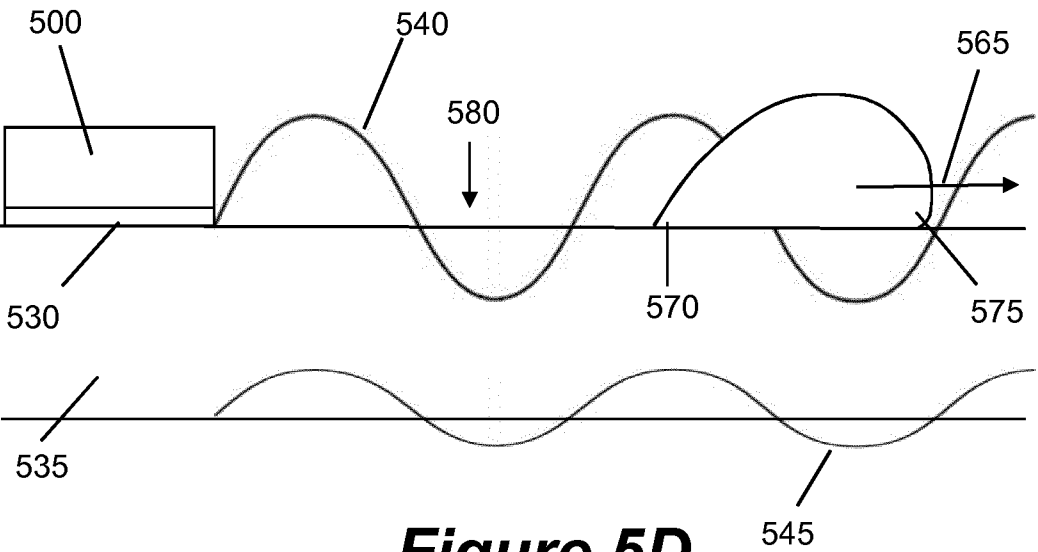


Figure 5D

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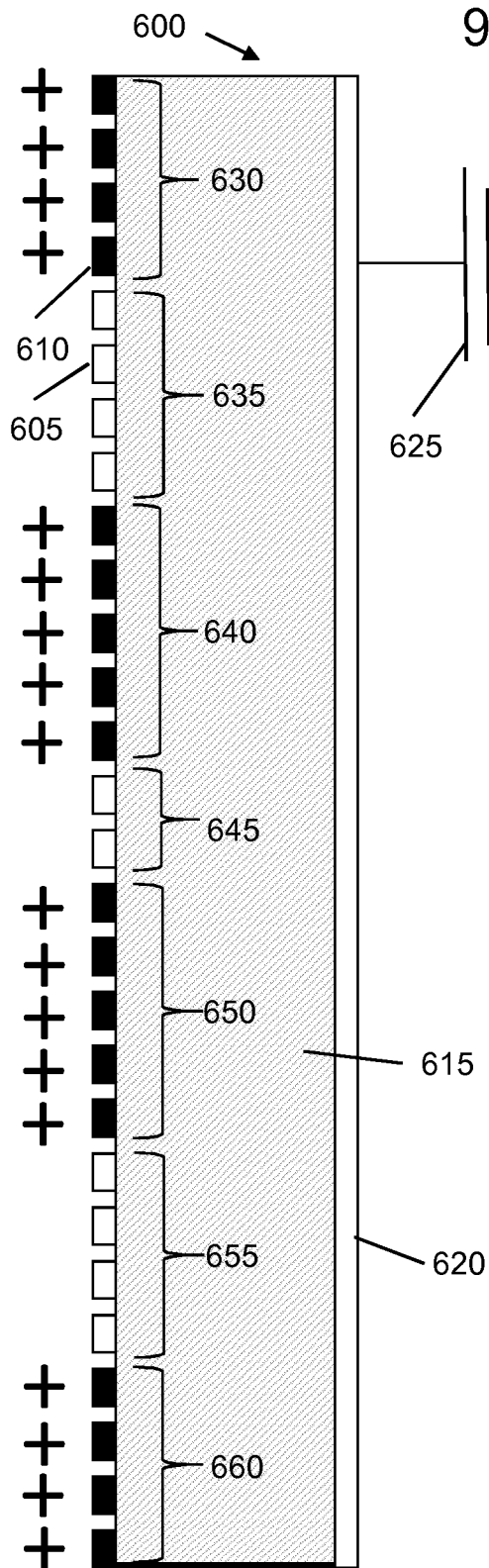


