

Description

Technical Field

5 **[0001]** This invention relates to an oscillating-velocity detecting device that detects the oscillating velocity of the emitting surface of an ultrasonic transducer.

Technical Background

10 **[0002]** Treating an object or a substance by the use of ultrasonic energy is called high-intensity ultrasonic application. High-intensity ultrasonic waves are used in cleaning, emulsifying, dispersing, fostering chemical reactions, forming plastic, cutting work, bonding plastic or joining metal or the like. A high-intensity ultrasonic-wave generator comprising an ultrasonic oscillator (a form of a high-frequency power source) and an ultrasonic transducer (electro-mechanical transducer) can generate high-intensity ultrasonic waves. Regarding the treatment of an object or a substance in using
15 a high-intensity ultrasonic generator, the oscillating velocity of the emitting surface of an ultrasonic transducer is closely related to the ultrasonic-treatment effect. Thus, the measured oscillating velocity of the emitting surface of an ultrasonic transducer (transducer emitting surface) has an important role in monitoring and controlling the product quality at the production site. Also, the oscillating velocity of a transducer-emitting surface is linked to fatigue rupture due to vibrational stress of the transducer material or to deterioration of the vibration property. Therefore, monitoring the oscillating velocity
20 of the transducer emitting surface is one of the important tasks in preventing the ultrasonic transducer from working abnormally or from failing, caused by excessive vibration.

[0003] As conventional devices for measuring the oscillating velocity of an ultrasonic transducer, there is the photonics sensor and the laser Doppler vibrometer or the like. However, these measuring devices are costly and hard to adopt at the job site (i.e. the production line or the like whereat an ultrasonic generator may be installed). Also, such measuring
25 devices need the adaptation of a method for measuring the oscillating velocity by exposing the transducer emitting surface to light, and another disadvantage of such devices is that the oscillating velocity of the transducer emitting surface cannot be measured when there is a sonic load, since such a transducer emitting surface is in contact with a solid, a liquid or the like.

[0004] In this light, Patent Document 1 shows a drive unit with a detecting means for detecting the oscillating velocity of the ultrasonic transducer. This detecting means comprises two series-connected resistors and emits the detected
30 voltage that is proportional to the oscillating velocity of the ultrasonic transducer by dividing the electric voltage being emitted from the electrodes of the ultrasonic transducer. Adapting this structure makes it possible to detect the oscillating velocity of the ultrasonic transducer, even if there is a sonic load. Patent Document 2 shows an ultrasonic cleaning device comprising a bridge circuit for detecting the oscillating velocity of an ultrasonic transducer. The bridge circuit
35 comprises an ultrasonic transducer that is provided on one side of the bridge circuit, three pieces of bridge-circuit condensers of which each is provided on the other three sides of the bridge circuit, and a bridge-circuit emitting-detector resistor for detecting the output current and output voltage. Of the bridge circuit, the ultrasonic transducer and the condenser of the bridge circuit are formed such that the impedance is equilibrated. The bridge circuit is formed such that the oscillating velocity is detected by the output voltage and by the output current that are detected by the bridge
40 circuit output-detector resistor. Should this structure be adopted, even if there is a sonic load, the oscillating velocity of the ultrasonic transducer can be detected.

Prior Arts

45 Patent Documents

[0005]

Patent Document 1: Japanese Published Unexamined Application No. H08-1091 (Refer to Fig. 1)
50 Patent Document 2: Japanese Published Unexamined Application No. 2009-166028 (Refer to Fig. 10)

Summary of the invention

Problems to be resolved by the invention

55 **[0006]** However, as shown in Patent Document 1, just detecting the electrode voltage of the ultrasonic transducer cannot get an accurate oscillating velocity reading. Specifically, even when impressing the same voltage onto the ultrasonic transducer, as the sonic load of the ultrasonic transducer increases, the impedance of the ultrasonic transducer

increases, thus decreasing the oscillating velocity. For this reason, just detecting the voltage by such a detecting means cannot get an accurate oscillating-velocity reading according to the sonic load. Thus, a condenser for the bridge circuit, matching the impedance of the ultrasonic transducer, is provided on the bridge circuit of Patent Document 2. Therefore, when using another ultrasonic transducer of a different property, the condenser for each bridge circuit should be changed, so that the impedance can be equilibrated in such bridge circuits. Therefore, it is necessary to equip such new and special bridge circuits, thus increasing the cost of equipment components.

[0007] This invention was achieved in light of the aforementioned problems in providing an oscillating-velocity detecting device that can precisely detect the oscillating velocity of the emitting surface of an ultrasonic transducer at low cost, in spite of there being a sonic load or not.

Means for solving the problems

[0008] To solve the above problems, the first aspect of this invention refers to an oscillating-velocity detecting device provided between an ultrasonic transducer having an emitting surface for emitting ultrasonic waves by vibrating in a specific oscillation mode and an ultrasonic oscillator for driving the ultrasonic transducer, which are all provided within an ultrasonic generator for doing specific processes in emitting ultrasonic waves from an emitting surface, characterized in that said oscillating-velocity detecting device comprises: an input means for entering digital signals that show both the braking capacity of the ultrasonic transducer and the force coefficient of the emitting surface while oscillating in said specific oscillation mode; a detecting means that is joined to an electric terminal of the ultrasonic transducer for detecting the analog signals of the voltage and of the current at the electric terminal; a conversion means for changing the analog signal of the voltage and of the current detected by the detecting means into digital signals; and a digital-signal processing means for doing arithmetic operations based on the basic formula of electro-acoustic conversion by using the digital signals of the braking capacity, of the force coefficient and of the voltage and current and then calculating the oscillating velocity of the emitting surface of the ultrasonic transducer.

[0009] The first aspect of this invention makes it possible, even when a sonic load is added onto the emitting surface of the ultrasonic transducer, to measure the oscillating velocity readily by providing an oscillating-velocity detecting device between the ultrasonic oscillator and the ultrasonic transducer, thus making it possible to detect and monitor the oscillating velocity of the emitting surface of the ultrasonic transducer in real time. Also, the oscillating-velocity detecting device of this invention does arithmetic operations using the basic formula of electro-acoustic conversion, thus making it possible to detect the oscillating velocity of the emitting surface at low cost, compared to using a photonics sensor or a laser Doppler vibrometer that uses light. Also, the oscillating-velocity detecting device of this invention computes the oscillating velocity of the emitting surface by using the braking capacity and force coefficient, as well as the voltage and the current at the electric terminal of the ultrasonic transducer, thus making it possible in getting accurately the oscillating velocity compared to the conventional arts of Patent Document 1. Also, even when measuring the ultrasonic transducer of a different property, the oscillating velocity of the emitting surface can be gotten only by entering the braking capacity and the force coefficient of the ultrasonic transducer by the input means. In this case, it is unnecessary to change the circuit according to the impedance of the ultrasonic transducer, unlike the invention as described in Patent Document 2, thus making it possible in getting the oscillating velocity easily and at low cost.

[0010] The second aspect of this invention refers to an oscillating-velocity detecting device according to the first aspect of this invention, characterized in that the ultrasonic oscillator mechanically vibrates the ultrasonic transducer at about the resonance frequency in the above oscillation mode, and in that the input means is for entering the digital signals of the force coefficient (A-type force coefficient) in motion with the resonance frequency (A-type resonance frequency).

[0011] Therefore, the second aspect of this invention makes it possible in getting more accurately the oscillating velocity of the emitting surface when activating the ultrasonic transducer at about the resonance frequency.

[0012] The third aspect of this invention refers to an oscillating-velocity detecting device according to the first aspect of this invention, characterized in that the ultrasonic oscillator mechanically vibrates the ultrasonic transducer at about the anti-resonance frequency in oscillation mode, and that the input means enters the digital signals (B-type force coefficient) in motion with the anti-resonance frequency (B-type resonance frequency).

[0013] Therefore, the third aspect of this invention makes it possible in getting more accurately the oscillating velocity of the emitting surface when the ultrasonic transducer is being driven at about the anti-resonance frequency.

[0014] The fourth aspect of this invention refers to an oscillating-velocity detecting device according to any one of the first to third aspects of this invention, characterized in that the digital-signal processing means is a means for processing digital signals by using a delay element, an adder-subtractor and a coefficient multiplier.

