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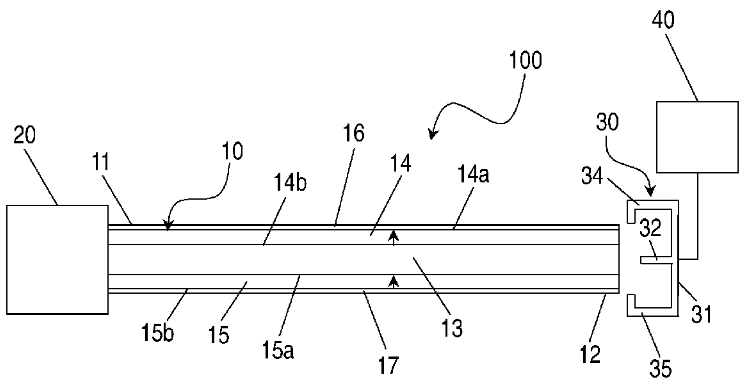

FIG. 1

(57) **Abstract:** The invention concerns a gong (100) for a clock strike device. The gong (100) comprises a multilayer main body (10), which includes a central layer (13) made of metallic material and an upper layer (14) and a lower layer (15) made of piezoelectric material, wherein the upper layer (14) and the lower layer (15) have a respective outer coating layer (16, 17) made of metallic material. The gong (100) further comprises a metal bridge (30), which can be operated between a first operating position of absence of contact with the multilayer main body (10), whereby the upper (14) and lower (15) layers are in an open circuit condition, and a second operating position of contact with the multilayer main body (10), whereby the upper (14) and lower (15) layers are in a short circuit condition. The invention also concerns a clock (1) comprising a gong (100) as defined above.

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GONG FOR A CLOCK STRIKE DEVICE

DESCRIPTION

TECHNICAL FIELD

The present invention refers generally to the technical field of clock strike devices. More particularly, the present invention concerns a gong for a clock strike device, configured so as to vary natural frequencies, and therefore the sound produced.

BACKGROUND

Nowadays, clocks are equipped with a chime that can be programmed to go off at a certain time or after a certain time period.

In the luxury watchmaking market, particularly in wristwatches with manual or automatic winding, preference is done to strike devices of the fully mechanical type, which represent an iconic complication that characterizes the flagship products.

The mechanical type strike devices are distinguished into chimes and repeaters. The chimes chime regularly with the passing of the hours, more specifically at predetermined times, both during the hour and precisely as the hour strikes. The chimes are, in turn, distinguished into large chimes and small chimes. The large chimes chime the number of the actual hour, and every quarter of an hour they repeat the hour by adding the quarter of an hour or the quarters of an hour, whereas the small chimes do not repeat the hour every quarter of an hour, but every hour they chime the actual hour, and every quarter of an hour they chime the quarter of an hour or the quarters of an hour. The repeaters chime the hours according to the setting by means of a button, which is usually placed on the side of the case of the clock. There are several variations, such as repeater every half-quarter and quarter of an hour, every five minutes and every minute.

Among the strike devices of known type, the minute repeater is particularly complex. In fact, more than a hundred individual components, in addition to those already present in a mechanical watch, are required to be able to repeat the hour acoustically until the individual minute is heard. The difficulty of realization is further increased by the choice of inserting the minute repeater inside an extremely compact object such as a wristwatch. Assembling a minute repeater takes an experienced watchmaker two to three hundred hours of work.

The minute repeater typically comprises three very elaborately shaped gears, specifically spiral cams, which move together with the hands of the clock, rotating at every minute. When the strike device is operated, a spring is wound up that starts the movement, thus activating the minute repeater. The position of the hour, quarter-hour and minute gears is read by a respective rack.

The strike device further comprises two gongs, or sound sources, and two hammers, one for each gong, which, operated by suitable operating means, strike the respective gong, which vibrates emitting a corresponding sound.

Each gong is positioned in a plane parallel to the dial of the clock and normally has the shape of an arc of a circle having one end free and the other end fixed to a support. The support is rigidly connected, for example screwed, to a metal plate of the case of the clock.

When the hammer strikes the respective gong, the latter starts vibrating at its natural frequency and the vibration is transferred from the support to the plate, with consequent propagation of the sound waves, which are audible by a user in the form of generated sound. The number of chimes performed on the two gongs depends on the position of the hands.

Generally, two gongs are used to obtain a low sound, which is repeated a number of times equal to the number of hours, an high/low sound to indicate the quarters elapsed since the last hour, and finally a high sound to indicate the minutes elapsed since the last quarter of an hour.

The clock strike devices of fully mechanical type briefly described above have the drawback that, in order to increase the number of sounds available, it is necessary to increase the number of sound sources, thus equipping the clock with a gong for each desired sound. In particular, in order to have two different sounds, one for the hours and one for the minutes, it is necessary to provide two gongs, which differ in diameter or length, so as to produce, when struck by the respective hammer, two different sounds, for example a low sound for the gong of the hours and a high sound for the gong of the minutes. This leads to problems of encumbrance and consequent limits in the number of sounds that the clock can have.

OBJECTS AND SUMMARY OF THE INVENTION

Object of the present invention is to overcome the limits of the prior art.

In particular, an object of the invention is to present a gong for a clock strike device, configured to vary its natural frequencies, so as to have at least two sounds available for each gong, thus obtaining a more elaborate strike device with the same sound sources used.

Yet another object of the invention is to present a gong for a clock strike device, configured so as to reduce the complexity, and thus the encumbrance, of the clock strike device.

Yet another object of the invention is to present a gong for a clock strike device, configured so as to produce at least two sounds which are distinguishable from one another by the human ear.

Last but not least, the object of the present invention is to present a gong for a clock strike device, which is fully mechanical and configured so as not to present batteries or electrical and/or electronic components, thus keeping with the tradition of luxury clocks.

These and other objects of the present invention are achieved by a gong for a clock strike device and by a clock incorporating the features of the appended claims, which form an integral part of the present description.

In a first aspect thereof, the invention is therefore directed to a clock strike device, comprising a multilayer main body, which includes a central layer made of metallic material, an upper layer and a lower layer made of piezoelectric material, wherein the upper layer and the lower layer have a respective outer coating layer made of metallic material. The gong further comprises a metal bridge, which can be operated between a first operating position of absence of contact with the multilayer main body, whereby the upper and lower layers are in an open circuit condition, and a second operating position of contact with the multilayer main body, whereby the upper and lower layers are in a short circuit condition.