Figure 6A

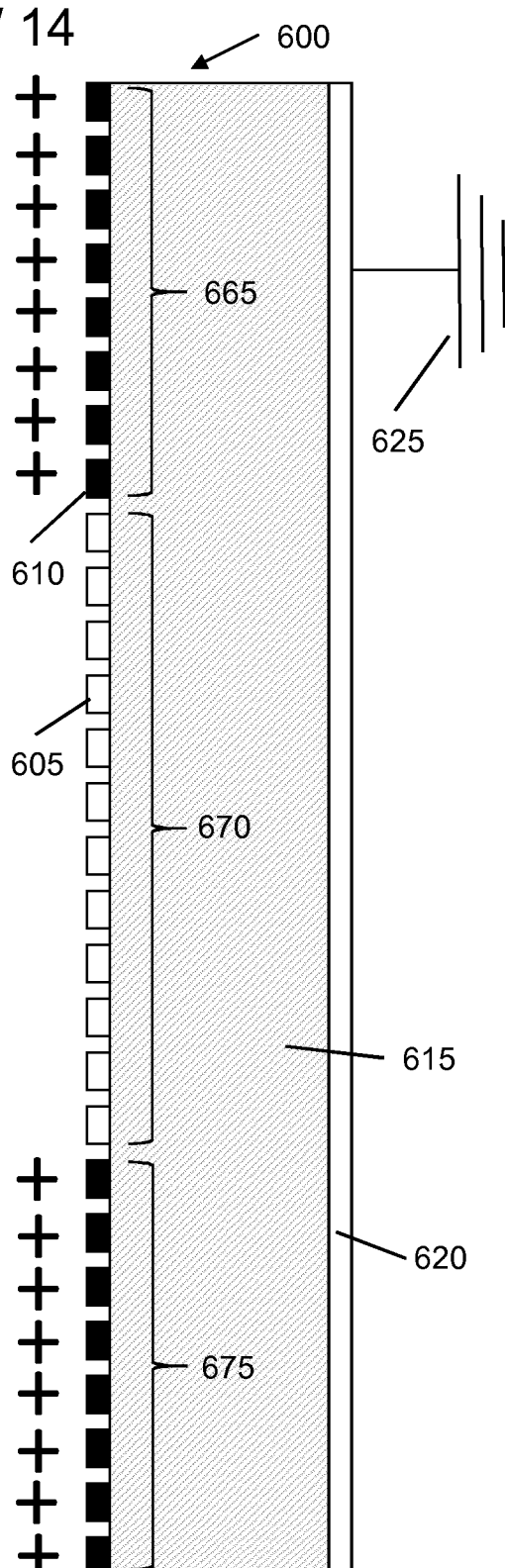


Figure 6B

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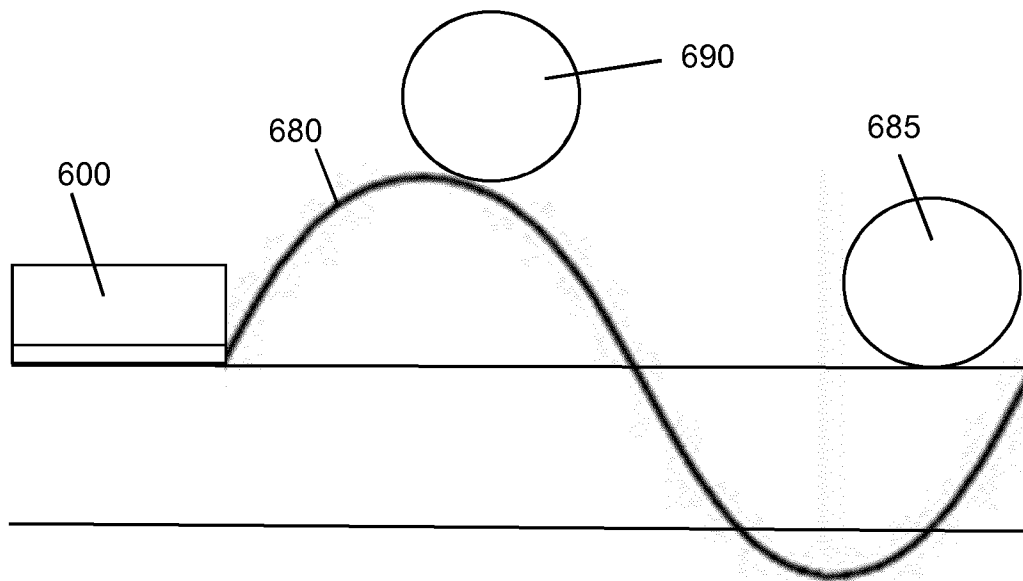


