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(54) ELECTRONIC ATOMIZATION APPARATUS AND CONTROL METHOD

(57) An electronic atomization apparatus (100) and a control method. The electronic atomization apparatus (100) includes: a liquid storage cavity (11) configured to store a liquid substrate; an ultrasonic atomization element (12) which is able to be driven by an alternating current to atomize the liquid substrate to generate aerosols; a drive unit which provides the alternating current to the ultrasonic atomization element (12); and a controller (221) configured to: control the drive unit to provide a frequency-varying alternating current to the ultrasonic atomization element (12), so as to obtain a first frequency at maximum power of the ultrasonic atomization element (12), and a second frequency when a phase difference between a voltage and a current of the ultrasonic atomization element (12) is zero; and control the drive unit to provide an alternating current with a third frequency to the ultrasonic atomization element (12) to drive the ultrasonic atomization element (12) to atomize the liquid substrate, where the third frequency is between the first frequency and the second frequency. In the electronic atomization apparatus (100), the third frequency between the first frequency and the second frequency is used as the operating frequency of the ultrasonic atomization element (12), so that the ultrasonic atomization element

(12) tends to operate in an optimal resonant state as much as possible.

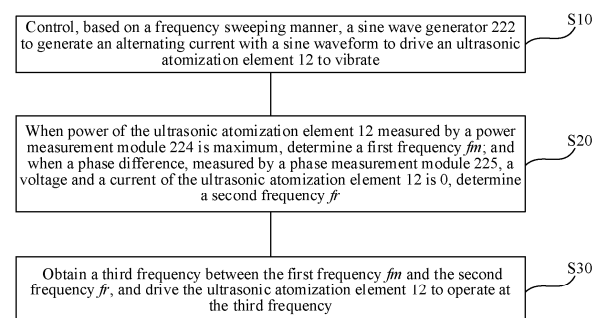


FIG. 10

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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to Chinese Patent Application No. 202311192341.9, filed with China National Intellectual Property Administration on September 15, 2023 and entitled "ELECTRONIC ATOMIZATION APPARATUS AND CONTROL METHOD", which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] Embodiments of this application relates to the field of electronic atomization technologies, and in particular, to an electronic atomization apparatus and a control method.

BACKGROUND

[0003] Tobacco products (such as cigarettes and cigars) burn tobacco during use to produce tobacco smoke. Attempts are made to replace these tobacco-burning products by manufacturing products that release compounds without being burnt.

[0004] Examples of such products are electronic atomization apparatuses, such as ultrasonic atomization apparatuses. This ultrasonic atomization apparatus includes a liquid. An ultrasonic atomization element capable of performing high-frequency reciprocating vibration, such as a piezoelectric ceramic plate, disperses the liquid transferred by a capillary element through high-frequency vibrations into micro-particles, thus forming inhalable aerosols. The liquid may include nicotine and/or fragrance and/or aerosol-generating substances (for example, glycerol). In an existing electronic atomization apparatus, to maximize the operating efficiency of the ultrasonic atomization element such as the piezoelectric ceramic plate, a frequency at maximum operating power of the ultrasonic atomization element is typically determined through frequency sweeping, and the frequency at the maximum operating power is used as an operating frequency of the ultrasonic atomization element. However, in practical operation, it has revealed through monitoring that when the frequency at the maximum power of the ultrasonic atomization element is used as the operating frequency, the ultrasonic atomization element is not in a resonant state.

SUMMARY

[0005] An embodiment of this application provides an electronic atomization apparatus, including:

- a liquid storage cavity configured to store a liquid substrate;
- an ultrasonic atomization element configured to be driven by an alternating current to atomize the liquid

substrate and generate aerosols; and
a drive unit which is connected to the ultrasonic atomization element and is configured to provide the alternating current to the ultrasonic atomization element; and
a controller configured to execute control steps, where the control steps include:

controlling the drive unit to provide a frequency-varying alternating current to the ultrasonic atomization element, obtaining power of the ultrasonic atomization element to determine a first frequency at maximum power of the ultrasonic atomization element, and obtaining a phase difference between a voltage and a current of the ultrasonic atomization element to determine a second frequency when the phase difference between the voltage and the current of the ultrasonic atomization element is zero; and
controlling the drive unit to provide an alternating current with a third frequency to the ultrasonic atomization element, to drive the ultrasonic atomization element to atomize the liquid substrate, where the third frequency is between the first frequency and the second frequency.

[0006] In some embodiments, the third frequency is a mean value of the first frequency and the second frequency.

[0007] In some embodiments, a difference between the third frequency and a mean value of the first frequency and the second frequency is less than half of a minimum step value of frequency modulation of the micro control unit (MCU) controller.

[0008] In some embodiments, the electronic atomization apparatus further includes:
a power measurement module configured to measure the power of the ultrasonic atomization element.

[0009] The MCU controller obtains the power of the ultrasonic atomization element by sampling or receiving a measurement result of the power measurement module.

[0010] In some embodiments, the power measurement module includes an operational amplifier.

[0011] In some embodiments, the electronic atomization apparatus further includes:

a phase measurement module configured to measure the phase difference between the voltage and the current of the ultrasonic atomization element.

[0012] The MCU controller obtains the phase difference between the voltage and the current of the ultrasonic atomization element by sampling or receiving a measurement result of the phase measurement module.

[0013] In some embodiments, the phase measurement module includes:

a waveform converter configured to convert the voltage of the ultrasonic atomization element into a first

square wave signal and the current of the ultrasonic atomization element into a second square wave signal; and

a phase comparator configured to calculate the phase difference between the first square wave signal and the second square wave signal.

[0014] In some embodiments, the phase measurement module further includes:

a direction comparator configured to compare a direction of the first square wave signal with a direction of the second square wave signal.

[0015] In some embodiments, the electronic atomization apparatus further includes:

an airflow sensor configured to sense inhalation of a user.

[0016] The controller is configured to repeatedly execute the control steps at a predetermined time interval during the inhalation of the user.

[0017] Still another embodiment of this application further provides a control method for an electronic atomization apparatus. The electronic atomization apparatus includes:

a liquid storage cavity configured to store a liquid substrate;

an ultrasonic atomization element configured to be driven by an alternating current to atomize the liquid substrate and generate aerosols; and

a drive unit which is connected to the ultrasonic atomization element and is configured to provide the alternating current to the ultrasonic atomization element; and

[0018] The control method includes:

controlling the drive unit to provide a frequency-varying alternating current to the ultrasonic atomization element, obtaining power of the ultrasonic atomization element to determine a first frequency at maximum power of the ultrasonic atomization element, and obtaining a phase difference between a voltage and a current of the ultrasonic atomization element to determine a second frequency when the phase difference between the voltage and the current of the ultrasonic atomization element is zero; and

controlling the drive unit to provide an alternating current with a third frequency to the ultrasonic atomization element, to drive the ultrasonic atomization element to atomize the liquid substrate and generate aerosols, where the third frequency is between the first frequency and the second frequency.

[0019] In the electronic atomization apparatus, the third frequency between the first frequency and the second frequency is used as the operating frequency of the ultrasonic atomization element, so that the ultrasonic atomization element tends to operate in an optimal re-

sonant state as much as possible.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] One or more embodiments are exemplarily described with reference to the corresponding figures in the accompanying drawings, and the descriptions are not to be construed as limiting the embodiments. Elements in the accompanying drawings that have same reference numerals are represented as similar elements, and unless otherwise particularly stated, the figures in the accompanying drawings are not drawn to scale.