Thanks to this combination of features, in particular thanks to the fact of providing two layers made of piezoelectric material that can switch between an open circuit condition and a short circuit condition, it is possible to modify the natural frequencies of the gong, thus having available at least two sounds for each gong inside the case of a clock. In fact, in the open circuit and short circuit condition, the layers made of piezoelectric material have different stiffness, whereby the overall stiffness of the gong is also different in the two operating conditions. It follows that, when the gong is struck by a hammer, it vibrates with different natural frequencies depending on whether the layers made of piezoelectric material are in an open circuit or short circuit condition, producing at least two distinct sounds. In addition, the bridge that allows switching between the two conditions of open circuit and short circuit can be operated so as to mechanically close the circuit formed by the upper and lower layers made of piezoelectric material, avoiding the presence, in the clock, of electrical and/or electronic components, as required in the field of luxury watchmaking.

In one embodiment, the upper and lower layers consist each of a foil made of polarized ceramic piezoelectric material.

In one embodiment, the bridge has a comb shape, comprising a back, from which a first, a second and a third tooth extend, wherein in the second operating condition of the bridge, the first tooth is in contact with the metal central layer, the second tooth is in contact with the outer coating layer of the upper layer made of piezoelectric material and the third tooth is in contact with the outer coating layer of the second layer made of piezoelectric material of the multilayer main body of the gong.

In one embodiment, the first tooth, the second tooth and the third tooth of the bridge consist each of a metal wire.

In one embodiment, the first tooth, the second tooth and the third tooth of the bridge consist each of a metal foil.

In one embodiment, the multilayer main body is rectilinear.

In one embodiment, the multilayer main body is in the form of a circle arc.

In one embodiment, the ratio ξ between the thicknesses of the metal central layer and the upper and lower layers made of piezoelectric material is obtained by inverting the ratio between the natural frequencies of the gong, in the open circuit f_o and short circuit f_s condition, according to the following formula:

$$\frac{f_o}{f_s} = \sqrt{\frac{1 + 2\,\psi\left(1 + \bar{k}_{13}^2\right)\left(4\xi + 6\xi^2 + 3\xi\right)}{1 + 2\,\psi\left(4\xi^3 + 6\xi^2 + 3\xi\right)}}$$

wherein $\bar{k}_{13}^2 = k_{13}^2/(1 - k_{13}^2)$, with k_{13} piezoelectric constant of the piezoelectric material of the upper layer and of the lower layer, ψ is a parameter calculated as follows

$$\psi = \frac{\bar{c}_{11}^{E}}{Y}$$

wherein Y is the Young's modulus of the metallic material of the central layer and $\bar{c}_{11}^{E}$ is the reciprocal of the short circuit pliability s_{11}^{E} of the upper and lower layers made of piezoelectric material and ξ is the ratio between the thickness of each layer, upper and lower, made of piezoelectric material and the metal central layer of the multilayer main body.

In one embodiment, the length L of the gong is given by the following formula:

$$L = \sqrt{\frac{\lambda_n^2}{2\pi f_s}\sqrt{\frac{Y\left(h_t^2/_{12}\right)\left[1 + 2\psi\left(4\xi^3 + 6\xi^2 + 3\xi\right)\right]}{\rho_t(1 + 2\varphi\xi)}}}$$

wherein ρ_t represents the density of the metallic material of the central layer and λ_n is one of the n (with n any positive integer) solutions of the characteristic equation of a jammed beam:

$$1 + cos(\lambda) \cdot cosh(\lambda) = 0$$

wherein cos() is the cosine function and cosh() is the hyperbolic cosine function.

In one embodiment, the upper layer and the lower layer made of piezoelectric material comprise a respective shunt circuit, which is connected to the respective layer made of piezoelectric material and has a characteristic impedance, by varying which it is possible to continuously modify the overall stiffness of the gong, with consequent modulation of the sounds produced.

In one embodiment, the metal central layer is preferably made of titanium and the metal bridge is made of copper or silver.

In one embodiment, the multilayer main body comprises an end fixed to a support, for fixing the gong to the case of the clock, and another free end.

In a second aspect thereof, the invention is directed to a clock, preferably a manually or automatically wound wristwatch, comprising a gong as defined above and a hammer, causing it to vibrate according to its natural frequencies, so as to produce two distinct and distinguishable sounds, depending on the position of the metal bridge.

Further features and objects of the present invention will be more evident from the description of the accompanying drawings.

In the following of this description, and in the attached claims, the term "gong" will refer to a device, which, once struck, is able to vibrate producing a sound.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described below with reference to some examples, provided by way of non-limiting example, and illustrated in the appended drawings. These drawings illustrate different aspects and embodiments of the present invention and reference numerals illustrating structures, components, materials and/or similar elements in different drawings are indicated by similar reference numerals, where appropriate.

Figure 1 is a schematic sectional view of a gong for a clock strike device according to a preferred embodiment of the present invention, showing the metal bridge in a first operating position, i.e. detached from the main body of the gong.

Figure 2 is a view, similar to that of Figure 1, showing the metal bridge in a second operating position, i.e. in contact with the main body of the gong.

Figure 3 is a schematic sectional view of the gong of Figure 1 equipped with a frequency tuning device.

Figure 4 is a schematic plan view of a clock containing the gong of Figure 1.

Figure 5 is a schematic perspective view of a gong for a clock strike device according to an alternative embodiment of the present invention.

Figure 5A is an enlarged view of the circled detail in Figure 5.

Figure 6 shows a graph of the frequency ratio between an open circuit condition and a short circuit condition based on the geometric ratio between the thicknesses of the metal intermediate layer and the upper and lower layers made of piezoelectric material of a gong of Figure 1.

DETAILED DESCRIPTION OF THE INVENTION

While the invention is susceptible to various modifications and alternative constructions, some embodiments provided for explanatory purposes are described below in detail.

It must in any case be understood that there is no intention to limit the invention to the specific embodiment illustrated, but, on the contrary, the invention intends covering all the modifications, alternative and equivalent constructions that fall within the scope of the invention as defined in the claims.

In the following description, therefore, the use of "e.g.", "etc.", "or" indicates non-exclusive alternatives without limitation, unless otherwise indicated; the use of "also" means "including, but not limited to" unless otherwise indicated; the use of "includes/comprises" means "includes/comprises, but not limited to" unless otherwise indicated.

Referring to Figures 1 and 2, there is illustrated a gong for a clock strike device according to a preferred embodiment of the present invention.