Figure 6C

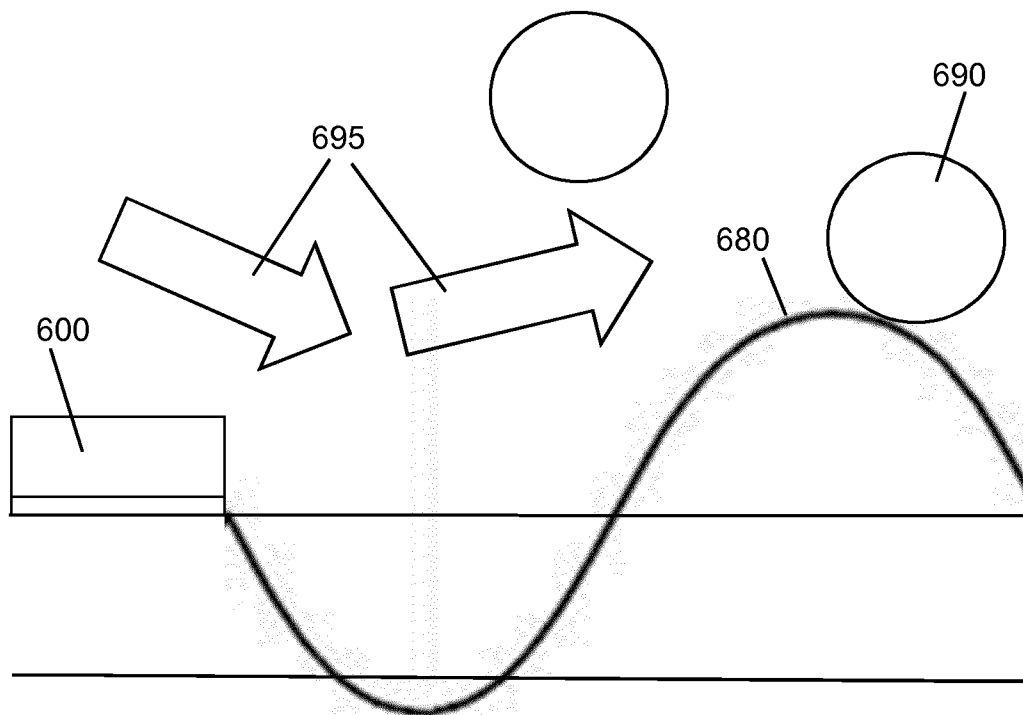