FIG. 1 is a schematic diagram of an electronic atomization apparatus according to an embodiment;

FIG. 2 is a block diagram of a structure according to one embodiment of a circuit in FIG. 1;

FIG. 3 is a schematic diagram of an admittance circle for representing an operating frequency characteristic of an ultrasonic atomization element;

FIG. 4 is a schematic diagram of basic devices of a sine wave generator and a sine wave amplifier in FIG. 2 according to an embodiment;

FIG. 5 is a schematic diagram of a basic device of a power measurement module in FIG. 2 according to an embodiment;

FIG. 6 is a schematic diagram of a basic device of a phase measurement module in FIG. 2 according to an embodiment;

FIG. 7 is a schematic diagram of comparison between a sine wave outputted by the sine wave generator and a sine wave amplified by the sine wave amplifier in FIG. 4;

FIG. 8 is a schematic diagram of converting an input sine wave signal into a square wave signal by a waveform converter;

FIG. 9 shows a schematic diagram of sampling power and an operating frequency of an ultrasonic atomization element according to an embodiment; and

FIG. 10 is a schematic diagram of a control process of an MCU controller in an embodiment.

DETAILED DESCRIPTION

[0021] To facilitate the understanding of this application, this application is described in more detail below with reference to accompanying drawings and specific implementations.

[0022] One embodiment of this application provides an electronic atomization apparatus configured to atomize a liquid substrate and generate aerosols for inhalation. The electronic atomization apparatus of this application can also be represented as an aerosol generating system or a drug delivery product. Therefore, this apparatus or system can be adapted to provide one or more substances in an inhalable form or state (such as flavorings and/or active pharmaceutical ingredients). For example, an in-

halable substance can be basically in a form of aerosols (i.e. a suspension of fine solid particles or liquid droplets in gas).

[0023] FIG. 1 shows a schematic diagram of a structure of an embodiment of an electronic atomization apparatus 100. The apparatus typically includes a plurality of components located within an external main body or a shell (which can be referred to as a case). The overall design of the external main body or the shell can vary, and a type or configuration of the external main body that can limit an overall size and shape of the electronic atomization apparatus 100 can vary. Typically, a slender main body similar to a cigarette or a cigar may be formed by a single integrated housing, or a slender case can be formed by two or more separable main bodies. For example, a control main body may be provided at one end of the electronic atomization apparatus 100. The control main body includes a case containing one or more reusable components (such as a rechargeable battery and/or a rechargeable super-capacitor storage battery, and various electronic devices for controlling operations of this product). In addition, an external main body or a shell that is removably coupled and includes a disposable component (such as a disposable fragrance-containing cartridge) is provided at another end of the electronic atomization apparatus.

[0024] As shown in FIG. 1, the electronic atomization apparatus 100 includes: an atomizer 10 which stores a liquid substrate and atomizes the liquid substrate to generate aerosols; and a power supply mechanism 20 for supplying power to the atomizer 10. The power supply mechanism 20 and the atomizer 10 are detachably aligned in a functional relationship. Various mechanisms can be used to connect the atomizer 10 to the power supply mechanism 20, thus achieving threaded connection, press fit, interference fit, magnetic connection, and the like. In some example implementations, when the atomizer 10 and the power supply mechanism 20 are in assembling configuration, the electronic atomization apparatus 100 may be basically rod-shaped, flatly cylindrical, rod-shaped, columnar, or the like.

[0025] In an optional embodiment, the power supply mechanism 20 and the atomizer 10 may include a separate case or an external main body that can be formed by any of a variety of different materials. The case can be formed by any suitable structurally intact material. In some examples, the case may be formed by a metal or alloy such as stainless steel or aluminum. Other suitable materials including various types of plastic (e.g. polycarbonate), metal-plating over plastic, ceramic, and the like may alternatively be used.

[0026] As shown in FIG. 1, the electronic atomization apparatus 100 has a near end 110 and a far end 120 that are opposite in a length direction. During use, the near end 110 is usually an inhalation end for a user, and the far end 120 is an end that is far away from the user. The atomizer 10 is arranged at the near end, and the power supply mechanism 20 is arranged at the far end 120.

[0027] As shown in FIG. 1, the power supply mechanism 20 includes:

a battery cell 21 configured to supply power, where the battery cell 21 may include, for example, a battery (disposable or rechargeable), a rechargeable super-capacitor, a rechargeable solid-state battery (SSB), a rechargeable lithium-ion battery (LiB), or a combination thereof; and
a circuit 22 configured to guide a current between the battery cell 21 and the atomizer 10.

[0028] As shown in FIG. 1, the atomizer 10 includes:

a mouthpiece 111 which is located at the near end 110 and is configured for user inhalation;
a liquid storage cavity 11 configured to store a liquid substrate;
an ultrasonic atomization element 12 which is in fluid communication with the liquid storage cavity 12 and atomizes, through mechanical vibrations, the liquid substrate transferred to the ultrasonic atomization element 12 into aerosols; and
a liquid transfer element 13 configured to transfer the liquid substrate between the liquid storage cavity 11 and the ultrasonic atomization element 12.

[0029] In an optional embodiment, the ultrasonic atomization element 12 may be a conventional sheet-like ultrasonic vibration component or sheet-like piezoelectric ceramic, or, for example, an ultrasonic atomization plate proposed in patent CN112335933A. These ultrasonic atomization elements 12 disperse the liquid substrate through high-frequency vibrations (preferably having an operating frequency of 1.0 MHz to 4.0 MHz, which is beyond a human auditory range and belongs to an ultrasonic frequency band) during use to produce aerosols with naturally suspended particles.

[0030] In an optional embodiment, the liquid transfer element 13 may be a conventional capillary element, such as fiber cotton, a porous body, or the like. In other preferred embodiments, the liquid transfer element 13 may be a micro pump that pumps a predetermined amount of liquid substrate from the liquid storage cavity 11 onto the ultrasonic atomization element 12, such as a micro pump based on a micro-electromechanical system (MEMS) technology. Examples of suitable micro pumps include an MDP2205 micro pump and other micro pumps in thinXXS Microtechnology AG, mp5 and mp6 micro pumps and other micro pumps in Bartels Mikrotechnik GmbH, and piezoelectric micro pumps in Takasago fluid systems.

[0031] In some other embodiments, the power supply mechanism 20 may further include:

an airflow sensor configured to sense an inhalation action of a user. Based on the airflow sensor having sensed the inhalation action of the user, the power supply mechanism 20 supplies power to the ultrasonic atomization ele-

ment 12 of the atomizer 100 to cause the ultrasonic atomization element 12 to atomize the liquid substrate and generate aerosols.

[0032] In some embodiments, the circuit 22 includes a plurality of electronic components. Furthermore, in some examples, the circuit may be formed on a printed circuit board (PCB) that supports and is electrically connected to the electronic components. The electronic components may include a microprocessor or a processor core, and a memory. In some examples, the control component may include a microcontroller with an integrated processor core and a memory, and may further include one or more integrated input/output peripherals.