The gong, generally indicated by the reference numeral 100, comprises a main body 10, preferably rectilinear, which has an end 11 fixed to a support 20, while the other end 12 is free. The main body is therefore similar to a cantilever beam with a rectangular section.

When the gong 100 is mounted on a clock, the support 20 is coupled, preferably screwed, onto a plate 3 of a case 2 of a clock 1, which is schematically illustrated in Figure 4 in the form of a wristwatch.

The main body 10 of the gong 100 is multi-layered and comprises a central layer 13 made of metallic material, an upper layer 14 made of piezoelectric material and a lower layer 15 made of piezoelectric material. The central layer 13 is sandwiched between the upper 14 and lower 15 layers. The upper layer 14 and the lower layer 15 made of piezoelectric material also have a respective outer coating layer 16, 17 made of metallic material. The outer coating layers 16, 17 have negligible thickness.

The upper layer 14 and the lower layer 15 made of piezoelectric material have, respectively, an upper surface 14a, 15a and a lower surface 14b, 15b. More particularly, the upper surface 14a of the upper layer 14 is in contact with the respective outer coating layer 16, while the lower surface 14b of the upper layer 14 is in contact with the central layer 13. The upper surface 15a of the lower layer 15 is in contact with the central layer 13, while the lower surface 15b of the lower layer 15 is in contact with the respective coating layer 17.

Preferably, the central layer 13 is made of a metal having good electrical conductivity, preferably titanium, while the upper 14 and lower 15 layers are made in the form of foils made of polarized ceramic piezoelectric material. The foils made of piezoelectric material 14 and 15 are preferably polarized such that, following a deformation, the electric charges move in the same direction in the two foils, for example from the bottom upwards in the example of Figure 1 and 2.

The gong 100 further comprises a metal bridge 30, preferably made of copper, more preferably silver, which is operated by suitable mechanical means 40 between a first operating position of absence of contact with the multilayer main body 10, whereby the upper 14 and lower 15 layers are in an open circuit condition, and a second operating position of contact with the multilayer main body 10, whereby the upper 14 and lower 15 layers are in a short circuit condition.

The bridge 30 has a comb shape and therefore comprises a back 31, from which a first 32, a second 34 and a third tooth 35 extend. More particularly, and as visible in Figure 2, in the second operating condition of the bridge 30, or short circuit condition of the upper 14 and lower 15 layers, the first tooth is in contact with the central layer 13, the second tooth 34 is in contact with the outer coating layer 16 of the upper layer 14 and the third tooth 35 is in contact with the outer coating layer 17 of the lower layer of the multilayer main body 10 of the gong 100.

The outer coating layers 16 and 17, respectively of the upper layer 14 and of the lower layer 15 made of piezoelectric material, thus act as an electrical contact electrode with the metal bridge 30, when the same is in its second operating short circuit position between the upper 14 and lower 15 layers made of piezoelectric material. The metal central layer 13, on the other hand, acts as an electrode for the lower surface 14b of the upper layer 14 and the upper surface 15a of the lower layer 15 and represents the reference or ground potential of the main body 10 of the gong 100.

Each tooth 32, 34 and 35 of the metal bridge 30 may consist of a metal wire or of a metal foil, while the mechanical means 40 for operating the bridge may be of any type known per se and therefore will not be described in detail here.

By way of example, the operating means 40 of the bridge 30 coincide with the operating means (not shown) of the hammer 4 (shown in Figure 4), which, once operated, strikes the gong 100 causing it to vibrate so as to produce at least two distinct sounds, as will be described in detail below.

As set out above, such operating means of the hammer 4 comprise, for example, a plurality of gears, for example three spiral cams, one for the hours, one for the quarters of an hour and one for the minutes, which are movable together with the hands of the clock and can be operated by a spring. The movement of the cams can therefore be used to operate the hammer and the metal bridge.

In particular, and with reference to Figure 1, in the first operating position, the bridge 30 is detached, and therefore not in contact, with the multilayer main body 10 of the gong 100 and the upper 14 and lower 15 layers made of piezoelectric material of the multilayer main body 10 are in the open circuit condition.

In this open circuit condition, the electric charges generated on the outer coating layer 16, i.e. on the electrode, of the upper layer 14 made of piezoelectric material cannot flow towards the ground electrode, represented by the central layer 13, and create, between the upper surface 14a and the lower surface 14b of the upper layer 14, an electric field that affects the stiffness of the upper layer 14 made of piezoelectric material.

Similarly, in an open circuit condition, the electric charges generated on the outer coating layer 17, i.e. on the electrode, of the lower layer 15 made of piezoelectric material cannot flow towards the ground electrode, represented by the central layer 13, and create, between the upper surface 15a and the lower surface 15b of the lower layer 15, an electric field that affects the stiffness of the lower layer 15 made of piezoelectric material.

In contrast, and as shown in detail in Figure 2, in the second operating position, the bridge 30 is in contact with the multilayer main body 10 of the gong 100. In particular, the bridge 30 puts the upper 14 and lower 15 layers in communication with the central layer 13, specifically the outer coating layers 16 and 17, or electrodes, respectively of the upper 14 and the lower 15 layer are connected with the central layer 13, bringing both surfaces of each layer 14, 15 made of piezoelectric material to the same potential, in a short circuit condition.

In such a short circuit condition, the electric charges generated by the deformation of each foil are free to move passing through the bridge 30 from one face to the opposite one, neutralizing the electric field that would otherwise be generated in an open circuit condition, and resulting in a lower stiffness of the piezoelectric element.

Therefore, when the upper 14 and lower 15 layers of the multilayer main body 10 of the gong 100 pass from an open circuit condition to a short circuit condition, and vice versa, the mechanical properties of the piezoelectric material of which they are composed vary and, consequently, the overall stiffness of the gong 100 changes.

It follows that, when the gong 100 is struck by the hammer 4 (shown in Figure 4) of a strike device of the clock 1, it vibrates with a different natural frequency depending on whether it is in the open circuit or short circuit operating condition, thus emitting two different sounds.

Preferably, the sounds produced by the gong 100 may be modulated. In this case, and as shown in Figure 3, the upper layer 14 and the lower layer 15 made of piezoelectric material are equipped with a respective shunt circuit 40 characterized by an impedance Z_{SH}. In fact, the open circuit and closed circuit conditions represent two limit conditions of a more generic embodiment, in which the upper layer 14 and the lower layer 15 made of piezoelectric material are connected to the respective shunt circuit 40.