[0015] The fourth aspect of this invention allows for the digital-signal processing means to process digital signals by using a delay element, an adder-subtractor and a coefficient multiplier. Thus, such digital-signal processing is less affected by variation in property due to change in temperature or the age of the circuit element. Digital-signal processing also boosts reproducibility and stability in getting the oscillating velocity and makes possible in getting such oscillating velocity precisely. Also, if the signal processing means consists of an analog circuit, there is the disadvantage of needing

too many circuit elements. Should such digital-signal processing be done by using a delay element, an adder-subtractor and a coefficient multiplier, then such a digital-signal processing means can be set up by computer software or by an LSI or the like, thus making it possible in reducing the size of such an oscillating-velocity detecting device or the cost of using such a device.

[0016] The fifth aspect of this invention refers to an oscillating-velocity detecting device according to the second aspect of this invention, characterized in that the digital-signal processing means comprises: a delay element and a first subtractor for doing differential processing of the digital signals regarding the voltage; a first-coefficient variable multiplier for multiplying the coefficient matching the digital signal of the braking capacity based on the subtraction value of the first subtractor; a second subtractor for subtracting the multiplication value of the first-coefficient variable multiplier from the digital signal of the current; and a second-coefficient variable multiplier for multiplying the coefficient matching the digital signal of the force coefficient by the subtraction value of the second subtractor and then emitting such multiplication value as the oscillating velocity.

[0017] The fifth aspect of this invention allows for arranging the digital-signal processing means that is discretized and approximated by using the backward difference method. Using the digital-signal processing means of this invention allows for the digital-signal processing to match the movement when the ultrasonic transducer is being driven at about the resonance frequency, thus making it possible in more precisely getting the oscillating velocity of the emitting surface at about the resonance frequency.

[0018] The sixth aspect of this invention refers to an oscillating-velocity detecting device according to the third aspect of this invention, characterized in that the digital-signal processing means comprises a first-coefficient variable multiplier for multiplying the coefficient matching the digital signal of the braking capacity by the digital signal regarding the current; a delay element and an adder for doing differential processing of the multiplication value of the first-coefficient variable multiplier; a subtractor for subtracting the addition value of the adder from the digital signal regarding the voltage; a second-coefficient variable multiplier for multiplying the coefficient that matches the digital signal of the force coefficient by the subtraction value of the subtractor and then emitting such multiplication value as the oscillating velocity.

[0019] The sixth aspect of this invention allows for arranging the digital-signal processing means that is discretized and approximated by using the backward difference method. Using the digital-signal processing means of this invention allows for the digital signal processing to match the movement when the ultrasonic transducer is being driven at about the anti-resonance frequency, thus making it possible in more precisely getting the oscillating velocity of the emitting surface at about the anti-resonance frequency.

[0020] A method for getting the oscillating velocity, instead of using the backward-difference method, is using the forward-difference method or the discretization method by applying bilinear transformation. However, should the backward-difference method be used, as described in the fifth and sixth aspects of this invention, the arithmetic process is relatively easy, thus making it possible in getting the oscillating velocity quickly.

[0021] The seventh aspect of this invention refers to an oscillating-velocity detecting device according to any one of the first to sixth aspects of this invention, characterized in that the sampling frequency of the conversion means is set at twice as much or more as the drive frequency of the ultrasonic transducer.

[0022] The seventh aspect of this invention sets the sampling frequency at twice as much or more as the drive frequency of the ultrasonic transducer (at about the resonance frequency or anti-resonance frequency), thus making it surely possible in getting the oscillating velocity of the emitting surface.

Effects of the invention

[0023] As described above, the first to seventh aspects of this invention allows for precisely detecting the oscillating velocity of the emitting surface of the ultrasonic transducer at low cost, with or without a sonic load.

Brief explanation of the drawings

[0024]

Fig. 1 is a block diagram showing the skeleton framework of the ultrasonic generator as the first embodiment of this invention.

Fig. 2 is a block diagram showing the digital-signal processing part as the first embodiment of this invention.

Fig. 3 is a timing chart showing the arithmetic-operation values of the oscillating velocity in the case that the sampling frequency is twice as much as the drive frequency.

Fig. 4 is a timing chart showing the arithmetic-operation values of the oscillating velocity in the case that the sampling

frequency is five times as much as the drive frequency.

Fig. 5 is a timing chart showing the arithmetic-operation values of the oscillating velocity in the case that the sampling frequency is 10 times as much as the drive frequency.

Fig. 6 is a timing chart showing the arithmetic-operation values of the oscillating velocity in the case that the sampling frequency is 20 times as much as the drive frequency.

Fig. 7 is a block diagram showing the digital-signal processing part as the second embodiment of this invention.

Modes for carrying out the invention

The first embodiment of this invention

[0025] Hereinafter, the first embodiment of the ultrasonic generator of this invention is described in reference to the drawings.

[0026] As shown in Fig. 1, the ultrasonic generator 1 of the embodiment of this invention comprises an ultrasonic oscillator 2, an ultrasonic transducer 3, an oscillating-velocity detecting device 4 provided between the ultrasonic oscillator 2 and the ultrasonic transducer 3, and a digital input device 5. The ultrasonic generator 1 is used e.g. in ultrasonic cleaning.

[0027] The ultrasonic oscillator 2 is joined to the ultrasonic transducer 3 by the oscillating-velocity detecting device 4 and emits a drive signal of 27.8kHz to drive the ultrasonic transducer 3. The ultrasonic transducer 3 is e.g. a bolted Langevin-type transducer and has an emitting surface 7 for emitting ultrasonic waves by mechanically vibrating in longitudinal-oscillation mode. Of the embodiment of this invention, the resonance frequency of the ultrasonic transducer 3 in longitudinal-oscillation mode is 27.8kHz. The ultrasonic transducer 3, while being mechanically vibrated by the drive signal that is being emitted from the ultrasonic oscillator 2, emits ultrasonic waves onto the cleaning-liquid W1, which is the sonic load.

[0028] The oscillating-velocity detecting device 4 comprises a voltage detector 11, a current detector 12, low-frequency pass filters 13, 14, 15, an A/D converter 16, 17, a digital-signal processing part 18, a D/A converter 19, a digital indicator 20 and an analog indicator 21. Also, a pair of input terminals 23a, 23b and output terminals 24a, 24b are provided on the oscillating-velocity detecting device 4. The input terminals 23a, 23b are joined to the ultrasonic oscillator 2, and the output terminals 24a, 24b are joined respectively to the electric terminals 25a, 25b of the ultrasonic transducer 3. Of the oscillating-velocity detecting device 4, the input terminal 23a is joined to the output terminal 24a by internal wiring and by the current detector 12. The other input terminal 23b is joined to the other output terminal 24b by internal wiring. The pair of input terminals 23a, 23b and output terminals 24a, 24b of the oscillating-velocity detecting device 4 send the drive signal that is emitted from the ultrasonic oscillator 2 to the ultrasonic transducer 3.

[0029] The voltage detector 11 as the detecting means is joined in parallel to each electric terminal 25a, 25b of the ultrasonic transducer 3 by each output terminal 24a, 24b. The voltage detector 11 consists e.g. of a resistant-voltage dividing circuit that detects the voltage $e_o(t)$ at the electric terminals 25a, 25b of the ultrasonic transducer 3 as a formula of the analog-signal voltage, $x_1(t) = e_o(t)/\alpha$. α is a constant number.

[0030] The current detector 12 as the detecting means is joined in series to the electric terminal 25a of the ultrasonic transducer 3 by the output terminal 24a. The current detector 12 comprises e.g. a current trans (CT), shunt resistance or the like and detects the current $i_o(t)$ at the electric terminal 25a of the ultrasonic transducer 3 as a formula of the analog-signal voltage, $x_2(t) = i_o(t)/\beta$. β is a constant number.

[0031] The voltage detector 11 is joined to the A/D converter 16 (conversion means) by the low-frequency pass filter 13. The A/D converter 16 is joined to the digital-signal processing part 18. The analog signal voltage $x_1(t)$ emitted from the voltage detector 11 goes through the low-frequency pass filter 13, so that the unnecessary high-frequency component is removed by the analog signal voltage $x_1(t)$. After that, the analog signal voltage $x_1(t)$ is quantized per-sampling period T_s within the A/D converter 16 and then changed into the digital signal $x_1(n)$. After such change, the digital signal $x_1(n)$ is sent to the digital-signal processing part 18 (digital signal processing means).

[0032] The current detector 12 is joined to the A/D converter 17 (conversion means) by the low-frequency pass filter 14. The A/D converter 17 is joined to the digital-signal processing part 18. The analog signal voltage $x_2(t)$ emitted from the current detector 12 goes through the low-frequency pass filter 14, so that the unnecessary high-frequency component is removed by the analog signal voltage $x_2(t)$. After that, the analog signal voltage $x_2(t)$ is quantized per-sampling period T_s within the A/D converter 17 and then changed to digital signal $x_2(n)$. After such change, the digital signal $x_2(n)$ is sent to the digital-signal processing part 18 (digital-signal processing means).