[0033] In some embodiments, the circuit 22 further includes:

a drive unit generates an alternating current based on a principle of high-frequency vibration and provides the alternating current to the ultrasonic atomization element 12, thereby causing the ultrasonic atomization element 12 to generate ultrasonic vibrations to atomize the liquid substrate. By driving the ultrasonic atomization element 12 with a periodic alternating current, the ultrasonic atomization element 12 generates high-frequency vibrations to atomize the liquid substrate. As shown in FIG. 2 and FIG. 4, the drive unit uses a standard sine wave alternating current to drive the ultrasonic atomization element 12. The drive unit includes:

a sine wave generator 222 configured to generate an alternating current signal with a sine waveform; and a sine wave amplification module 223 configured to: amplify the alternating current signal with the sine waveform which is generated by the sine wave generator 222 until the alternating current signal reaches an intensity or amplitude that drives the ultrasonic atomization element 12 to vibrate, and provide the alternating current signal to the ultrasonic atomization element 12.

[0034] In the embodiments of FIG. 2 and FIG. 4, the sine wave generator 222 includes a sine wave chip U1. The sine wave chip U1 generates the alternating current signal with the sine waveform based on a frequency, a phase, an amplitude, and other parameters provided by an MCU controller 221, and outputs the alternating current signal through an output interface SW_SUT.

[0035] In the embodiments of FIG. 2 and FIG. 4, since the strength of the signal with the sine waveform, which is generated by the sine wave chip U1, is very small, the signal cannot be directly applied to driving the ultrasonic atomization element 12 to operate. Therefore, after the signal is subjected to secondary amplification by a plurality of amplifiers in the sine wave amplification module 223, such as an amplifier U2 and an amplifier U3, the signal is outputted to the ultrasonic atomization element 12. For example, in FIG. 7, a curve S1a shows a schematic diagram of the alternating current signal with the sine waveform, which is generated by the sine wave chip

U1, in an embodiment, and a curve S1b shows a schematic diagram of the alternating current signal with the sine waveform after multi-stage amplification by the sine wave amplification module 223.

[0036] Or, in still some other changing embodiments, the drive unit may further provide similar triangular wave or square wave alternating currents or the like to the ultrasonic atomization element 12 to drive the ultrasonic atomization element 12 to vibrate. Correspondingly, the drive unit may include a square wave generator or a triangular wave generator to replace the sine wave generator 222 to generate the triangular wave or square wave alternating currents or the like.

[0037] As shown in FIG. 2 and FIG. 4, to facilitate sampling and monitoring of electrical characteristics of the ultrasonic atomization element 12 during operation, a first sampling point W1 and a second sampling point W2 are respectively arranged at two ends of the ultrasonic atomization element 12. During measurement, a voltage at the first end of the ultrasonic atomization element 12 can be sampled and obtained by the first sampling point W1, and a current flowing through the ultrasonic atomization element 12 can be sampled and measured through the second sampling point W2.

[0038] As shown in FIG. 2 and FIG. 5, the circuit 22 further includes:

a power measurement module 224 configured to measure the power of the ultrasonic atomization element 12. In FIG. 5, the power measurement module 224 mainly includes an operational amplifier U4, and the operational amplifier U4 receives and calculates the current and/or power of the ultrasonic atomization element 12.

[0039] Or, in some other embodiments, since the voltage of the ultrasonic atomization element 12 can be directly sampled and obtained from the first sampling point W1 by a sampling pin of the MCU controller 221, one signal input end of the operational amplifier U4 is connected to the second sampling point W2 to sample and calculate the current of the ultrasonic atomization element 12. Then, the MCU controller 221 multiplies the voltage and the current of the ultrasonic atomization element 12 to obtain the power of the ultrasonic atomization element 12.

[0040] As shown in FIG. 2 and FIG. 6, the circuit 22 further includes:

a phase measurement module 225 configured to measure a phase difference between the voltage and the current of the ultrasonic atomization element 12. Specifically, as shown in FIG. 6, the phase measurement module 225 includes:

a waveform converter 2251 configured to convert the voltage with a sine waveform of the ultrasonic atomization element 12 into a first square wave signal and the current with a sine waveform of the ultrasonic atomization element 12 into a second square wave signal.

[0041] For example, FIG. 8 shows a schematic diagram of comparison of converting an input sine wave

signal S2a into a square wave signal S2b by the waveform converter 2251. The waveform converter 2251 converts the voltage and the current, which have the sine waveforms and difficultly identified phases, into a square wave shape for ease of sampling and identification. The first square wave signal subjected to waveform conversion by the waveform converter 2251 has the same cycle, direction, and phase as the voltage with the sine waveform, and the second square wave signal has the same cycle, direction, and phase as the current. Thus, by sampling and measuring the easily identifiable square wave signals, directions and phases of a present voltage and a present current of the ultrasonic atomization element 12 can be obtained. As shown in FIG. 8, an amplitude of the square wave signal S2b decreases compared with an amplitude of the sine wave signal S2a, so that the strength of the signal is suitable for being received by a downstream signal interface.

[0042] As shown in FIG. 2 and FIG. 6, the phase measurement module 225 further includes:

- a direction comparator 2252 configured to compare a direction of the first square wave signal converted from the voltage with a direction of the second square wave signal converted from the current; and
- a phase comparator 2253 configured to calculate the phase difference between the first square wave signal converted from the voltage and the second square wave signal converted from the current.

[0043] In this embodiment, the MCU controller 221 finds and determines an optimal resonant frequency for the operation of the ultrasonic atomization element 12 based on the electrical principle of the admittance circle of an operating frequency characteristic of the ultrasonic atomization element 12 and in conjunction with measurement results of the power measurement module 224 and the phase measurement module 225.

[0044] Specifically, FIG. 3 shows an admittance circle diagram of the operating frequency characteristic of the ultrasonic atomization element 12. Admittance is a general term for conductance and susceptance. In power electronics, the admittance is defined as a reciprocal of an impedance R. In the field of power electronics, the admittance is represented by symbol Y, the unit of which is Siemens. Like impedance, the admittance is also a complex number composed of a real part (conductance g) and an imaginary part (admittance b): $Y = g + jb$. As shown in FIG. 3, the horizontal axis represents the conductance of the ultrasonic atomization element 12, and the vertical axis represents the susceptance of the ultrasonic atomization element 12. The circle represents values of conductance and susceptance corresponding to different frequency points of the ultrasonic atomization element 12. The frequency of the ultrasonic atomization element 12 gradually increases clockwise along the circle.

[0045] As shown in FIG. 3, when the operating fre-

quency of the ultrasonic atomization element 12 is a first frequency f_m , a corresponding admittance is maximum, and the impedance R is minimum. In this case, the power of the ultrasonic atomization element 12 is maximum. When the operating frequency of the ultrasonic atomization element 12 is a second frequency f_r , the susceptance is equal to zero, and the ultrasonic atomization element 12 is equivalent to a pure resistor. In this case, the phases of the voltage and the current on the ultrasonic atomization element 12 are the same, and the phase difference between the voltage and the current is zero. Furthermore, when the operating frequency of the ultrasonic atomization element 12 is f_s , a corresponding conductance is maximum. The frequency f_s is between f_m and f_r , i.e. $f_m < f_s < f_r$.

[0046] In this embodiment, the MCU controller 221 obtains a third frequency between the first frequency f_m and the second frequency f_r as the operating frequency of the ultrasonic atomization element 12, so that the ultrasonic atomization element 12 tends to operate in an optimal resonant state as much as possible. As shown in FIG. 10, a method used by the MCU controller 221 to obtain the third frequency includes:

S10: Control, based on a frequency sweeping manner, the drive unit including the sine wave generator 222 and the sine wave amplification module 223 to provide a frequency-varying alternating current with a sine waveform to the ultrasonic atomization element 12.