Variations of this impedance Z_{SH} imply variations in the equivalent elastic modulus of the respective layer 14, 15 made of piezoelectric material and, consequently, of the stiffness of the entire gong 100 and of the associated natural frequencies.

This mechanism is such that it is possible to manually “tune” the gong 100 by acting on the impedance of the shunt circuit reaching exactly the desired frequency upon manufacture, which may otherwise not occur due to manufacturing defects and tolerances.

Figure 4 illustrates a clock 1, specifically a wristwatch, inside which a gong 100 according to the present invention is fitted.

The clock 1 comprises a case 2, inside which the plate 3 is positioned, on which the support 20 of the gong 100 is fixed, for example screwed. Inside the case 2 there is also housed the hammer 4, which, suitably operated by a set of gears of known type, and therefore not described, strikes the gong 100, causing it to vibrate according to its natural frequencies, so as to produce two distinct sounds. The vibration of the gong 100 is transferred from the support 20 to the plate 3 of the clock, by means of which the sound is diffused to the outside so as to be audible by a user.

With reference to Figures 5 and 5A, there is illustrated a gong according to an alternative embodiment of the present invention, which differs from the gong 100, described above and illustrated in Figures 1 to 4, in the different conformation of the multilayer main body 10, which, instead of being rectilinear, has the shape of an arc of a circle.

The gong, generally indicated by the reference numeral 1100, comprises a multilayer main body 110 having one end 111 fixed to a support 20, while the other end 112 is free.

The multilayer main body 10 of the gong 1100 comprises a central layer 113 made of metallic material, and an upper layer 114 and a lower layer 115 made of piezoelectric material. The upper layer 114 and the lower layer 115 made of piezoelectric material also have a respective outer coating layer 116, 117 made of metallic material and of negligible thickness.

As discussed further above with reference to the gong 100, the passage from a natural frequency to another of the gong is obtained by switching, by means of the bridge 30, the upper 14 and lower 15 layers made of piezoelectric material of the multilayer main body 10 between an open circuit condition and a short circuit condition.

The two sounds obtained by striking by means of the hammer 4, the gong 100 in the two conditions of open circuit and short circuit of the upper 14 and lower 15 layers made of piezoelectric material must be distinguishable by the human ear, whereby the gong 100 must be suitably sized.

This is done by calculating the ratio between the thickness of the metal intermediate layer 13 and the thickness of the upper 14 and lower 15 layers made of piezoelectric material such as to guarantee a change of sound in the passage from the open circuit condition to the short circuit condition that is sufficient to be perceived by the human ear.

To this end, and by way of example, for the gong 100, which, as explained above, can be schematized as a cantilever beam with rectangular section, it is possible to use the Euler-Bernoulli model:

$$\left(YJ_t + 2Y_p^*J_p\right)\frac{\partial^4 v}{\partial x^4} + \left(\rho_t A_t + 2\rho_p A_p\right)\frac{\partial^2 v}{\partial t^2}) = 0 \qquad (1)$$

wherein Y is the Young's modulus of the metallic material of the central layer 13, ρ_t is the density of the metallic material of the central layer 13, ρ_p is the density of the piezoelectric material of the upper layer 14 and the lower layer 15, and v is the vertical displacement of the gong 100,

and wherein the following geometric parameters have been introduced:

$$A_t = bh_t \qquad A_p = bh_p$$

$$J_t = \frac{bh_t^3}{12} \qquad J_p = b\left(\frac{h_p^3}{3} + h_p^2\frac{h_t}{2} + h_p\frac{h_t^2}{4}\right)$$

which represent the area of the rectangular section of the central layer 13 and of the upper 14 and lower 15 layers and the moments of inertia of the rectangular section of the central layer 13 and of the upper 14 and lower 15 layers,

and wherein h_t and hp are, respectively, the thickness of the central layer 13 and of the upper 14 and lower 15 layers and b is the base of the rectangular section of the gong 100,

and the following physical property:

$$Y_{p,short}^* = \bar{c}_{11}^E = \frac{1}{s_{11}^E}$$

$$Y_{p,open}^* = \bar{c}_{11}^E\left(1 + \bar{k}_{13}^2\right) = \frac{1}{s_{11}^E(1 - k_{13}^2)}$$

which represents the Young's modulus of the upper layer 14 and of the lower layer 15 made of piezoelectric material in short circuit ($Y_{p,short}^*$) and open-circuit ($Y_{p,open}^*$) condition,

wherein s_{11}^E represents the pliability of the piezoelectric material in the plane of the upper layer 14 and of the lower layer 15, and wherein k_{13} is the piezoelectric constant, which is linked to the other physical parameters of the upper 14 and lower 15 layers by the following formulas:

$$k_{13}^2 = \frac{d_{13}^2}{s_{11}^E \varepsilon_{33}^T} \qquad \bar{k}_{13}^2 = \frac{k_{13}^2}{1 - k_{13}^2}$$

and represents the coupling efficiency between mechanical domain and electrical domain and regulates the variation of the Young's modulus of the upper 14 and lower 15 layer made of piezoelectric material. The parameter s_{11}^E represents the pliability of the piezoelectric material in short circuit in a direction x_1 orthogonal to the polarization direction x_3, ε_{33}^T is the electrical permittivity characteristic of the polarization direction for zero stress conditions, and d_{13} is the piezoelectric coefficient.

These formulas, which allow to obtain the equivalent Young's modulus of the layers 14 and 15 made of piezoelectric material in a closed circuit and open circuit condition, can be interpreted as special cases of the more general formula:

$$Y_p^* = Y_{p,open}^* \left(1 - \frac{k_{13}^2}{1 + i\omega C_p^S Z_{SH}}\right) \qquad (2)$$

wherein Z_{SH} is the impedance of the circuit to which the piezoelectric material layer is connected, $i = \sqrt{-1}$ represents the imaginary unit, ω the angular pulsation, and C_p^S is the characteristic capacity of the piezoelectric foil, which can be calculated as:

$$C_p^S = \frac{\varepsilon_{33}^T (1 - k_{13}^2) A}{h_p}$$

wherein A indicates the area of the upper surface of the foils. It is obtained in fact that for open circuit $Z_{SH} = \infty$ and $Y_p^* = Y_{p,open}^*$, while for short circuit $Z_{SH} = 0$ and $Y_p^* = Y_{p,open}^*(1 - k_{13}^2) = Y_{p,short}^*$. an impedance of capacitive type $Z_{SH} = 1/i\omega C$ can be varied in a purely mechanical way simply by modifying the distance between two parallel conductors, results in a real elastic modulus independent of the working frequency.