Figure 6D

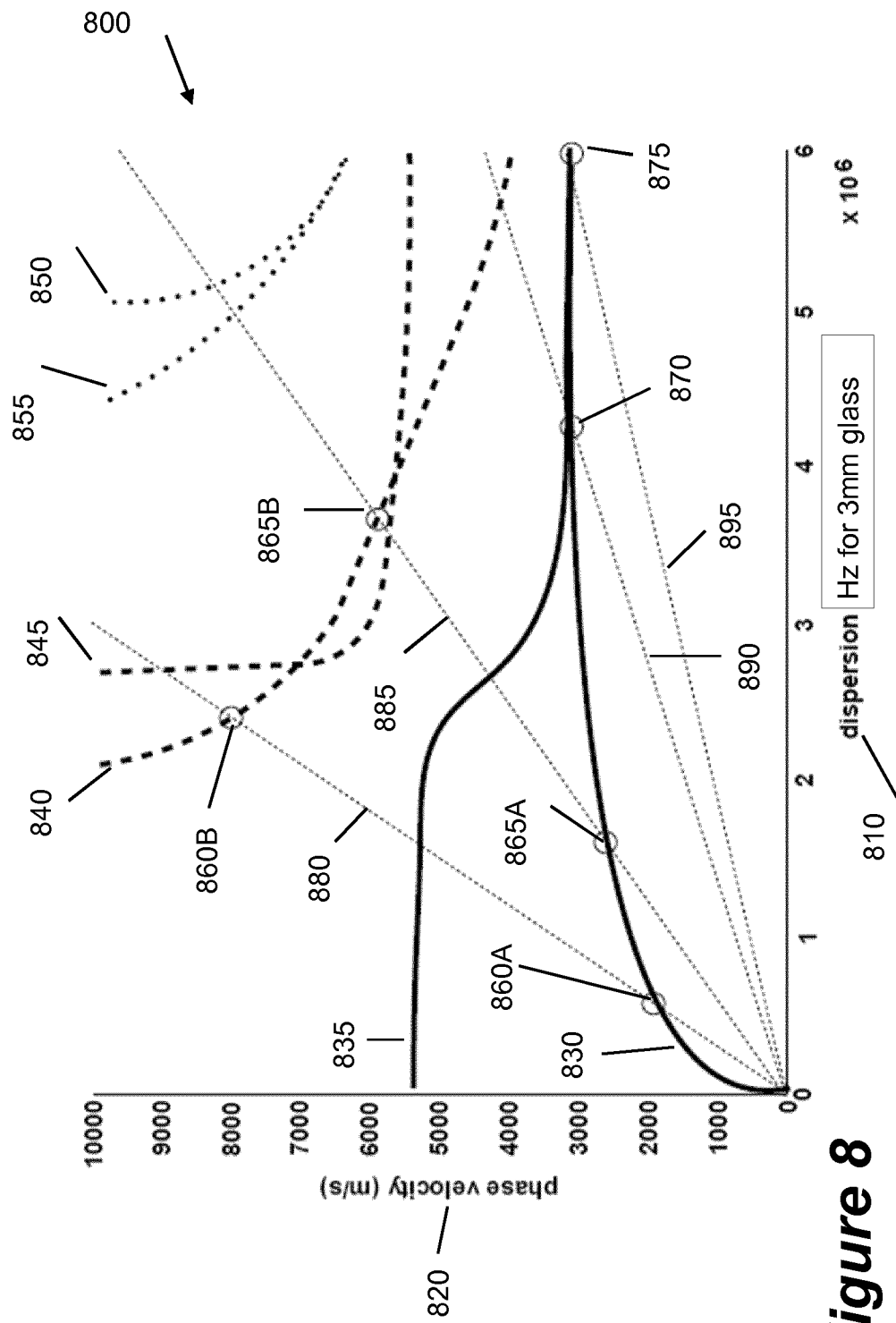