[0047] In the frequency sweeping process in step S10, the frequency-varying alternating current may be carried out in a fast frequency sweeping manner of gradual increase or decrease a reference frequency. Or, in some embodiments, the frequency sweeping manner can employ a difference frequency sweeping manner.

[0048] S20: When the power of the ultrasonic atomization element 12 measured by the power measurement module 224 is maximum, determine the corresponding first frequency f_m ; and when the voltage and the current, measured by the phase measurement module 225, of the ultrasonic atomization element 12 have the same directions and a phase difference of 0, determine the corresponding second frequency f_r .

[0049] In step S20, based on FIG. 9 of a schematic diagram of changes in the power and operating frequency of the ultrasonic atomization element 12, the power measurement module 224 measures the power of the ultrasonic atomization element 12 in the frequency sweeping process, and the MCU controller 221 determines the corresponding first frequency f_m when the power is maximum;

[0050] Furthermore, in step S20, the phase measurement module 225 measures the directions of the voltage and the current that have the sine waveform of the ultrasonic atomization element 12 and the phase difference between the voltage and the current. The MCU controller 221 determines the corresponding second frequency f_r based on the direction comparator 2252 determining that the voltage and the current have the same direction and

the phase difference, measured by the phase comparator 2253, between the voltage and the current being 0.

[0051] S30: Obtain the third frequency between the first frequency fm and the second frequency fr based on the first frequency fm and the second frequency fr that are obtained in step S20, and drive the ultrasonic atomization element 12 to operate at the third frequency.

[0052] In step S30 of this embodiment, since both the first frequency fm and the second frequency fr have errors with the truest and optimal resonant frequency fs , and true values of the optimal resonant frequency fs cannot be calculated and obtained, the third frequency between the first frequency fm and the second frequency fr is used. The third frequency is closer to the optimal resonant frequency fs than either of the first frequency fm or the second frequency fr , and then is used as the operating frequency of the ultrasonic atomization element 12 for operation, so that the ultrasonic atomization element 12 tends to be in the optimal resonant state as much as possible.

[0053] In some specific embodiments, in step S10 and step S20 above, the frequency-varying alternating current is provided to the ultrasonic atomization element 12 for frequency sweeping in a manner of increasing the frequency from small to large, and the power of the ultrasonic atomization element 12 is correspondingly measured and obtained to find the first frequency fm . Specifically, finding the first frequency fm includes:

S10a: Calculate or select a reference frequency value: for example, reference frequency value=last resonant frequency - empirical value. The MCU controller 221 uses the reference frequency value as an initial value of frequency sweeping, and performs forward frequency modulation in a manner of increase by a minimum step value each time, so as to gradually increase a drive frequency provided to the ultrasonic atomization element 12.

S20a: Obtain the power of the ultrasonic atomization element 12 measured by the power measurement module 224, and record power values of consecutive five times as W_{n-2} , W_{n-1} , W_n , W_{n+1} , and W_{n+2} , respectively.

[0054] When W_n is greater than both W_{n-2} and W_{n-1} , and W_{n+1} and W_{n+2} are both less than W_n , the MCU controller 221 determines W_n as the maximum power. Thus, frequency modulation corresponding to the maximum power W_n is determined as the first frequency fm .

[0055] Or, in some changing embodiments, in step S20a, a maximum power value is determined. The number of consecutive sampling of power values can be increased to enhance the accuracy. For example, power values that are measured within consecutive 7, 9, 11, or more times are compared. When a sampled power value is greater than the power values of several previous times and the power values of several following times, the sampled power value can be determined as the maximum power value.

imum power value.

[0056] Similarly, the MCU controller 221 uses the reference frequency value as the initial value of frequency sweeping, and performs forward frequency modulation in a manner of increase by the minimum step value each time, so as to gradually increase the drive frequency provided to the ultrasonic atomization element 12. The comparator determines whether the phase difference, measured by the phase comparator 2253, between the voltage and the current is 0. When the comparator measures that the phase difference, measured by the phase comparator 2253, between the voltage and the current is 0, the MCU controller 221 can determine the corresponding second frequency fr based on the phase difference, measured by the phase comparator 2253, between the voltage and the current being 0.

[0057] Or, in some other changing embodiments, when the MCU controller 221 controls the frequency sweeping to find the first frequency fm , forward frequency modulation is used to increase a sweeping frequency and backward frequency modulation is used to decrease the sweeping frequency, to gradually find the first frequency fm . Specifically, the MCU controller 221 uses the reference frequency value as the initial value of frequency sweeping and obtains the power of the ultrasonic atomization element 12 measured by the power measurement module 224. If a current measured power is greater than a previous power value, the forward frequency modulation is continued to increase the sweeping frequency. If the current measured power is less than the previous power value, the reverse frequency modulation is performed to decrease the sweeping frequency. By cyclically and continuously adjusting the sweeping frequency until the power of the ultrasonic atomization element 12 is maximum, the corresponding sweeping frequency is determined as the first frequency fm .

[0058] Similarly, in still some changing embodiments, when the MCU controller 221 controls the frequency sweeping to find the second frequency fr , forward frequency modulation is used to increase a sweeping frequency and backward frequency modulation is used to decrease the sweeping frequency, to gradually find the second frequency fr . Specifically, the MCU controller 221 uses the reference frequency value as the initial value of frequency sweeping and obtains the phase difference, measured by the phase comparator 2253, between the voltage and the current. If a current measured phase difference is less than a previous measured phase difference, the forward frequency modulation is continued to increase the sweeping frequency. If the current measured phase difference is greater than the previous measured phase difference, the backward frequency modulation is performed to decrease the sweeping frequency. By cyclically and continuously adjusting the sweeping frequency until the phase difference, measured by phase comparator 2253, between the voltage and the current is 0, the corresponding sweeping frequency is determined as the second frequency fr .

[0059] The frequency modulation based on the MCU controller 221 in the product is carried out based on the reference frequency value in a manner of increase or decrease by the minimum step value. That is, the frequency value that the MCU controller 221 can obtain is equal to reference frequency value (e.g. 3.0 MHz)+ $n \times$ minimum step value (0.005 MHz), where n is a positive integer. Furthermore, in a specific product, a difference between the first frequency fm and the second frequency fr is about 0.01 MHz, the MCU controller 221 determines that at most only two n values can be actually selected during the obtaining of the third frequency. Thus, in a specific implementation of the product, the MCU controller 221 is configured to select any one of the only two available frequency values as the third frequency, and an error can be ignored compared with a conventional operating frequency range of 3.2 MHz to 3.4 MHz.

[0060] In still some changing embodiments, based on the fact that a difference between the first frequency fm and the second frequency fr of the ultrasonic atomization element 12 is about 0.01 MHz during general use of the product, which is much less than the conventional operating frequency range of 3.2 MHz to 3.4 MHz of the ultrasonic atomization element 12, a mean value of the first frequency fm and the second frequency fr is used as the third frequency. This can be considered as an optimal resonant frequency point, namely: third frequency=(first frequency fm + second frequency fr)/2.

[0061] In a more preferred embodiment, the frequency modulation based on the MCU controller 221 in the product is carried out based on the reference frequency value in a manner of increase or decrease by the minimum step value. That is, a frequency value that the MCU controller 221 can obtain is equal to reference frequency value (e.g. 3.0 MHz)+ $n \times$ minimum step value (0.005 MHz), where n is a positive integer. In a specific embodiment, a frequency value, closest to (first frequency fm + second frequency fr)/2, among frequency values that the MCU controller 221 can obtain is selected as the third frequency. A difference between the closest third frequency obtained by the MCU controller 221 according to this specific manner and a mean value of the first frequency fm and the second frequency fr is less than half of the minimum step value (0.005 MHz).