$$Y_p^* = Y_{p,open}^* \left(1 - \frac{C k_{13}^2}{C + C_p^S}\right)$$

The natural frequencies of the gong 100, respectively in the short circuit condition (f_s) and in the open circuit condition (f_o) can be obtained from the following formulas:

$$f_s = \frac{\lambda_n^2}{2\pi L^2} \sqrt{\frac{Y J_t + 2\bar{c}_{11}^E J_p}{\rho_t A_t + 2\rho_p A_p}}$$

$$f_o = \frac{\lambda_n^2}{2\pi L^2} \sqrt{\frac{Y J_t + 2\bar{c}_{11}^E J_p (1 + \bar{k}_{13}^2) J_p}{\rho_t A_t + 2\rho_p A_p}}$$

wherein λ is a fixed number characteristic of each natural frequency and L is the length of the gong 100. More in detail, the coefficient λ_n is one, for example the one with lower value, of the n (with n any positive integer) solutions of the characteristic equation of a jammed beam:

$$1 + cos(\lambda) \cdot cosh(\lambda) = 0$$

wherein cos() is the cosine function and cosh() is the hyperbolic cosine function.

For example, if it were necessary to calculate the length of the gong such that its first natural frequency in a short circuit condition was tuned to the desired frequency f_s , it would be necessary to use the value λ_1= 1.87510407 obtained as the lowest among the values that satisfy the previously reported characteristic equation.

In particular, in the case of the gong 100 which can be assimilated to a cantilever beam, for the first three natural frequencies we obtain:

n	λ_n
1	1.87510407
2	4.69409113
3	7.85475744

Defining the following dimensionless parameters:

$$\psi = \frac{\bar{c}_{11}^E}{Y} \; ; \qquad \varphi = \frac{\rho_p}{\rho_t} \; ; \qquad \xi = \frac{h_p}{h_t}$$

wherein Y is the Young's modulus and $\bar{c}_{11}^E$ is the reciprocal of the short circuit pliability s_{11}^E of the piezoelectric material, φ is the ratio between the density of the piezoelectric material and of the metallic material and ξ is the ratio between the thickness of each layer, upper 14 and lower 15, made of piezoelectric material and the metal central layer 13 of the multilayer main body 10, it is possible to obtain the ratio between the two fundamental frequencies such as:

$$\frac{f_o}{f_s} = \sqrt{\frac{1 + 2\,\psi\left(1 + \bar{k}_{13}^2\right)\left(4\xi^3 + 6\xi^2 + 3\xi\right)}{1 + 2\,\psi\left(4\xi^3 + 6\xi^2 + 3\xi\right)}} \qquad (3)$$

which depends only on three dimensionless parameters.

Once the materials of the metal central layer 13 and of the upper 14 and lower 15 layers made of piezoelectric material have been chosen, it is possible to invert the formula (3) in order to obtain the ratio ξ between the thickness h_p of the layers 14 and 15 made of piezoelectric material and the thickness h_t of the metal central layer 13, which guarantees a certain change of sound when switching between an open circuit condition and a short circuit condition.

Once the interval difference between the two obtainable sounds has been assigned through the choice of ξ, it is possible to tune the gong 100 to the desired frequency by adjusting its length, using the following formula:

$$L = \sqrt{\frac{\lambda_n^2}{2\pi f_s}\sqrt{\frac{Y\left(h_t^2/12\right)\left[1+2\psi\left(4\xi^3+6\xi^2+3\xi\right)\right]}{\rho_t(1+2\varphi\xi)}}} \qquad (4)$$

wherein ρ_t represents the density of the metallic material and λ_n is the coefficient described above.

By way of example, consider using, for the upper layer 14 and the lower layer 15 of the gong 100, a commercially available piezoelectric material in form of a foil (PZT PIC151). The metal intermediate layer 13 is made of titanium.

Figure 6 shows the graph of the frequency ratio between an open circuit condition and a short circuit condition based on the geometric ratio ξ between the thickness h_p of the layers 14 and 15 made of piezoelectric material and the thickness h_t of the metal intermediate layer 13.

The characteristic ratio of the tempered semitone range is indicated by a dashed line, highlighting that, with a ratio ξ of thicknesses equal to 0.42, it is possible to obtain two distinguishable sounds, i.e. with the open circuit/short circuit switching.

Once the ratio is established, it is possible to tune the first natural frequency of the gong 100 in a short circuit condition to a sample frequency of 1568 Hz (G note, 5th octave), choosing a gong length equal to L= 1.82 cm.

From the above description it is evident how the gong described above, allows to achieve the purposes proposed. In particular, it is evident how the gong according to the invention allows to create more elaborate chimes with the same number of sound sources used.

It is finally obvious to a person skilled in the art that it is possible to make changes and variations to the solution described with reference to the figures without departing from the scope of protection of the present invention as defined by the appended claims.

CLAIMS

1. Gong (100; 1100) for a clock strike device, comprising:

- a multilayer main body (10; 110), which includes a central layer (13; 113) made of metallic material, an upper layer (14; 114) and a lower layer (15; 115) made of piezoelectric material, wherein the upper layer (14; 114) and the lower layer (15; 115) have a respective outer coating layer (16, 17; 116, 117) made of metallic material; and

- a metal bridge (30), which can be operated between a first operating position of absence of contact with the multilayer main body (10; 110), whereby the upper (14; 114) and lower (15; 115) layers are in an open circuit condition, and a second operating position of contact with the multilayer main body (10; 110), whereby the upper (14; 114) and lower (15; 115) layers are in a short circuit condition.

2. Gong (100; 1100) according to claim 1, wherein the upper (14; 114) and lower (15; 115) layers consist each of a foil made of polarized ceramic piezoelectric material.

3. Gong (100; 1100) according to claim 1 or 2, wherein the bridge (30) has a comb shape, comprising a back (31), from which a first (32), a second (34) and a third tooth (35) extend, wherein in the second operating condition of the bridge (30), the first tooth (32) is in contact with the metal central layer (13; 113), the second tooth (34) is in contact with the outer coating layer (16; 116) of the upper layer (14; 114) made of piezoelectric material and the third tooth (35) is in contact with the outer coating layer (17; 117) of the second layer (15) made of piezoelectric material of the multilayer main body (10; 110) of the gong (100; 1100).