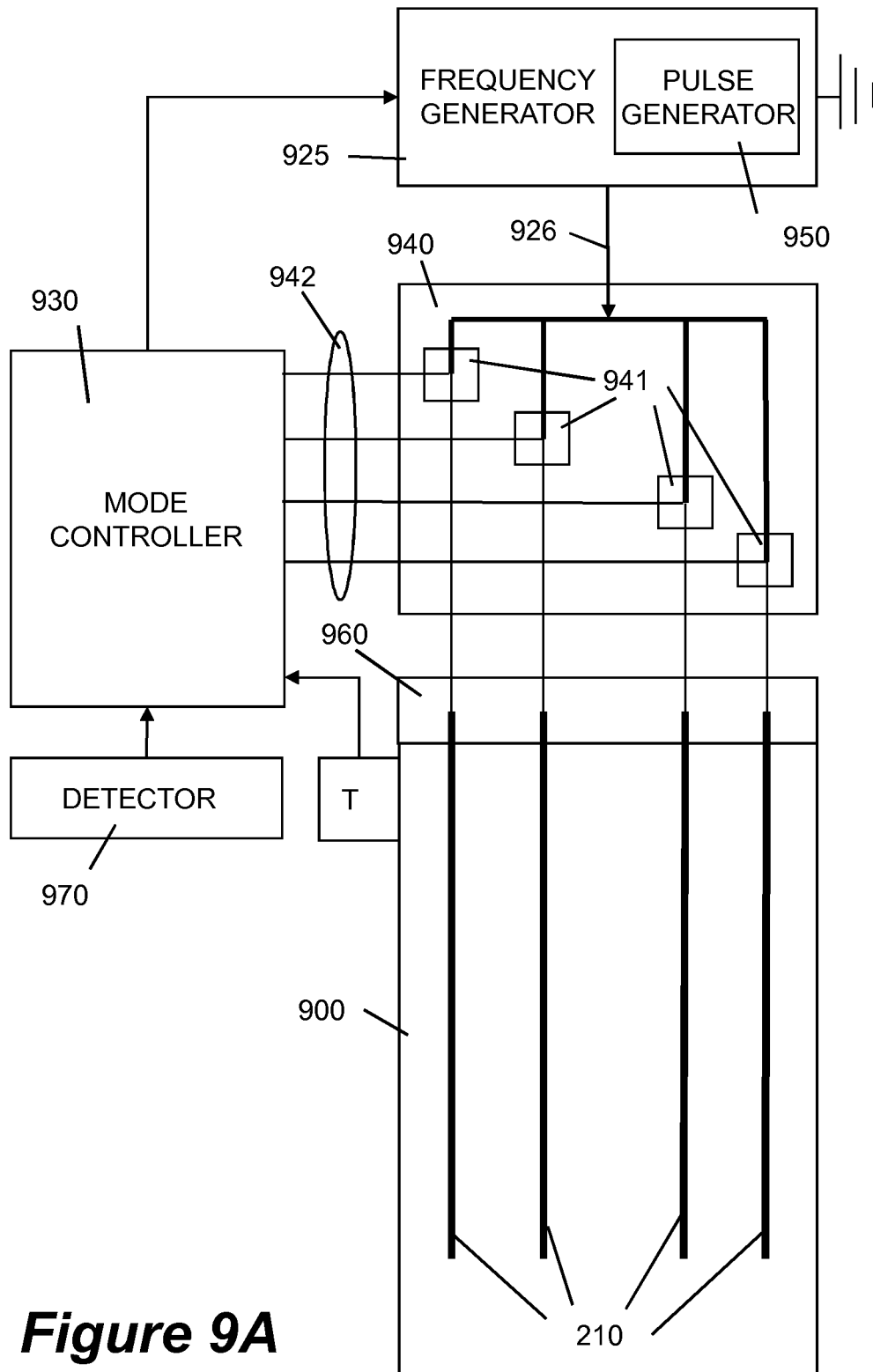