[0033] When the drive frequency (resonance frequency of the embodiment of this invention) of the ultrasonic transducer 3 is f_o , the sampling period T_s is set to keep the relationship of $T_s < 1/(2f_o)$. In other words, the sampling frequency f_s of the A/D converter 16, 17 is set at twice as much or more ($f_s > 2f_o$) as the drive frequency f_o of the ultrasonic transducer 3.

[0034] As the input means, two external input terminals 27a and 27b are provided on the oscillating-velocity detecting device 4, and each is joined to the digital input device 5. An operator runs the digital input device 5 to enter the braking capacity C_d of the ultrasonic transducer 3 and the digital signal of the force coefficient A_A into the digital-signal processing part 18 by the external input terminals 27a, 27b. The force coefficient A_A is the ratio between the applied voltage at the electric terminals 25a, 25b and the drive force generated on the emitting surface 7 (mechanical terminal) of the ultrasonic transducer 3 while being mechanically vibrated by the resonance frequency (A-type resonance frequency) and is called an "A-type force coefficient." Also, the braking capacity C_d and the force coefficient A_A are both typical values of the ultrasonic transducer 3 that are measured prior to shipping the product. The values that are measured just before or while using the product can also be used as the braking capacity C_d and the force coefficient A_A .

[0035] The digital-signal processing part 18 is the device for applying arithmetic operations based on the basic formula of electro-acoustic conversion and is actualized e.g. by the digital-signal processor (DSP) of this invention. Specifically, when the ultrasonic transducer 3 is vibrated at about the resonance frequency (A-type resonance frequency), the detected value $y_0(t)$ of the oscillating velocity within the continuous-time domain can be gotten by the following formula. (1).
Formula (1)

$$y_0(t) = \frac{1}{A_A} \left[\beta x_2(t) - \alpha C_d \frac{dx_1(t)}{dt} \right] \quad \dots (1)$$

[0036] The digital-signal processing part 18 computes the oscillating velocity by discretizing and approximating the detected value $y_0(t)$ as the oscillating velocity of the above formula (1) and then emits the digital signal $y_0(n)$. Specifically, the digital-signal processing part 18 as the embodiment of this invention computes the digital signal $y_0(n)$ of the oscillating velocity of the emitting surface 7 of the ultrasonic transducer 3 by using the digital signals $x_1(n)$, $x_2(n)$ matching the voltage $e_0(t)$ and the current $i_0(t)$ at the electric terminals 25a, 25b of the ultrasonic transducer 3, as well as by using the digital signal of the braking capacity C_d and of the force-coefficient A_A . Hereinafter, the signal processing of the digital-signal processing part 18 as the embodiment of this invention is described.

[0037] As shown in Fig. 2, the digital-signal processing part 18 comprises the delay element 31, the first subtractor 32, the first-coefficient variable multiplier 33, the coefficient multiplier 34, the second subtractor 35 and the second-coefficient variable multiplier 36. Within the digital-signal processing part 18, the digital signal $x_1(n)$ of the voltage $e_0(t)$ that is detected by the voltage detector 11 enters the first subtractor 32. Then, the digital signal $x_1(n-1)$ that is first delayed by the delay element 31 enters the first subtractor 32. The first subtractor 32 then subtracts the digital signal $x_1(n-1)$ delayed response from the digital signal $x_1(n)$ to enter such subtraction value into the first-coefficient variable multiplier 33. The delay element 31 and first subtractor 32 work as a differentiator for differentially processing the digital signal $x_1(n)$ regarding the voltage $e_0(t)$. The digital signal of the braking capacity C_d enters the first-coefficient variable multiplier 33 by the external input terminal 27a. The first-coefficient variable multiplier 33 then multiplies the coefficient $\alpha \cdot C_d / T_s$ that matches the digital signal of the braking capacity C_d by the subtraction value of the first subtractor 32 and then enters such multiplication value into the second subtractor 35.

[0038] On the other hand, the digital signal $x_2(n)$ of the current $i_0(t)$ that is detected by the current detector 12 enters the coefficient multiplier 34. Then, the coefficient multiplier 34 multiplies the digital signal $x_2(n)$ by the coefficient 6 and then enters such multiplication value into the second subtractor 35. The second subtractor 35 then subtracts the multiplication value of the first-coefficient variable multiplier 33 from the subtraction value (the digital signal regarding the current $i_0(t)$) of the coefficient subtractor 34 and then enters such subtraction value into the second-coefficient variable multiplier 36. The digital signal of the force coefficient A_A then enters the second-coefficient variable multiplier 36 by the external input terminal 27b. The second-coefficient variable multiplier 36 multiplies the subtraction value of the second subtractor 35 by the coefficient $1/A_A$ that matches the digital signal of the force coefficient A_A and then emits the multiplication value as the digital signal $y_0(n)$ of the oscillating velocity.

[0039] As shown in Fig. 1, the digital signal $y_0(n)$ of the oscillating velocity emitted from the digital-signal processing part 18 is emitted to the outer side of the device by the output terminal 28 for digital signals. Also, the digital signal $y_0(n)$ of the oscillating velocity enters the digital signal indicator 20. Then, the detected value of the oscillating velocity is digitally shown. A liquid-crystal display (LCD) or a vacuum-fluorescent display tube (VFD) or the like can also be used as the digital signal indicator 20.

[0040] Furthermore, the digital signal $y_0(n)$ of the oscillating velocity is changed from digital signal to analog signal by the D/A convertor 19. Such analog signal then enters the low-frequency pass filter 15 where the high-frequency component is removed. Then, the analog signal of the oscillating velocity is emitted to the outer side of the device by the output terminal 29 for such analog signals. Also, analog signals passing through the low-frequency pass filter 15 enter the analog indicator 21. A meter or the like shows the detected value of the oscillating velocity in the analog way.

[0041] The inventor of this invention changed the sampling frequency f_s of the A/D converters 16, 17 of the oscillation-velocity detecting device 4 to twice, five times, 10 times and 20 times as much as the drive frequency of the ultrasonic transducer 3 and then verified the oscillating velocity gotten by simulation. The values are shown in Figs. 3 to 6. Fig. 3 shows the result of simulation should the sampling frequency f_s be twice as much as the drive frequency f_o . Fig. 4 shows the result of simulation should the sampling frequency f_s be five times as much as the drive frequency f_o . Fig. 5 shows the result of simulation should the sampling frequency f_s be 10 times as much as the drive frequency f_o . Fig. 6 shows the result of simulation should the sampling frequency f_s be 20 times as much as the drive frequency f_o . At the bottom of Figs. 3 to 6, the theoretical values of the oscillating velocity are shown as a dotted line, which values are to be computed based on the waveform of the voltage as shown at the top of Figs. 3 to 6 and based on the current as shown in the middle of Figs. 3 to 6. The result of simulation of the oscillating velocity matching each sampling frequency f_s is shown as a solid line at the bottom of Figs. 3 to 6. Also, as shown in Figs. 3 to 6, should the sampling frequency f_s be twice as much as the drive frequency f_o , there is a discrepancy in the theoretical value of the oscillating velocity. However, increasing the sampling frequency f_s to five times, 10 times and 20 times as much as the drive frequency f_o confirmed that the oscillating velocity had been precisely detected.

[0042] Therefore, the embodiment of this invention realizes the following effects.

(1) Of the ultrasonic generator 1 of the embodiment of this invention, providing the oscillating-velocity detecting device 4 between the ultrasonic oscillator 2 and the ultrasonic transducer 3 makes it possible in getting the oscillating velocity easily, even when a sonic load is added onto the emitting surface 7 of the ultrasonic transducer 3, thus making it possible to detect and monitor in real time the oscillating velocity of the emitting surface 7 of the ultrasonic transducer 3 on site, wherever such ultrasonic generator 1 is being used. Also, the oscillating-velocity detecting device 4 of the embodiment of this invention does arithmetic operations by using the basic formula of electro-acoustic conversion, which makes it possible in detecting the oscillating velocity of the emitting surface 7 at low cost, compared to using a photonics sensor that uses light or to using a laser Doppler oscillator. Also, the oscillating-velocity detecting device 4 of this invention computes the oscillating velocity of the emitting surface 7 by using the braking capacity C_d and the force coefficient A_A , as well as the voltage $e_o(t)$ and the current $i_o(t)$ at the electric terminals 25a, 25b of the ultrasonic transducer 3, thus making it possible, compared to the conventional arts, of getting the oscillating-velocity reading precisely. Even when measuring the ultrasonic transducer 3 of different properties, the oscillating-velocity reading of the emitting surface 7 can be gotten only by entering the braking capacity C_d and the force coefficient A_A of the ultrasonic transducer 3 by the external input terminals 27a, 27b. In this case, it is unnecessary to change the circuit according to the impedance of the ultrasonic transducer 3, thus making it possible in getting the oscillating-velocity reading of the emitting surface 7 easily and at low cost.