4. Gong (100; 1100) according to claim 3, wherein the first tooth, the second tooth and the third tooth of the bridge (30) consist each of a metal wire.

5. Gong (100; 1100) according to claim 3, wherein the first tooth, the second tooth and the third tooth of the bridge (30) consist each of a metal foil.

6. Gong (100) according to any one of the preceding claims, wherein the multilayer main body (10) is rectilinear.

7. Gong (1100) according to any one of claims 1 to 5, wherein the multilayer main body (110) has the shape of an arc of a circle.

8. Gong (100) according to claim 6, wherein the ratio (ξ) between the thicknesses of the metal central layer (13) and the upper (14) and lower (15) layers

made of piezoelectric material is obtained by inverting the ratio between the natural frequencies of the gong, in the open circuit (f_o) and short circuit (f_s) condition according to the following formula:

$$\frac{f_o}{f_s} = \sqrt{\frac{1 + 2\psi(1 + \bar{k}_{13}^2)(4\xi + 6\xi^2 + 3\xi)}{1 + 2\psi(4\xi^3 + 6\xi^2 + 3\xi)}}$$

wherein $\bar{k}_{13}^2 = k_{13}^2/(1 - k_{13}^2)$, con k_{13} piezoelectric constant of the piezoelectric material of the upper layer (14) and the lower layer (15), ψ is a parameter calculated as follows

$$\psi = \frac{\bar{c}_{11}^E}{Y}$$

wherein Y is the Young's modulus of the metallic material of the central layer and $\bar{c}_{11}^E$ is the reciprocal of the short circuit pliability s_{11}^E of the piezoelectric material and ξ is the ratio between the thickness of each layer, upper (14) and lower (15), made of piezoelectric material and the metal central layer (13) of the multilayer main body (10).

9. Gong (100) according to any one of the preceding claims, wherein the length (L) of the gong (100) is given by the following formula:

$$L = \sqrt{\frac{\lambda_n^2}{2\pi f_s}\sqrt{\frac{Y\left(h_t^2/_{12}\right)[1 + 2\psi(4\xi^3 + 6\xi^2 + 3\xi)]}{\rho_t(1 + 2\varphi\xi)}}}$$

wherein ρ_t represents the density of the metallic material of the central layer (13; 113) and λ_n is a coefficient satisfying the equation:

$$1 + cos(\lambda) \cdot cosh(\lambda) = 0$$

wherein cos() is the cosine function and cosh() is the hyperbolic cosine function.

10. Gong (100) according to claim 9, wherein λ_n is the least value solution among the solutions of the equation:

$$1 + cos(\lambda) \cdot cosh(\lambda) = 0$$

11. Gong (100; 1100) according to any one of the preceding claims, wherein

the upper layer (14; 114) and the lower layer (15; 115) made of piezoelectric material comprise a respective shunt circuit (40), which is connected to the respective layer (14, 15; 114, 115) made of piezoelectric material and has a characteristic impedance (Z_{SH}), by varying which it is possible to continuously modify the overall stiffness of the gong (100; 1100), with consequent modulation of the sounds produced.

12. Gong (100; 1100) according to any one of the preceding claims, wherein the metal central layer (13; 113) is preferably made of titanium and the metal bridge (30) is made of copper or silver.

13. Gong (100; 1100) according to any one of the preceding claims, wherein the multilayer main body (10; 110) comprises an end (11; 111) fixed to a support (20), for fixing the gong to the case (2) of the clock (1) and another free end (12; 112).

14. Clock (1) comprising a gong (100; 1100) according to any one of the preceding claims and a hammer (4), which is operated to strike the multilayer main body (10; 110) of the gong (100; 1100), causing it to vibrate according to natural frequencies, thereby producing two distinct and distinguishable sounds based on the position of a metal bridge (30).

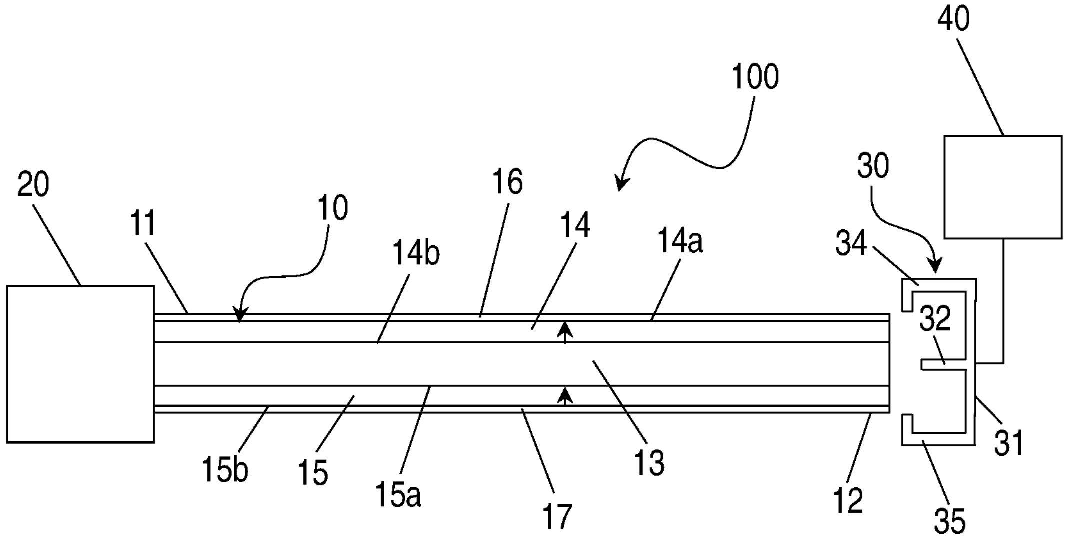
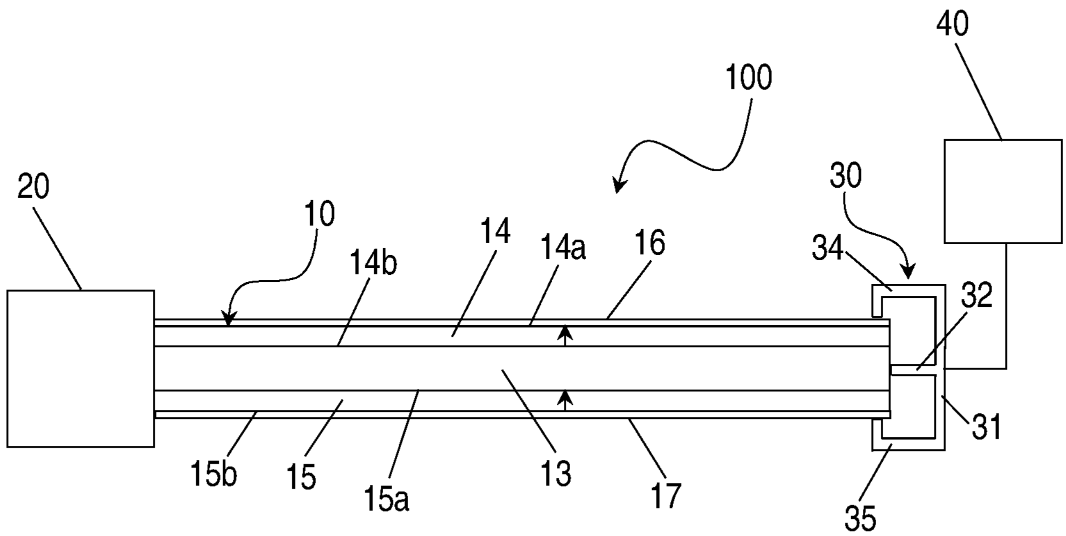