[0062] In some embodiments, after the production and assembling of the electronic atomization apparatus 100 is completed, the MCU controller 221 controls the execution of the above control steps S10 to S30 to obtain the third frequency, and saves or stores the third frequency, and the third frequency is then used as a subsequent operating frequency of the ultrasonic atomization element 12 to control the operation of the ultrasonic atomization element 12.

[0063] Or, in some embodiments, changes in a temperature of the ultrasonic atomization element 12 or the amount of the liquid substrate accumulated on a surface of the ultrasonic atomization element 12 in each inhalation action may cause a shift in the optimal resonant

frequency of the ultrasonic atomization element 12. The MCU controller is configured to cyclically and repeatedly execute the above control steps S10 to S30 at a time interval of 20 ms to 500 ms in each inhalation action of a user, so as to track the frequency and control atomization in real time through the inhalation action of the user, and continuously adjust the operating frequency of the ultrasonic atomization element 12 in real time in each inhalation action of the user to make the ultrasonic atomization element 12 in the optimal resonant state.

[0064] Or, in still some changing embodiments, the optimal resonant frequency of the ultrasonic atomization element 12 may shift due to changes in factors such as the mechanical wear of the ultrasonic atomization element 12 caused by long-term use or the viscosity of the liquid substrate. The MCU controller 221 is configured to execute the above control steps S10 to S30 at a predetermined time interval to re-update or calibrate the third frequency.

[0065] It should be noted that the preferred embodiments of this application are provided in the specification and the accompanying drawings of this application, but are not limited to the embodiments described in this specification. Further, a person of ordinary skill in the art can make improvements or modifications according to the foregoing descriptions, and all of the improvements and modifications shall fall within the protection scope of the appended claims of this application.

Claims

1. An electronic atomization apparatus, comprising:

a liquid storage cavity configured to store a liquid substrate;
an ultrasonic atomization element configured to be driven by an alternating current to atomize the liquid substrate and generate aerosols;
a drive unit connected to the ultrasonic atomization element and configured to provide the alternating current to the ultrasonic atomization element; and
a controller configured to execute control steps, wherein the control steps comprise:

controlling the drive unit to provide a frequency-varying alternating current to the ultrasonic atomization element, obtaining power of the ultrasonic atomization element to determine a first frequency at maximum power of the ultrasonic atomization element, and obtaining a phase difference between a voltage and a current of the ultrasonic atomization element to determine a second frequency when the phase difference between the voltage and the current of the ultrasonic atomization element is zero;

- and
controlling the drive unit to provide an alternating current with a third frequency to the ultrasonic atomization element, to drive the ultrasonic atomization element to atomize the liquid substrate, wherein the third frequency is between the first frequency and the second frequency.
2. The electronic atomization apparatus according to claim 1, wherein the third frequency is a mean value of the first frequency and the second frequency.
3. The electronic atomization apparatus according to claim 1, wherein a difference between the third frequency and a mean value of the first frequency and the second frequency is less than half of a minimum step value of frequency modulation of the MCU controller.
4. The electronic atomization apparatus according to any one of claims 1 to 3, further comprising:
a power measurement module configured to measure the power of the ultrasonic atomization element, wherein
the MCU controller obtains the power of the ultrasonic atomization element by sampling or receiving a measurement result of the power measurement module.
5. The electronic atomization apparatus according to claim 4, wherein the power measurement module comprises an operational amplifier.
6. The electronic atomization apparatus according to any one of claims 1 to 3, further comprising:
a phase measurement module configured to measure the phase difference between the voltage and the current of the ultrasonic atomization element, wherein
the MCU controller obtains the phase difference between the voltage and the current of the ultrasonic atomization element by sampling or receiving a measurement result of the phase measurement module.
7. The electronic atomization apparatus according to claim 6, wherein the phase measurement module comprises:
a waveform converter configured to convert the voltage of the ultrasonic atomization element into a first square wave signal and the current of the ultrasonic atomization element into a second square wave signal; and
a phase comparator configured to calculate the
- phase difference between the first square wave signal and the second square wave signal.
8. The electronic atomization apparatus according to claim 7, wherein the phase measurement module further comprises:
a direction comparator configured to compare a direction of the first square wave signal with a direction of the second square wave signal.
9. The electronic atomization apparatus according to any one of claims 1 to 3, further comprising:
an airflow sensor configured to sense inhalation of a user, wherein
the controller is configured to repeatedly execute the control steps at a predetermined time interval during the inhalation of the user.
10. A control method for an electronic atomization apparatus, wherein the electronic atomization apparatus comprises:
a liquid storage cavity configured to store a liquid substrate;
an ultrasonic atomization element configured to be driven by an alternating current to atomize the liquid substrate and generate aerosols; and
a drive unit which is connected to the ultrasonic atomization element and is configured to provide the alternating current to the ultrasonic atomization element; and
the control method comprises:
controlling the drive unit to provide a frequency-varying alternating current to the ultrasonic atomization element, obtaining power of the ultrasonic atomization element to determine a first frequency at maximum power of the ultrasonic atomization element, and obtaining a phase difference between a voltage and a current of the ultrasonic atomization element to determine a second frequency when the phase difference between the voltage and the current of the ultrasonic atomization element is zero; and
controlling the drive unit to provide an alternating current with a third frequency to the ultrasonic atomization element, to drive the ultrasonic atomization element to atomize the liquid substrate and generate aerosols, wherein the third frequency is between the first frequency and the second frequency.