(2) The digital-signal processing part 18 of the embodiment of this invention does digital-signal processing by using the delay element 31, the subtractor 32, 35 and the coefficient multipliers 33, 34, 35. Such digital-signal processing is less influenced by variation in property such as a change in temperature or the age of a circuit element, compared to analog-signal processing if such signal-processing part 18 were made of an analog circuit. Digital-signal processing also boosts reproducibility and stability in getting the oscillating velocity, thus making possible in getting such oscillating velocity precisely. Also, if such a signal-processing means is made of an analog circuit, there is the disadvantage of needing too many circuit elements. However, of the embodiment of this invention, the digital-signal processing part 18 consists of computer software in a digital-signal processor, thus making possible in reducing both the size of such oscillating-velocity detecting device 4 and the cost of using such detecting device 4.

(3) The ultrasonic oscillator 2 of the embodiment of this invention is a generator that mechanically vibrates the ultrasonic transducer 3 at about the resonance frequency in longitudinal-oscillation mode. The digital signal of the coefficient A_A at the resonance frequency enters the external input terminal 27b of the oscillating-velocity detecting device 4. The signal-processing part 18 is the processing means for computing the detected value $y_o(t)$ of the oscillating velocity as shown in the above formula (1) by discretizing and approximating based on the backward-infinite differential method and then emits such detected oscillating velocity as the digital signal $y_o(n)$. Using the digital-signal processing part 18 of the embodiment of this invention lets the digital-signal processing to match the motion when driving the ultrasonic transducer 3 at about the resonance frequency, thus making it possible in more accurately getting the oscillating velocity of the emitting surface 7 at about the resonance frequency.

(4) Of the ultrasonic generator 1 of the embodiment of this invention, the sampling frequency f_s of the A/D converters 16, 17 is set at twice as much or more as the drive frequency f_o (resonance frequency) of the ultrasonic transducer 3, thus making it possible in getting the oscillating velocity of the emitting surface 7 of the ultrasonic transducer 3. When the sampling frequency f_s is set at five times as much or more as the drive frequency f_o of the ultrasonic transducer 3, it is possible to get the oscillating velocity of the emitting surface 7 of the ultrasonic transducer 3 more

accurately.

(5) Of the embodiment of this invention, when driving the ultrasonic generator 1, the oscillating velocity is shown in real time on the digital indicator 20 and on the analog indicator 21. Thus, in viewing for any defect of the ultrasonic transducer 3 according to the oscillating velocity, it is possible to prevent the ultrasonic transducer 3 from failing.

The second embodiment of this invention

[0043] The second embodiment of this invention is described in reference to Fig. 7. As shown in the ultrasonic generator 1 as the above first embodiment of this invention, the ultrasonic transducer 3 is driven at about the resonance frequency (A-type resonance frequency). However, the second embodiment of this invention differs from the first embodiment in that the ultrasonic transducer 3 is driven at about the anti-resonance frequency (B-type resonance frequency). Specifically, the shape of the digital-signal processing part 18 and the value of the force coefficient A_B are different from that of the first embodiment of this invention. Hereinafter, the differences of the first and second embodiments are mainly described.

[0044] Should the ultrasonic transducer 3 be vibrated at about the anti-resonance frequency, the detected value $y_0(t)$ of the oscillating velocity within the continuous-time domain is expressed as the following formula (2).

$$y_0(t) = \frac{1}{A_B} \left[\alpha x_1(t) - \frac{\beta}{C_d} \int x_2(t) dt \right] \quad \dots (2)$$

[0045] The digital-signal processing part 18 of the embodiment of this invention discretizes and approximates the detected value $y_0(t)$ as shown in the above formula and then, based on the backward-differentiate method, computes the oscillating velocity and emits such velocity as the digital signal $y_0(n)$.

[0046] As shown in Fig. 7, the digital-signal processing part 18 of the embodiment of this invention comprises a coefficient multiplier 41, a first-coefficient variable multiplier 42, a delay element 43, an adder 44, a subtractor 45 and a second-coefficient variable multiplier 46. The digital-signal processing part 18 computes the oscillating velocity $y_0(n)$ of the emitting surface 7 of the ultrasonic transducer 3 by using the digital signals $x_1(n)$, $x_2(n)$ that matches the voltage $e_o(t)$ and the current $i_o(t)$ at the electric terminals 25a, 25b of the ultrasonic transducer 3, together with the digital signal of the braking capacity C_d and the force coefficient A_B . The force coefficient A_B of the embodiment of this invention is the ratio between the current running through the electric terminal 25a, 25b and the driving force generated on the emitting surface 7 (mechanical terminal) of the ultrasonic transducer 3 when mechanically vibrating at the anti-resonance frequency (B-type resonance frequency), thus being called a B-type force coefficient.

[0047] Of the digital-signal processing part 18, the digital signal $x_1(n)$ of the voltage $e_o(t)$ detected by the voltage detector 11 enters the coefficient multiplier 41 that then multiplies the digital signal $x_1(n)$ by the coefficient α . Then, such multiplication value enters the subtractor 45. The digital signal $x_2(n)$ of the current $i_o(t)$ detected by the current detector 12 enters the first-coefficient variable multiplier 42 while the digital signal of the braking capacity C_d enters the first-coefficient variable multiplier 42 by the external input terminal 27a. The first-coefficient variable multiplier 42 then multiplies the digital signal $x_2(n)$ of the current $i_o(t)$ by the coefficient $\beta \cdot T_s / C_d$ matching the digital signal of the braking capacity C_d . Then, such multiplication value enters the adder 44 but not before it is delayed by the delay element 43. The adder 44 then adds the multiplication value of the coefficient variable multiplier 42 to the delayed signal. Then, the addition value enters the subtractor 45. Thus, the delay element 43 and the adder 44 work as an integrator in integrating the multiplication value and the first-coefficient variable multiplier 42.

[0048] The subtractor 45 subtracts the addition value of the adder 44 from the multiplication value (the digital signal of the voltage $e_o(t)$) of the coefficient multiplier 41. Then, the subtraction value enters the second-coefficient variable multiplier 46. The digital signal of the force coefficient A_B enters the second-coefficient variable multiplier 46 by the external input terminal 27b. The second-coefficient variable multiplier 46 then multiplies the coefficient $1/A_B$ matching the digital signal of the force coefficient A_B by the subtraction value of the subtractor 45 and then emits such multiplication value as the digital signal $y_0(n)$ of the oscillating velocity.

[0049] Even in using the digital-signal processing part 18 of the second embodiment of this invention, it is possible to get a similar effect in the first embodiment of this invention. The digital-signal processing part 18 of the embodiment of this invention enters the digital signal of the force coefficient A_B (B-type force coefficient) in the motion of the anti-resonance frequency (B-type resonance frequency) and then does digital-signal processing in matching the motion when driving the ultrasonic transducer 3 at about the anti-resonance frequency, thus making it possible in getting more accu-

rately the oscillating velocity of the emitting surface 7 at about the anti-resonance frequency.

[0050] Each embodiment of this invention can be modified, as described below.