40
100
30
20
11
10
16
14
14a
14b
34
32
15b
15
15a
13
17
12
31
35

FIG. 1


40
100
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10
14b
14
14a
16
34
32
15b
15
15a
13
17
31
35

FIG. 2

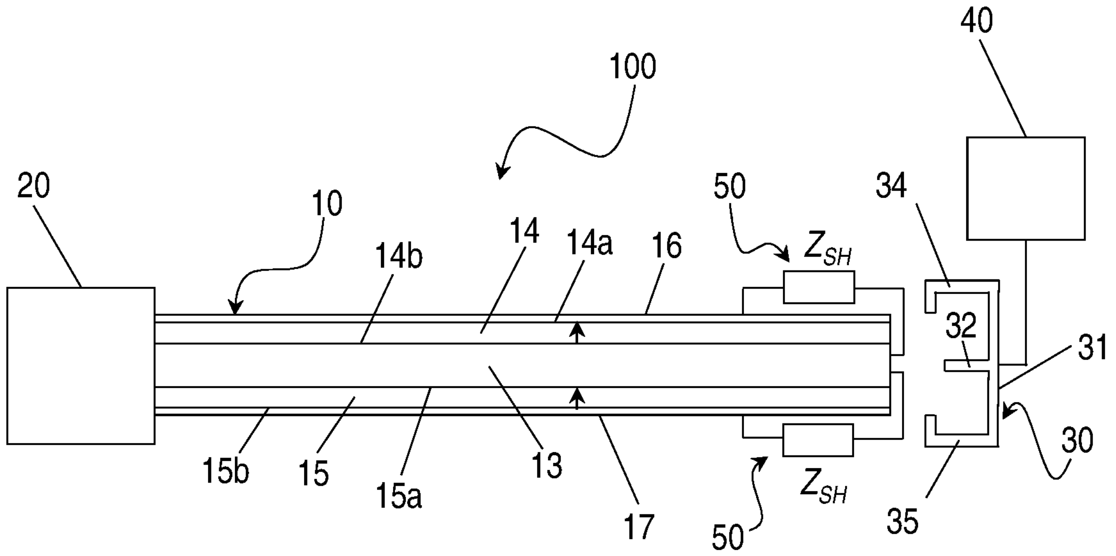
100
40
20
10
14b
14
14a
16
50
Z_{SH}
34
32
31
30
15b
15
15a
13
17
50
Z_{SH}
35