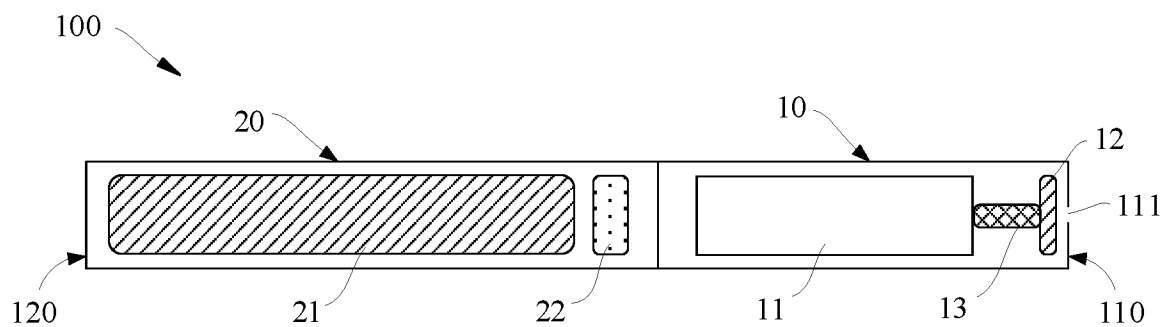


FIG. 1

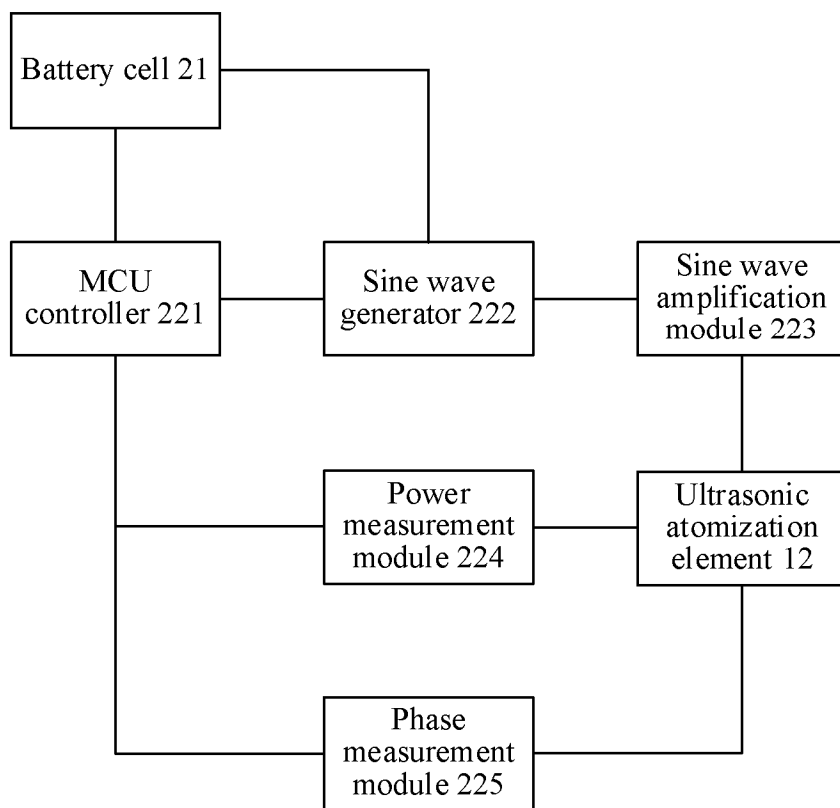


FIG. 2

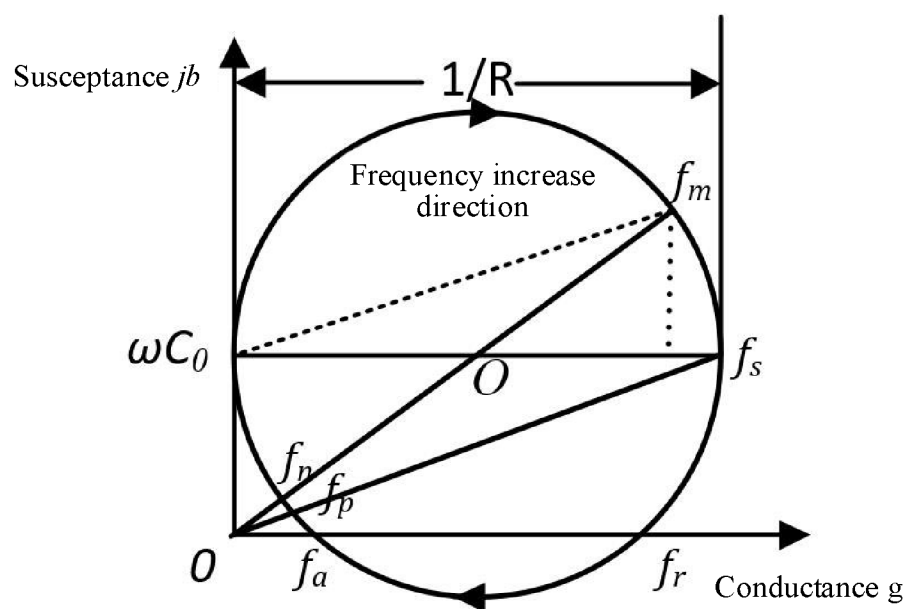


FIG. 3

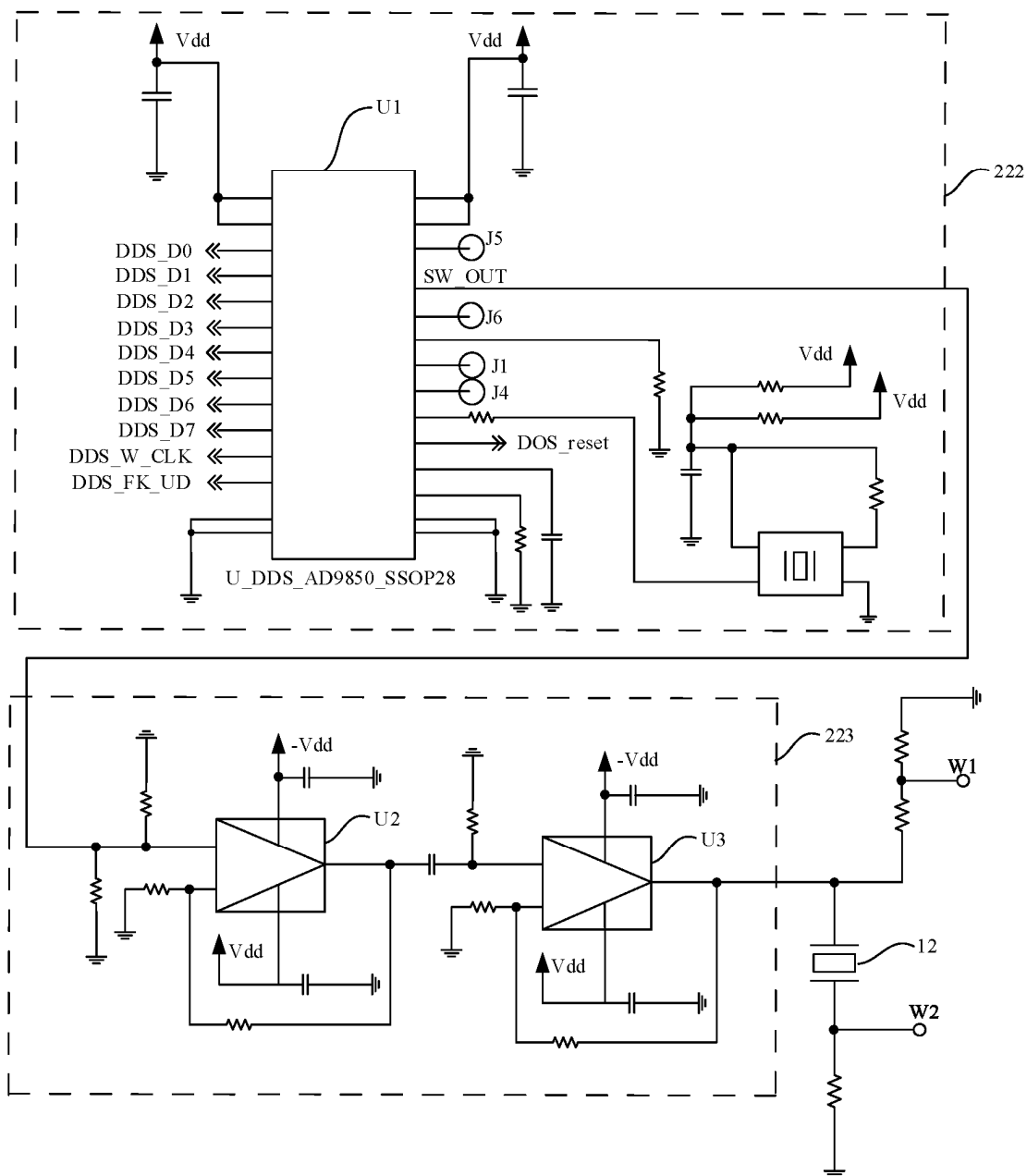


FIG. 4

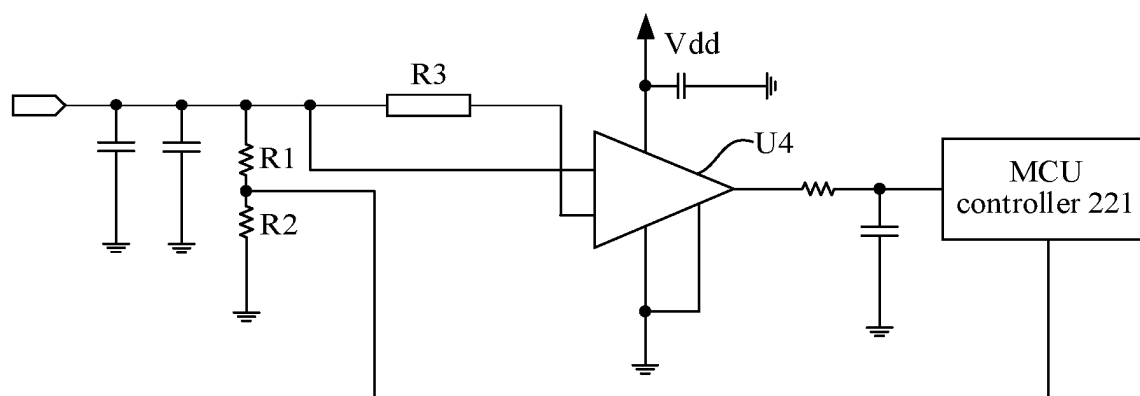


FIG. 5

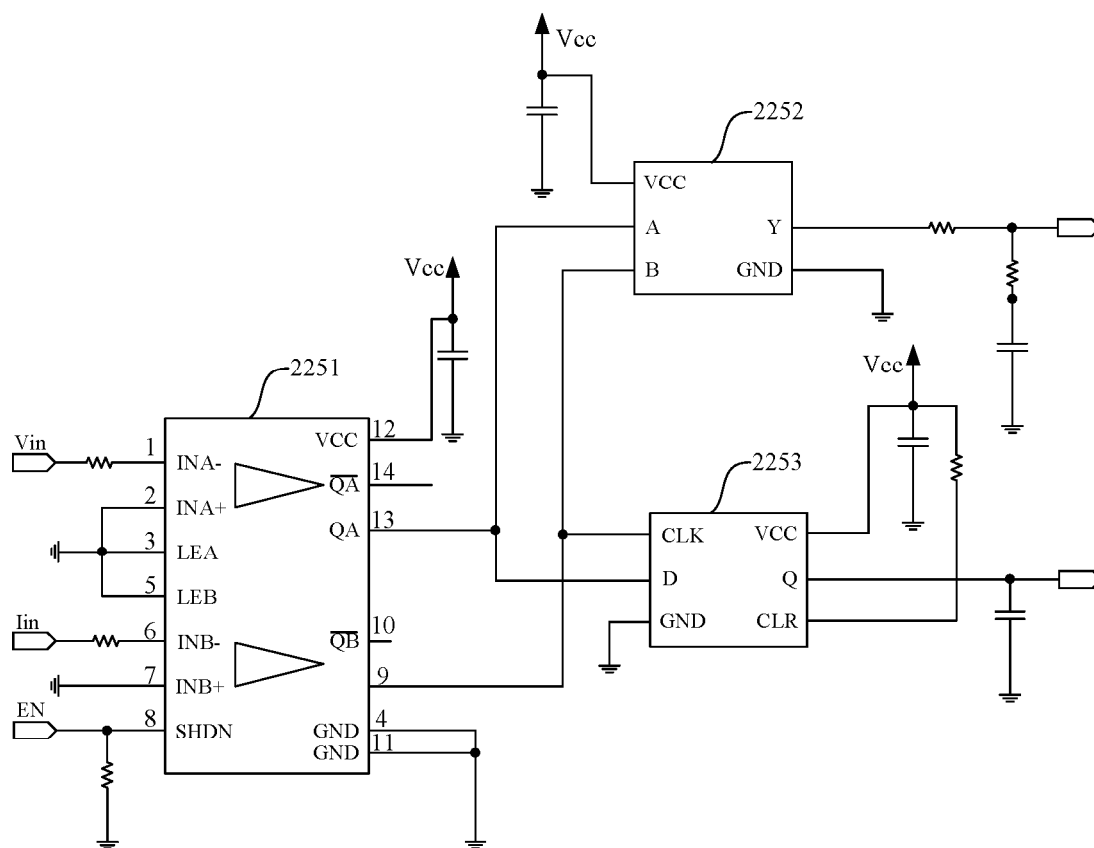


FIG. 6

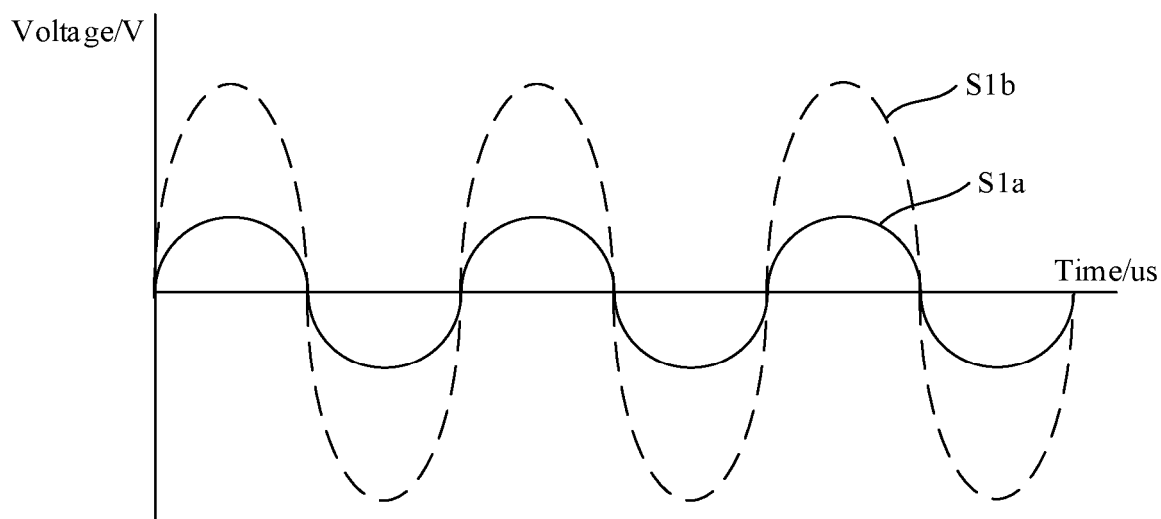


FIG. 7

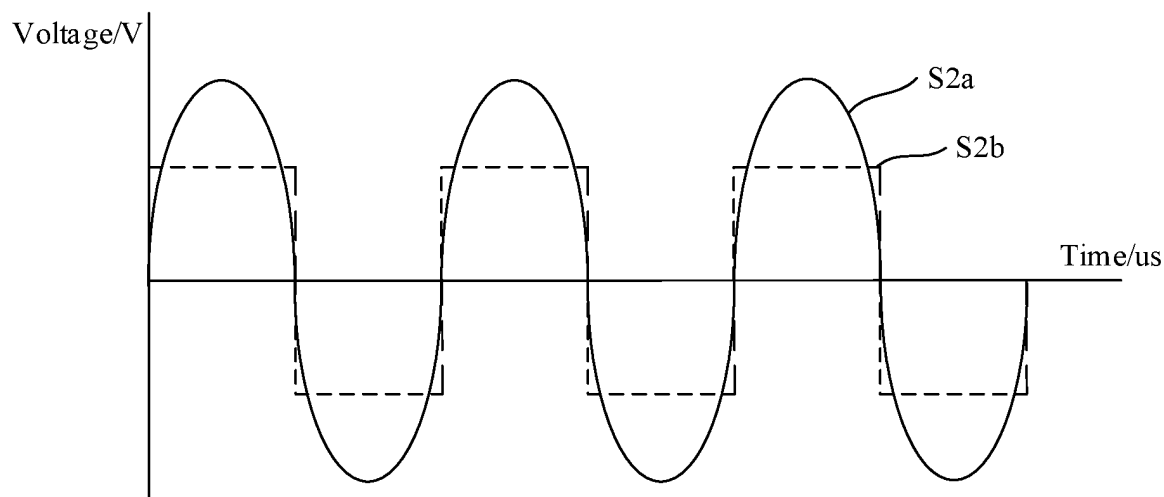


FIG. 8

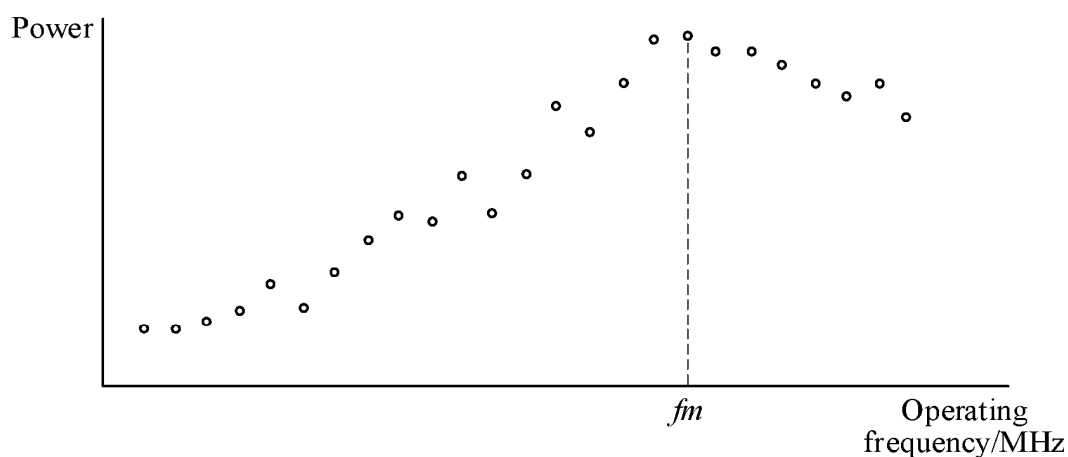


FIG. 9

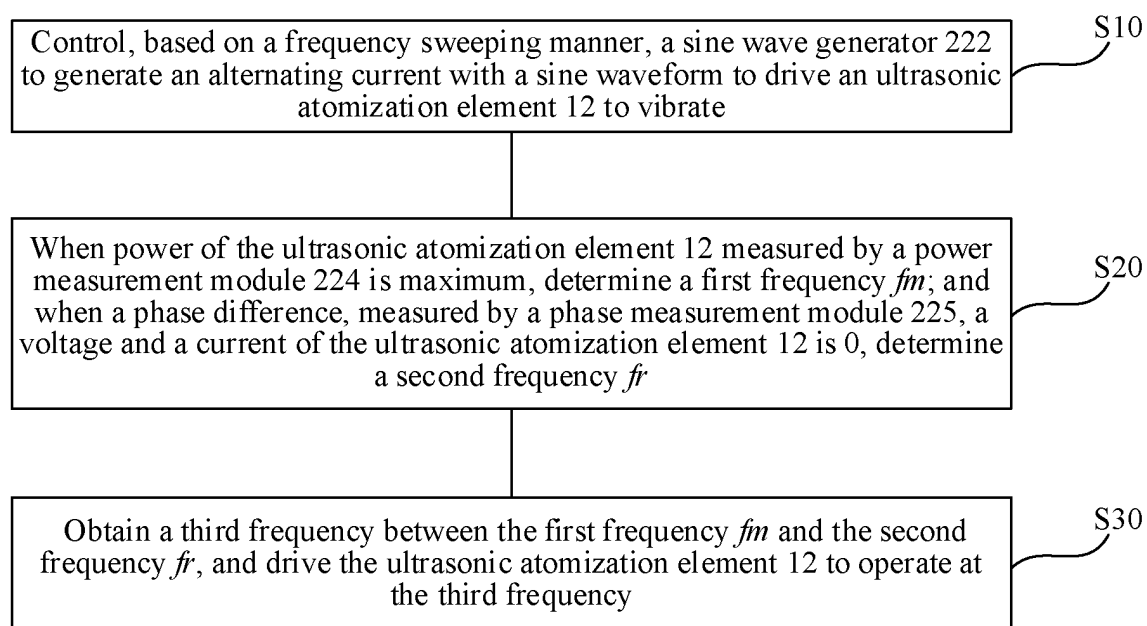


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2024/119080

A. CLASSIFICATION OF SUBJECT MATTER

A24F 40/50 (2020.01)i; A24F40/10(2020.01)i; B05B17/06(2006.01)i

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)

IPC:A24F B05B

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)

CNTXT: ENTXTC; VEN: 电子烟, 雾化, 气溶胶, 电压, 电流, 功率, 超声, 频率, 谐振, electronic cigarette, atomize, aerosol, voltage, current, power, ultrasound, frequency, resonance