- Of the above ultrasonic generator 1 of each embodiment of this invention, the oscillating-velocity detecting device 4 monitors the oscillating velocity of the ultrasonic transducer 3 to prevent it from malfunctioning. However, it is not limited to that. For example, according to the result detected by the oscillating-velocity detecting device 4, the controller (not described in the drawings) can control the output of the ultrasonic oscillator 2, so that the oscillating velocity of the ultrasonic transducer 3 can be kept constant. As such, the ultrasonic processing can be evenly and surely done, thus making it possible in keeping the quality of the devices excellent.
- As described in the above embodiment of this invention, the bolted Langevin-type transducer is used as the ultrasonic transducer 3. However, another type of ultrasonic transducer, such as the solid type or the like can be used. Also, besides using the longitudinal-oscillation mode in driving the ultrasonic transducer 3, such oscillation modes as longitudinal-effect thickness oscillation, transversal-effect extension oscillation, sliding oscillation, radial oscillation, flexural oscillation or torsional oscillation or the like can be used.
- As described in the above embodiment of this invention, the oscillating-velocity detecting device 4 comprises the digital-signal processor (DSP) for realizing the digital-signal processing part 18. However, it is possible to realize it by software-programming the central-processing unit (CPU). Also, it is possible to make the digital-signal processing part 18 by using an integral circuit (LSI, FPGA or the like) or other hardware such as gate array or the like.
- As shown in each of the above embodiments of this invention, the oscillating-velocity detecting device 4 is arranged such that the digital signal of the pre-measured braking capacity C_d and of the force coefficient A_A , A_B enters by the external input terminals 27a, 27b. Yet, it is not limited to that. For example, it is possible to provide memory as the input means, to store the digital values of the braking capacity C_d and of the force coefficient A_A , A_B within the oscillating-velocity detecting device 4, to enter such digital values of said braking capacity C_d and force coefficient A_A , A_B from such memory as the digital signal into the digital-signal processing part 18. Also, depending on the environment, sometimes the temperature around the ultrasonic transducer 3 may drastically change while the ultrasonic transducer 3 is in use. Such a change in temperature may thus change the braking capacity C_d . Thus, a new capacity meter for measuring the braking capacity C_d should be provided inside or outside of the oscillating-velocity detecting device 4 to make it possible in entering the digital signal of the braking capacity C_d , measured by the capacity meter, into the digital-signal processing part 18. As such, the braking capacity C_d is regularly measured, and such input data is updated, thus making it possible to detect the oscillating velocity more accurately.
- As described in the above embodiment of this invention, the oscillating-velocity detecting device 4 comprises the digital indicator 20 and the analog indicator 21. However, it is possible that such detecting device 4 be composed of just one of either of the two indicators. It is possible still that an indicator not be provided within the oscillating-velocity detecting device 4 but that the arithmetic value of the oscillating velocity be shown on an indicator provided outside of the oscillating-velocity detecting device 4.
- As described in the above embodiment of this invention, the oscillating-velocity detecting device 4 is provided on the ultrasonic generator 1 for ultrasonic cleaning. However, it is not limited to that. Specifically, it is possible to provide the oscillating-velocity detecting device 4 of this invention on an ultrasonic generator used e.g. in cleaning, emulsifying, dispersing, fostering chemical reactions, forming plastic, cutting work, bonding plastic or joining metal or the like. Also, as described in the above embodiment of this invention, the ultrasonic generator 1 comprises a single ultrasonic transducer 3. However, it is possible to have multiple ultrasonic transducers on the ultrasonic-processing device or on the ultrasonic-cleaning device. As such, the ultrasonic generator 1 is arranged so that the single oscillating-velocity detecting device 4 is joined to the multiple ultrasonic transducers 3 to detect the normal oscillating velocity of all of the multiple ultrasonic transducers 3. It is possible still that the oscillating-velocity detecting device 4 be provided on each of the multiple ultrasonic transducers 3, thus making it possible to detect the individual oscillating velocity of each ultrasonic transducer 3. In this case, it is possible to provide the ultrasonic generator 1 with a switch circuit, so that a single oscillating-velocity detecting device 4 can selectively detect the oscillating velocity of the multiple ultrasonic transducers 3 by switching from one connection path to another of the multiple ultrasonic transducers 3.
- Regarding the oscillating-velocity detecting device 4 of each embodiment of this invention, it is possible to provide an integrator or a differentiator inside or outside of the detecting device 4 to do the integral processing and differential processing with respect to the oscillating velocity that is being emitted from the digital-signal processing part 18,

thus to get the data about the oscillatory displacement and acceleration of the ultrasonic transducer 3.

- As described in the above embodiment of this invention, the oscillating-velocity detecting device 4 is arranged such that the digital-signal processing part 18 computes the oscillating velocity by discretization and approximation by applying the backward-difference method. However, it is possible to arrange the detecting device 4 to compute the oscillating velocity by discretization and approximation by applying the forward-difference method or the bilinear-transformation method.
- As described of the ultrasonic-generator 1 of the above embodiment of this invention, the oscillating-velocity detecting device 4 is provided between the ultrasonic oscillator 2 and the ultrasonic transducer 3. However, it is not limited to that. For example, it is possible to arrange the ultrasonic oscillator 2 such that the oscillating-velocity detecting device 4 is joined to the output terminal to emit the drive signal of the ultrasonic waves. It is also possible to arrange the ultrasonic generator 1 using an ultrasonic-transducer unit by which the oscillating-velocity detecting device 4 is joined to the electric terminals 25a, 25b of the ultrasonic transducer 3. In this case, it is possible to have a communication means on such oscillating-velocity detecting device 4 for emitting the arithmetic value of the oscillating velocity by such communication means, thus making it further possible by such communication means of entering the digital signal of the braking capacity C_d and of the force coefficient A_A , A_B . As such, in providing such a communication means on the oscillating-velocity detecting device 4, it is possible to use the ultrasonic transducer 3 as a sensor of IoT (Internet of Things).

[0051] Besides the technical ideas of this invention, as described above, other technical ideas to be understood are described hereinafter.

(1) An oscillating-velocity detecting device according to the seventh aspect of this invention, characterized in that the sampling frequency of the conversion means is set five times as much or more as the drive frequency of the ultrasonic transducer.

(2) An oscillating-velocity detecting device according to the fourth aspect of this invention, characterized in that the digital-signal processing means computes the oscillating velocity by discretization by applying the backward-difference method.

(3) An oscillating-velocity detecting device according to the fourth aspect of this invention, characterized in that the digital-signal processing means calculates the oscillating velocity by discretization by applying the forward-difference method.

(4) An oscillating-velocity detecting device according to the fourth aspect of this invention, characterized in that the digital-signal processing means computes the oscillating velocity by discretization by applying the bilinear transformation method.

(5) An oscillating-velocity detecting device according to any one of the first to the seventh aspects of this invention, characterized by comprising an integrator for integrating the output signal of the digital-signal processing means.

(6) An oscillating-velocity detecting device according to any one of the first to the seventh aspects of this invention, characterized by comprising a differentiator for differentiating the emitting signal of the digital-signal processing means.

(7) An oscillating-velocity detecting device according to any one of the first to the seventh aspects of this invention, characterized by comprising an indicator showing the arithmetic result of the oscillating velocity computed by the digital-signal processing means.

(8) An oscillating-velocity detecting device according to any one of the first to the seventh aspects of this invention, characterized by comprising a communication means that emits the arithmetic result of the oscillating velocity computed by the digital-signal processing means.

(9) An ultrasonic oscillator according to any one of the first to seventh aspects of this invention, characterized by incorporating the oscillating-velocity detecting device.

(10) An ultrasonic-transducer unit according to any one of the first to seventh aspects of this invention, characterized

by incorporating the oscillating-velocity detecting device and the ultrasonic transducer.

Description of the reference signs

5 [0052]

- 1: Ultrasonic generator
- 2: Ultrasonic oscillator
- 3: Ultrasonic transducer
- 10 4: Oscillating-velocity detecting device
- 7: Emitting surface
- 11: Voltage detector as the detecting means
- 12: Current detector as the detecting means
- 16, 17: A/D convertor as the conversion means
- 15 18: Digital-signal processing part as the digital-signal processing means
- 27a, 27b: External input terminal as the input means
- 31, 43: Delay element
- 32: First subtractor
- 33, 42: First-coefficient variable multiplier
- 20 35: Second subtractor
- 36, 46: Second-coefficient variable multiplier
- 44: Adder
- 45: Subtractor
- A_A : A-type force coefficient when driving the resonance frequency (A-type resonance frequency)
- 25 A_B : B-type force coefficient when driving the anti-resonance frequency
(B-type anti-resonance frequency)
- C_d : braking capacity