Figure 8

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**Figure 9A**

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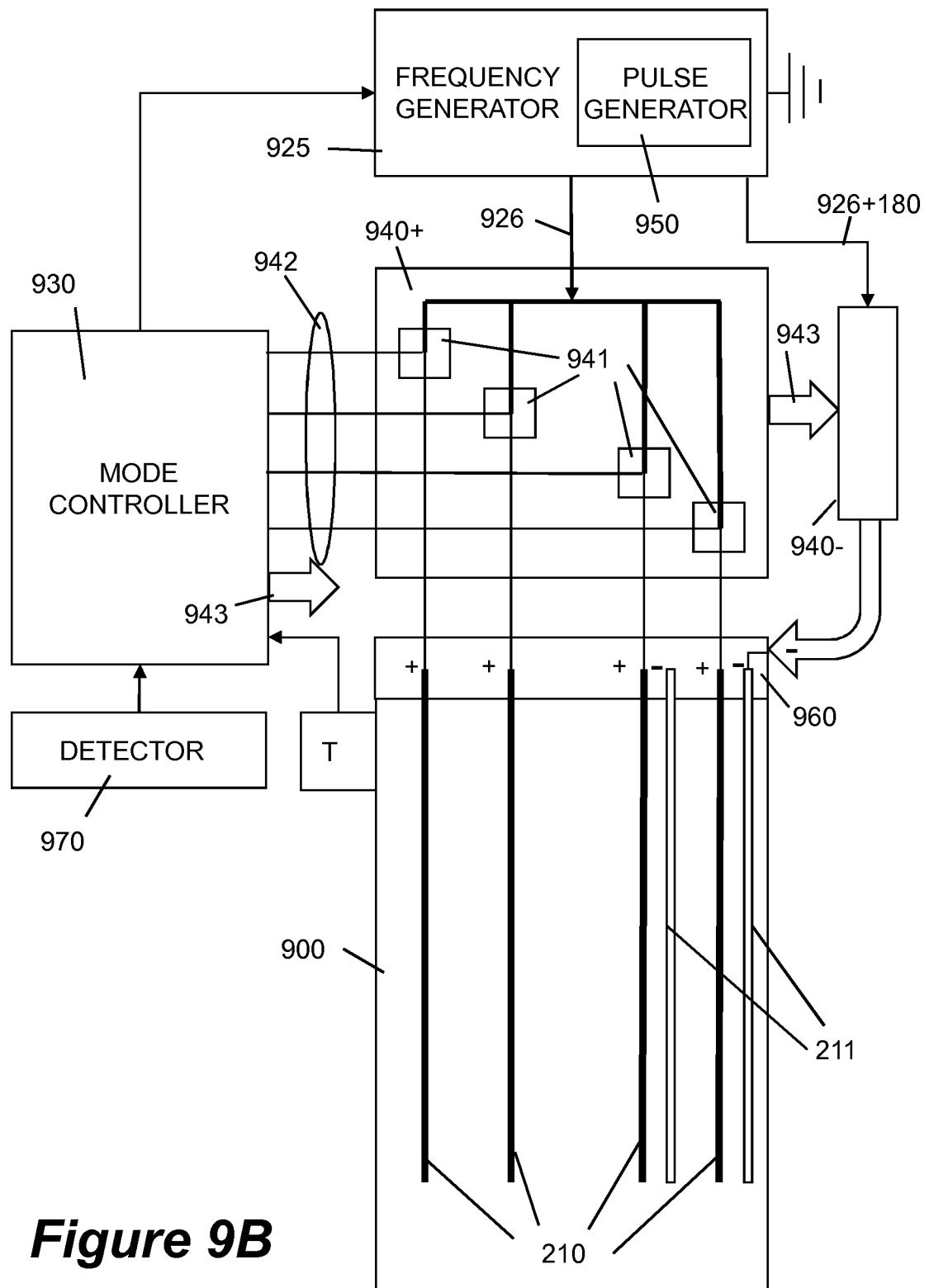