FIG. 3

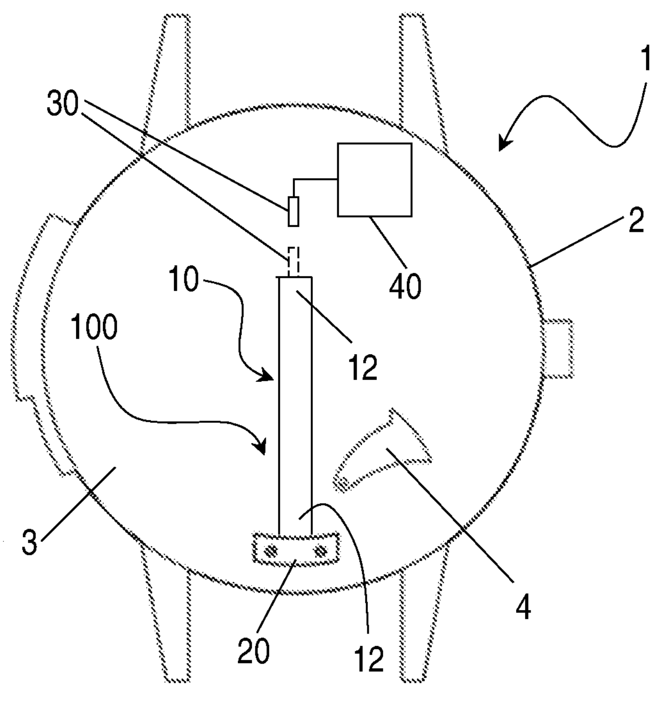
1
30
2
40
10
100
12
3
4
20
12

FIG. 4

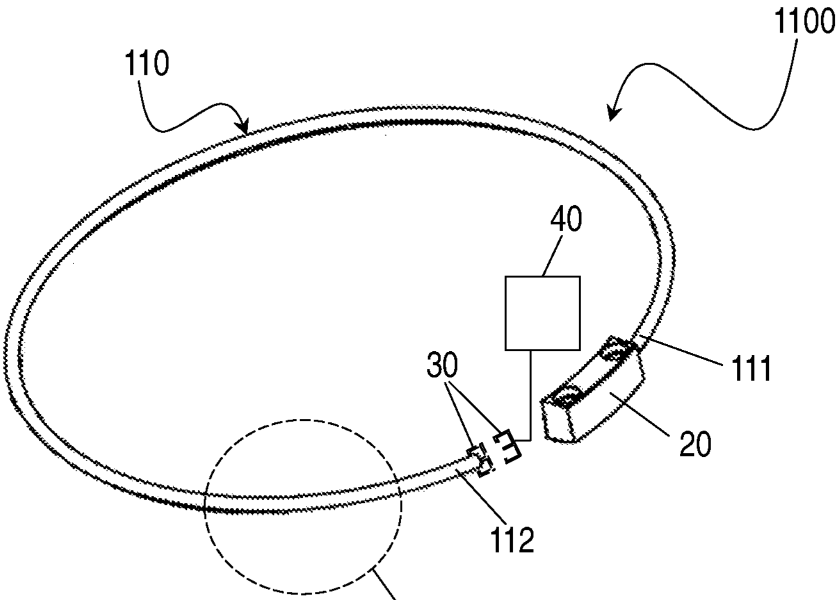

FIG. 5

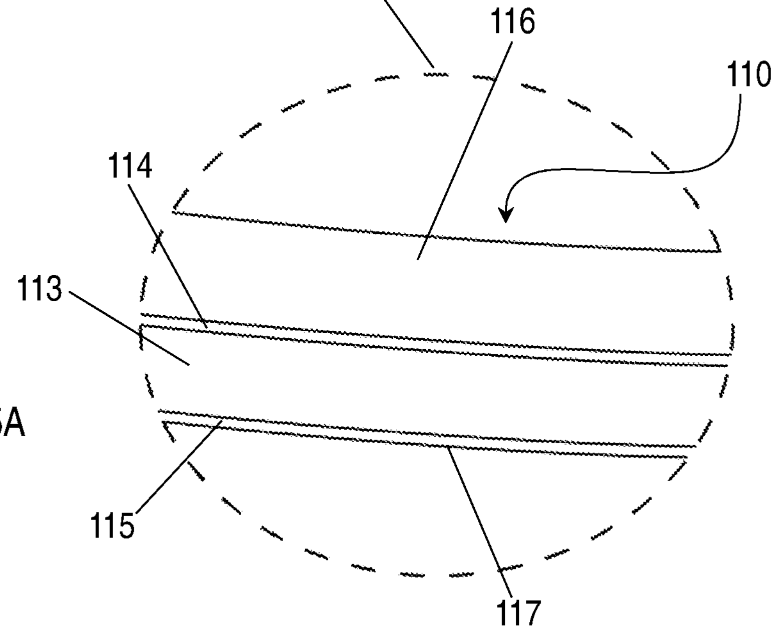

FIG. 5A

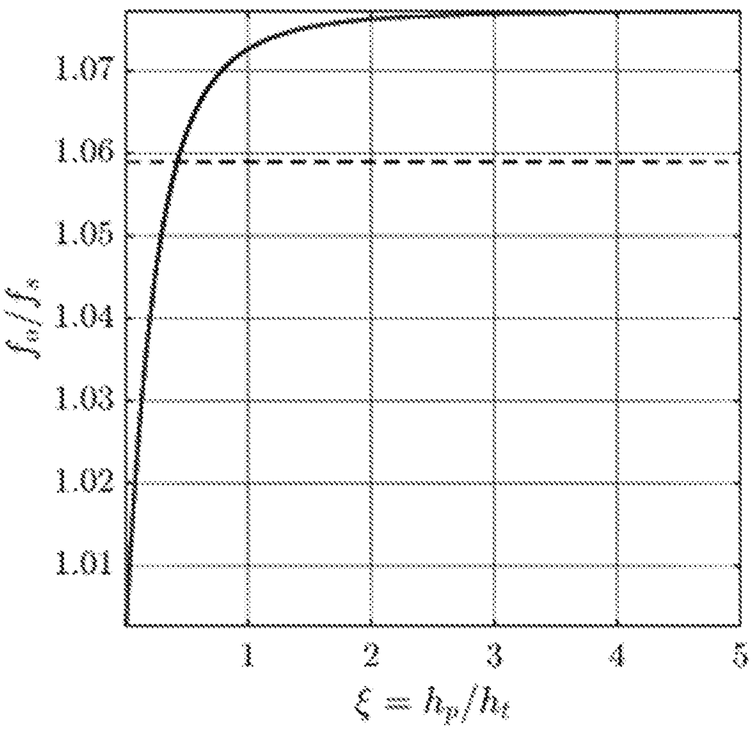

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2023/050776

A. CLASSIFICATION OF SUBJECT MATTER
INV. G04B21/08 G04B23/02 G10D13/10
ADD. G04B21/12

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)
G04B G10B G10D

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP S55 70894 A (CITIZEN WATCH CO LTD) 28 May 1980 (1980-05-28) columns 1-7; figures 1,2 -----	1-14
A	EP 3 537 228 A1 (MONTRES BREGUET SA [CH]) 11 September 2019 (2019-09-11) paragraphs [0016] - [0036]; figures 1-3 -----	1-14
A	US 2014/355398 A1 (KARAPATIS POLYCHRONIS NAKIS [CH] ET AL) 4 December 2014 (2014-12-04) paragraphs [0018] - [0048]; figures 1-4 -----	1-14
A	US 2014/104994 A1 (RAGGI LUCAS [CH] ET AL) 17 April 2014 (2014-04-17) paragraph [0040]; figure 4 -----	1-14
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 May 2023	31/05/2023

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Cavallin, Alberto

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Form PCT/ISA/210 (second sheet) (April 2005)

International application No
PCT/IB2023/050776

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
T	WO 2004/021091 A1 (SEIKO EPSON CORP [JP]) 11 March 2004 (2004-03-11) pages 4-20; figure 5 -----	1

3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2023/050776

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
JP S5570894	A	28-05-1980	NONE		
EP 3537228	A1	11-09-2019	CH 714716	A2	13-09-2019
			EP 3537228	A1	11-09-2019
US 2014355398	A1	04-12-2014	CH 708095	A2	28-11-2014
			CN 104216270	A	17-12-2014
			EP 2808745	A1	03-12-2014
			HK 1205292	A1	11-12-2015
			JP 5797811	B2	21-10-2015
			JP 2014232104	A	11-12-2014
			US 2014355398	A1	04-12-2014
US 2014104994	A1	17-04-2014	CH 707078	A1	15-04-2014
			CN 103728869	A	16-04-2014
			EP 2720091	A1	16-04-2014
			JP 6247070	B2	13-12-2017
			JP 2014081374	A	08-05-2014
			US 2014104994	A1	17-04-2014
WO 2004021091	A1	11-03-2004	CN 1578934	A	09-02-2005
			EP 1439435	A1	21-07-2004
			JP WO2004021091	A1	22-12-2005
			US 2004233793	A1	25-11-2004
			WO 2004021091	A1	11-03-2004