30 Claims

1. An oscillating-velocity detecting device provided between an ultrasonic transducer having an emitting surface for emitting ultrasonic waves by vibrating in a specific oscillation mode and an ultrasonic oscillator for driving the ultrasonic transducer, which are all provided within an ultrasonic generator for doing specific processes in emitting
35 ultrasonic waves from an emitting surface, **characterized in that** said oscillating-velocity detecting device comprises: an input means for entering digital signals that show both the braking capacity of the ultrasonic transducer and the force coefficient of the emitting surface while oscillating in said specific oscillation mode; a detecting means that is joined to an electric terminal of the ultrasonic transducer for detecting the analog signals of the voltage and of the current at the electric terminal; a conversion means for changing the analog signal of the voltage and of the current
40 detected by the detecting means into digital signals; and a digital-signal processing means for doing arithmetic operations based on the basic formula of electro-acoustic conversion by using the digital signals of the braking capacity, of the force coefficient and of the voltage and current and then calculating the oscillating velocity of the emitting surface of the ultrasonic transducer.
- 45 2. An oscillating-velocity detecting device according to Claim 1, **characterized in that** the ultrasonic oscillator mechanically vibrates the ultrasonic transducer at about the resonance frequency in the above oscillation mode, and that the input means is for entering the digital signals of the force coefficient (A-type force coefficient) in motion with the resonance frequency (A-type resonance frequency).
- 50 3. An oscillating-velocity detecting device according to Claim 1, **characterized in that** the ultrasonic oscillator mechanically vibrates the ultrasonic transducer at about the anti-resonance frequency in oscillation mode, and that the input means enters the digital signals (B-type force coefficient) in motion with the anti-resonance frequency (B-type resonance frequency).
- 55 4. An oscillating-velocity detecting device according to any one of Claims 1 to 3, **characterized in that** the digital-signal processing means is a means for processing digital signals by using a delay element, an adder-subtractor and a coefficient multiplier.

5. An oscillating-velocity detecting device according to Claim 2, **characterized in that** the digital-signal processing means comprises: a delay element and a first subtractor for doing differential processing of the digital signals regarding the voltage; a first-coefficient variable multiplier for multiplying the coefficient matching the digital signal of the braking capacity based on the subtraction value of the first subtractor; a second subtractor for subtracting the multiplication value of the first-coefficient variable multiplier from the digital signal of the current; and a second-coefficient variable multiplier for multiplying the coefficient matching the digital signal of the force coefficient by the subtraction value of the second subtractor and then emitting such multiplication value as the oscillating velocity.
6. An oscillating-velocity detecting device according to Claim 3, **characterized in that** the digital-signal processing means comprises a first-coefficient variable multiplier for multiplying the coefficient matching the digital signal of the braking capacity by the digital signal regarding the current; a delay element and an adder for doing differential processing of the multiplication value of the first-coefficient variable multiplier; a subtractor for subtracting the addition value of the adder from the digital signal regarding the voltage; a second-coefficient variable multiplier for multiplying the coefficient that matches the digital signal of the force coefficient by the subtraction value of the subtractor and then emitting such multiplication value as the oscillating velocity.
7. An oscillating-velocity detecting device according to any one of Claims 1 to 6, **characterized in that** the sampling frequency of the conversion means is set at twice as much or more as the drive frequency of the ultrasonic transducer.