Figure 9B

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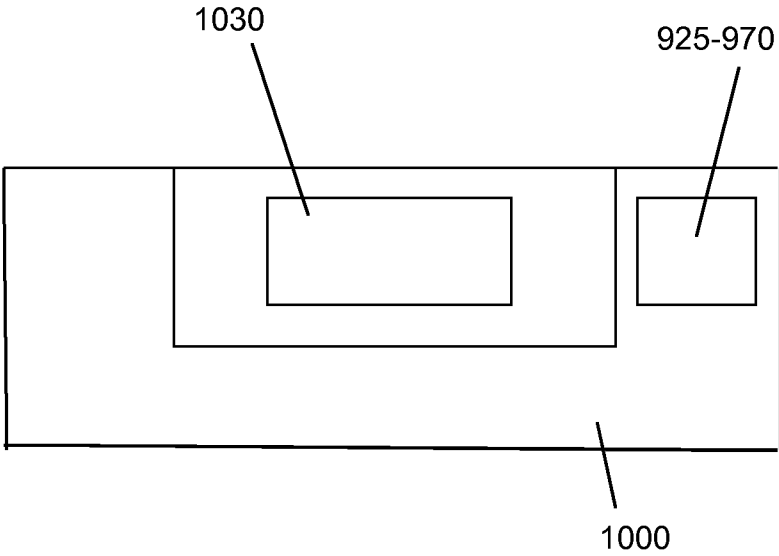


Figure 10A

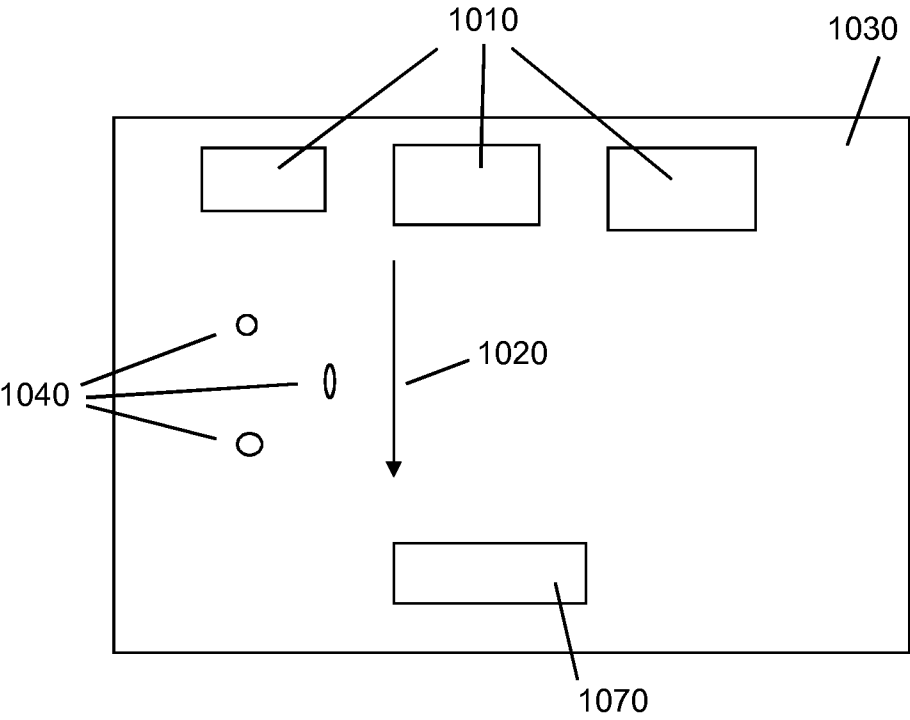


Figure 10B

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/065694

A. CLASSIFICATION OF SUBJECT MATTER
INV. B08B7/02 B23Q11/08 B60S1/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B08B B23Q B60S B63B B06B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 869 055 A2 (BLECHSCHMIDT WOLFGANG JOERG [US]) 7 October 1998 (1998-10-07) column 1, lines 12-24 column 3, line 49 - column 4, line 1 figure 1	1-34
Y	DE 100 05 341 A1 (CTS FAHRZEUG DACHSYSTEME GMBH [DE]) 16 August 2001 (2001-08-16) column 1, lines 47-49 column 2, lines 1-6 column 2, lines 28-55 column 3, lines 27-33 column 3, lines 57-61 figure 1	1-34



Further documents are listed in the continuation of Box C.



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Information on patent family members

International application No

PCT/EP2014/065694

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