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 115363282 A (SHENZHEN FIRST UNION TECHNOLOGY CO., LTD.) 22 November 2022 (2022-11-22) description, pages 3-7, and figures 1-11	1-10
A	CN 115381152 A (SHENZHEN FIRST UNION TECHNOLOGY CO., LTD.) 25 November 2022 (2022-11-25) entire document	1-10
A	CN 109689229 A (OMRON HEALTHCARE CO., LTD.) 26 April 2019 (2019-04-26) entire document	1-10
A	CN 112957573 A (HUIZHOU YOUWEI CHUANGKE ELECTRONICS CO., LTD.) 15 June 2021 (2021-06-15) entire document	1-10
A	WO 2022242733 A1 (SHENZHEN FIRST UNION TECHNOLOGY CO., LTD.) 24 November 2022 (2022-11-24) entire document	1-10

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"D" document cited by the applicant in the international application	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"E" earlier application or patent but published on or after the international filing date	"&" document member of the same patent family
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 07 January 2025	Date of mailing of the international search report 07 January 2025
Name and mailing address of the ISA/CN China National Intellectual Property Administration (ISA/CN) China No. 6, Xitucheng Road, Jimenqiao, Haidian District, Beijing 100088	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 2022)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2024/119080

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CN	115363282	A	22 November 2022	None			
CN	115381152	A	25 November 2022	None			
CN	109689229	A	26 April 2019	DE	112017004833	T5	13 June 2019
				DE	112017004833	B4	24 November 2022
				WO	2018061494	A1	05 April 2018
				US	2019210055	A1	11 July 2019
				US	10603683	B2	31 March 2020
				JP	2018050821	A	05 April 2018
				JP	6711225	B2	17 June 2020
CN	112957573	A	15 June 2021	None			
WO	2022242733	A1	24 November 2022	EP	4353107	A1	17 April 2024
				EP	4353107	A4	25 December 2024
				US	2024268480	A1	15 August 2024

REFERENCES CITED IN THE DESCRIPTION

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