FIG. 1

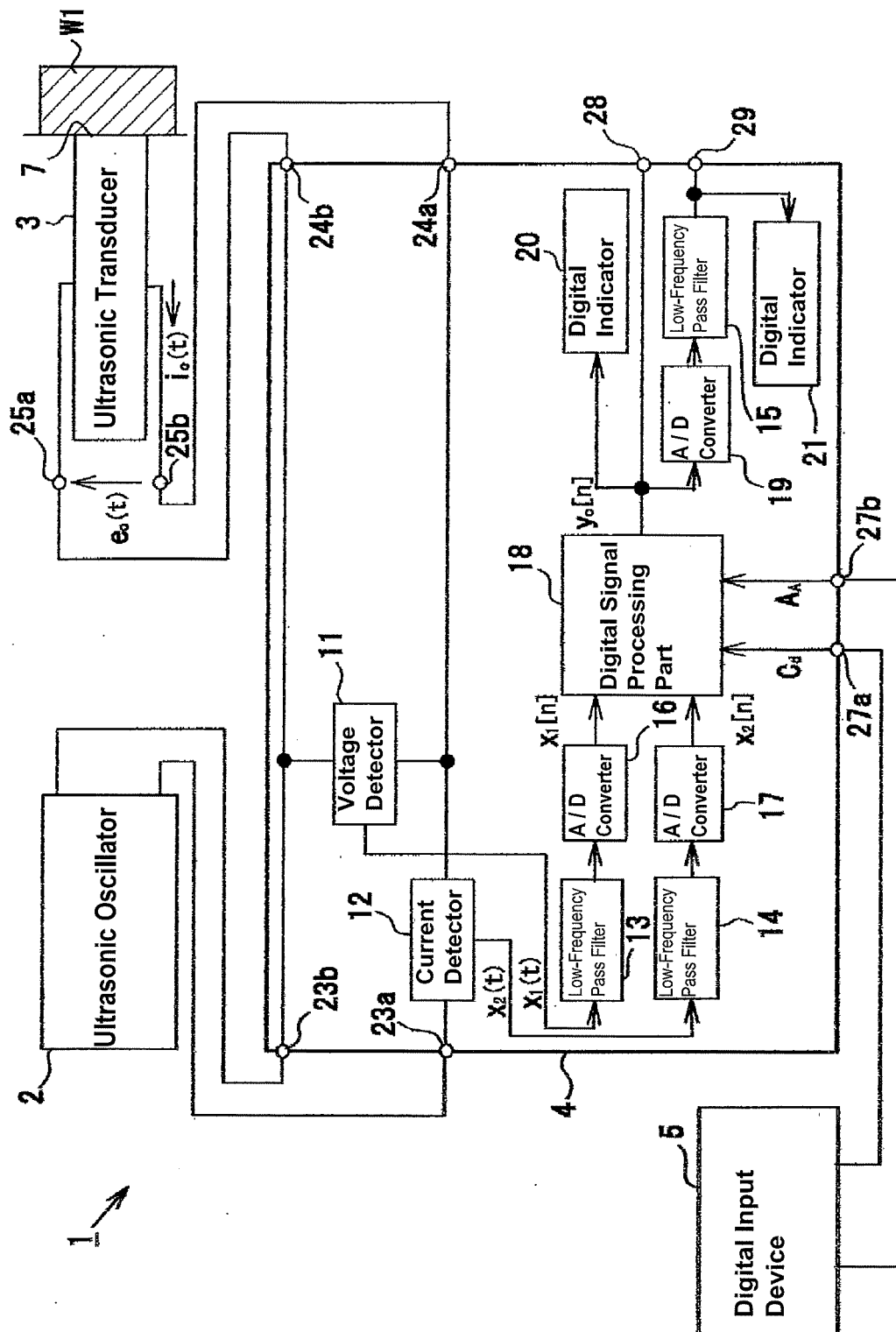


FIG. 2

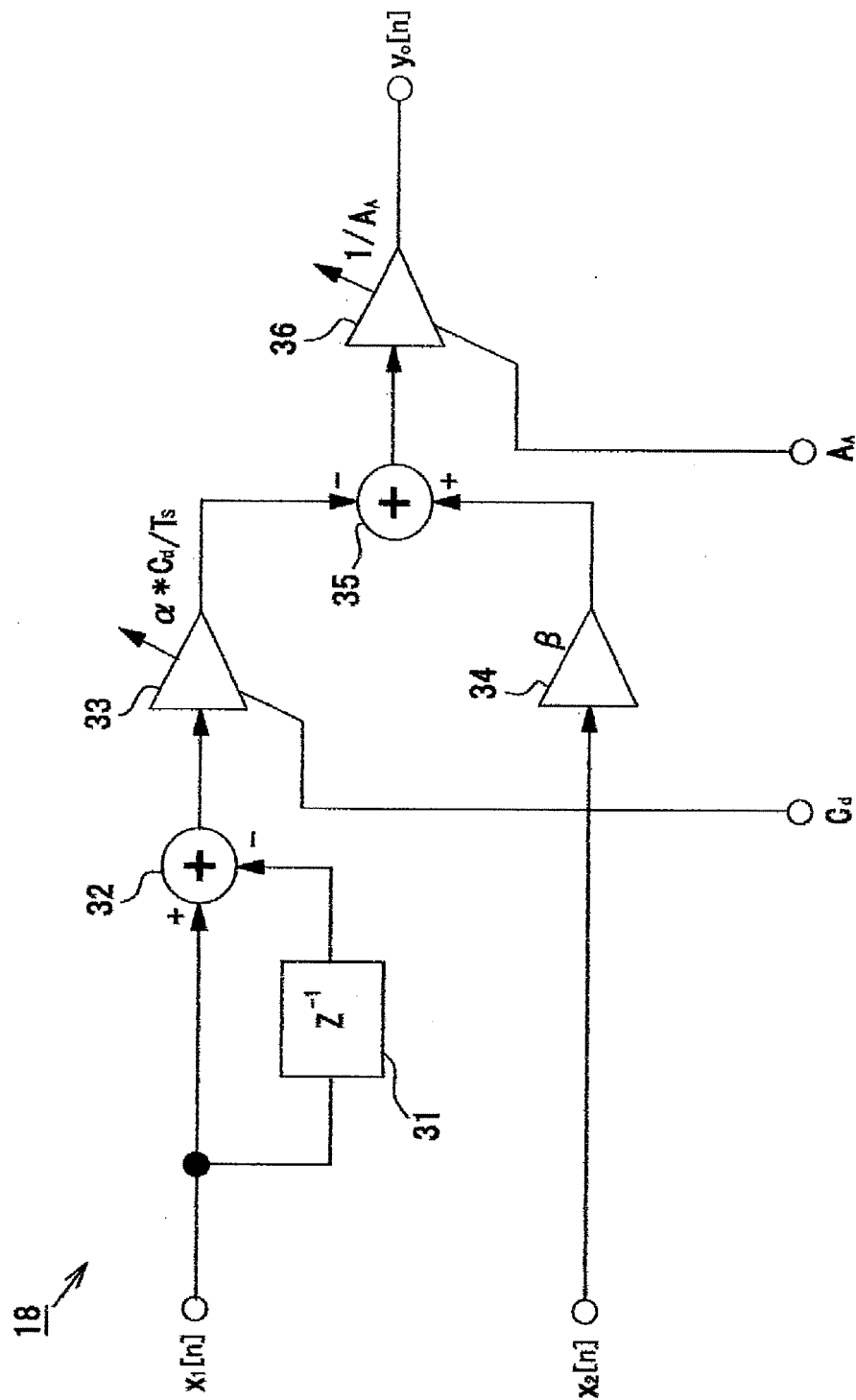


FIG. 3

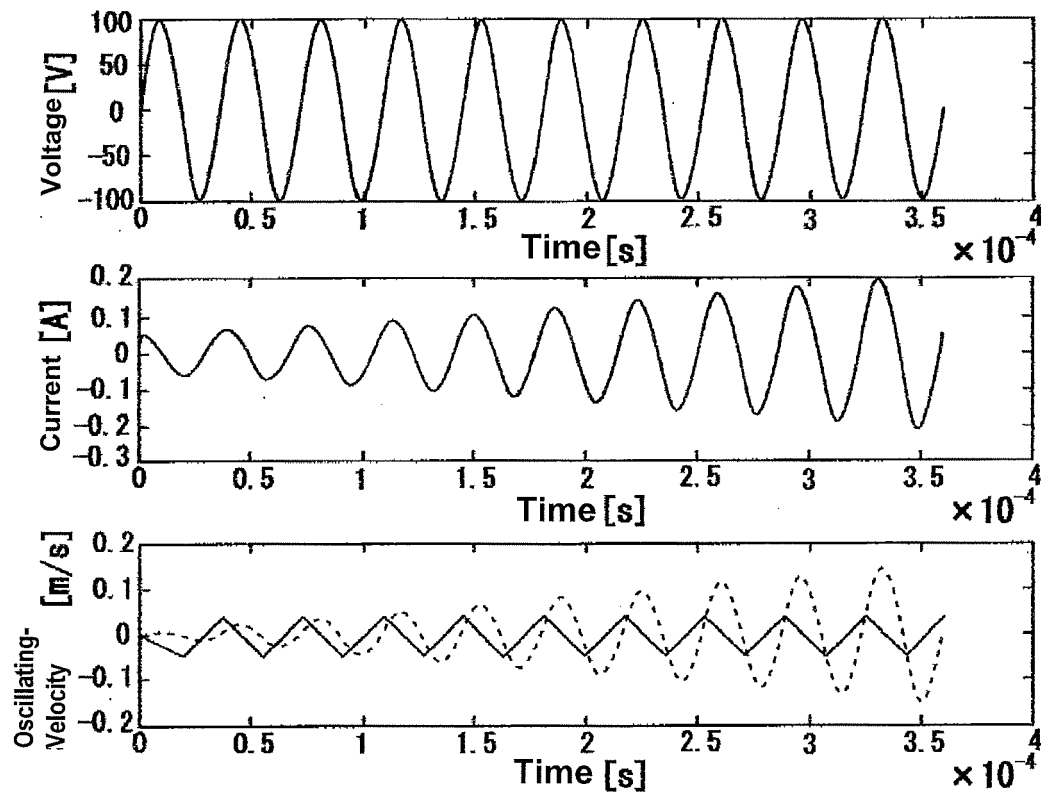


FIG. 4

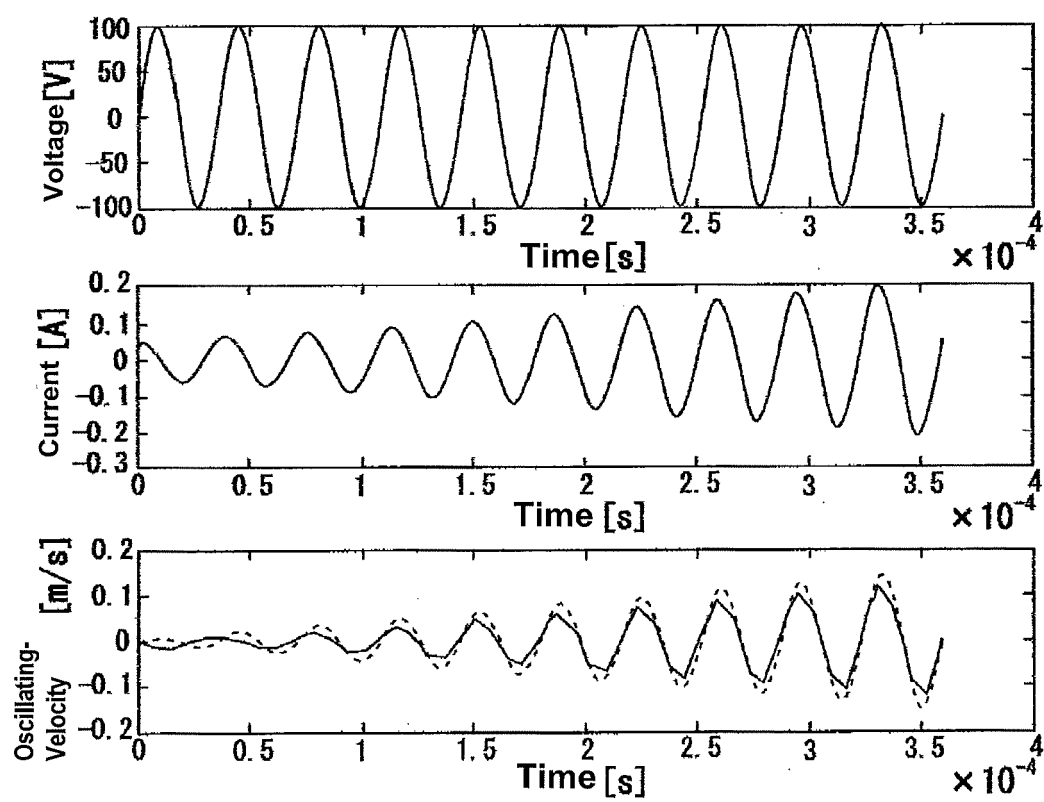


FIG. 5

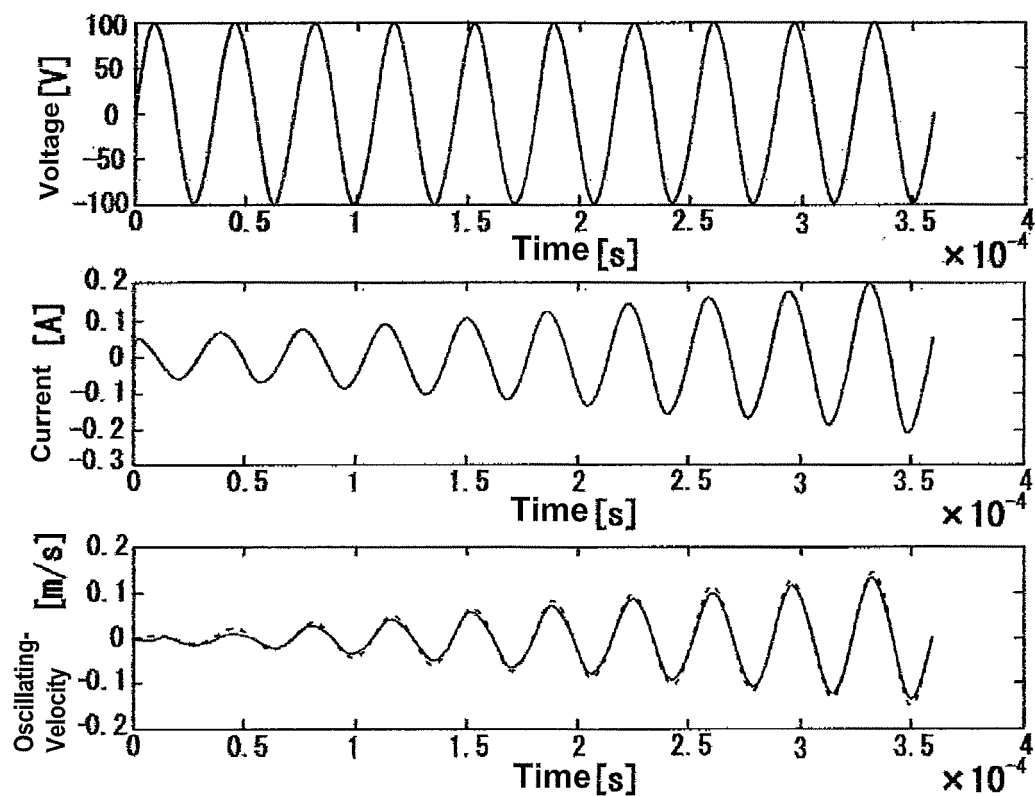


FIG. 6

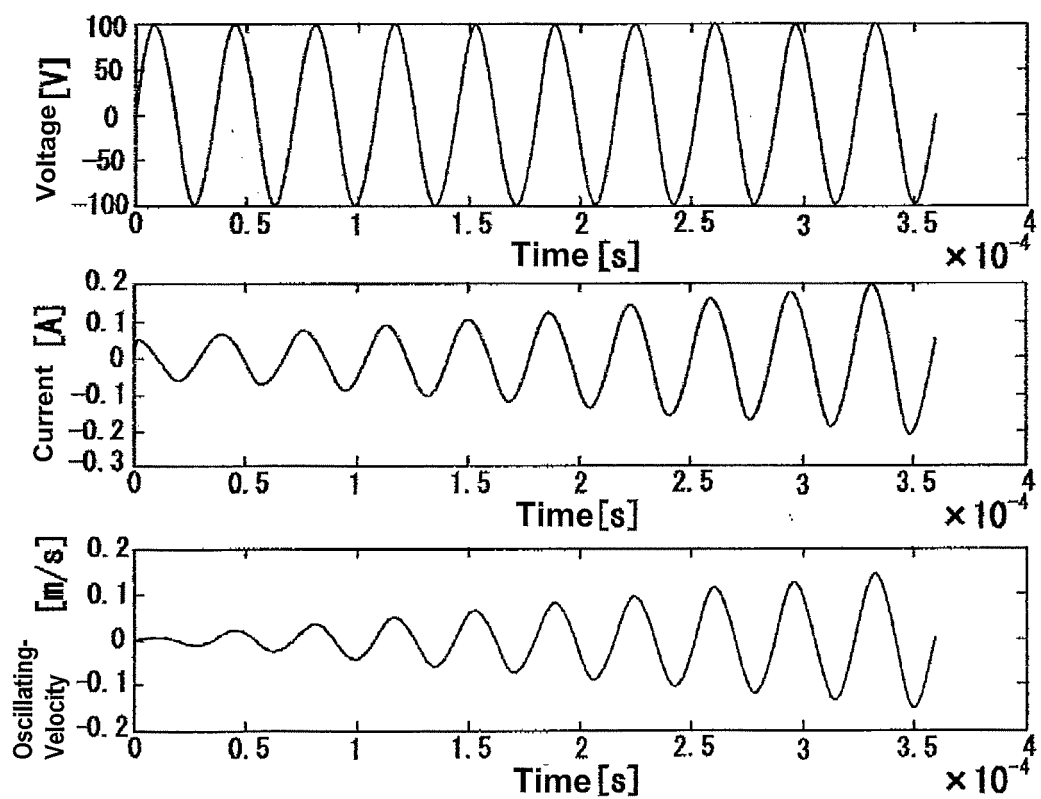
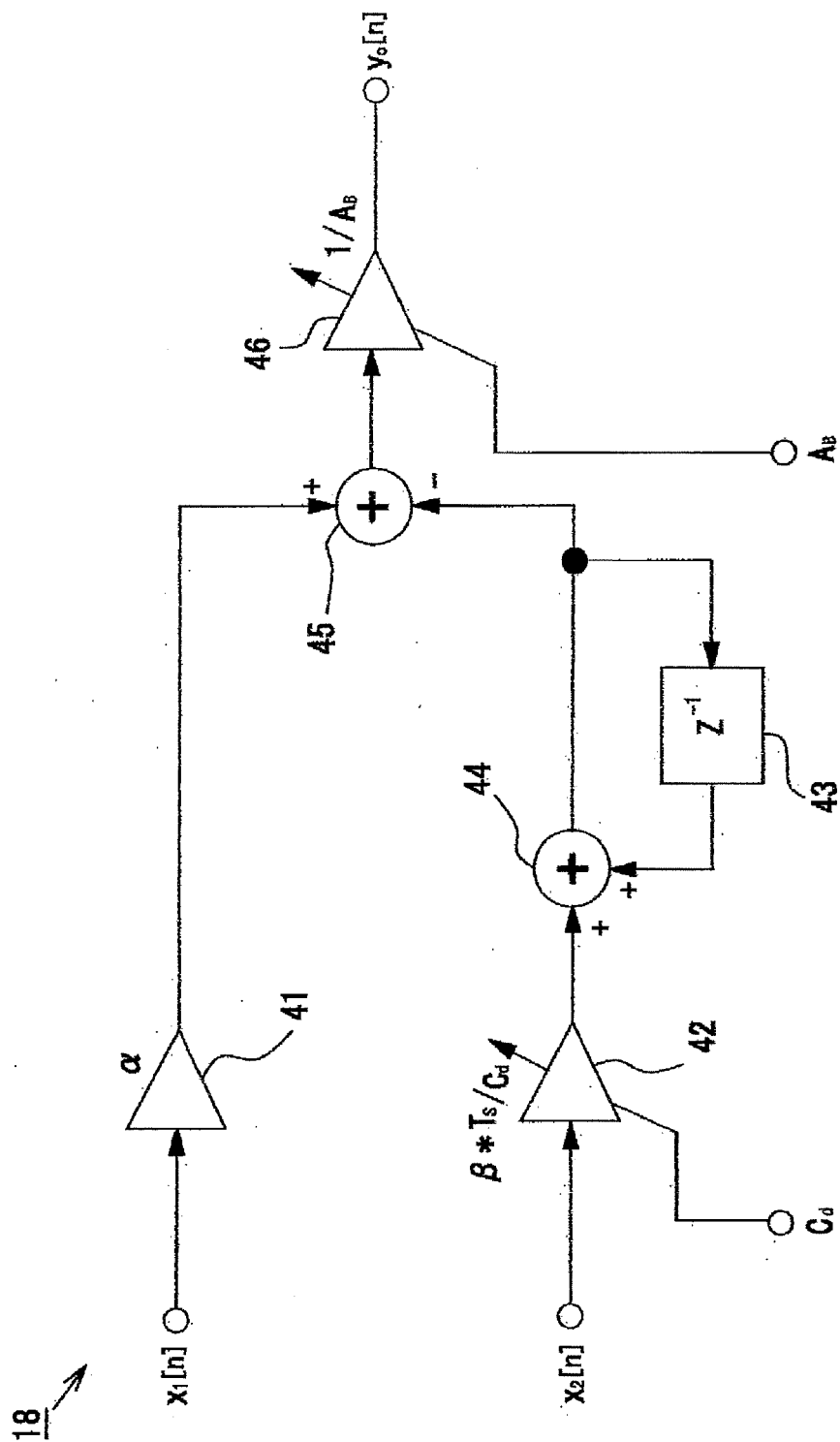


FIG. 7





EUROPEAN SEARCH REPORT

Application Number
EP 17 16 1532

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A	* paragraph [0023] - paragraph [0024] * * paragraph [0053] *	5,6	TECHNICAL FIELDS SEARCHED (IPC) B06B B08B G11B G10K
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The present search report has been drawn up for all claims			
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