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(54) **Title:** CONTACTLESS MANIPULATION OF OBJECTS USING CONTROLLED ELECTROACOUSTIC TRANSDUCERS

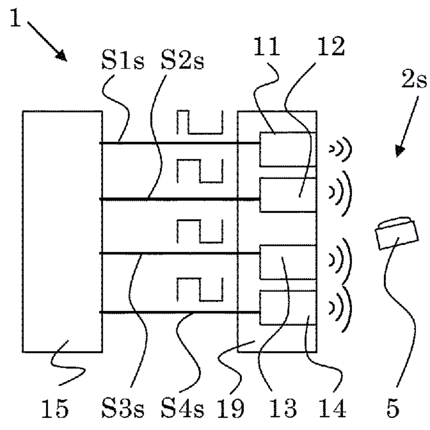

Fig. 1B

(57) **Abstract:** The method for operating a device (1) for contactless manipulation of objects (5), involves a device (1) comprising a plurality of electroacoustic transducers (11, 12,...). It comprises: - applying to each of the transducers (11, 12,...) an electrical control signal (S1s, S2s,...) to produce an acoustic pressure field, wherein a control signal applied to a first one of the transducers is referred to as first control signal (S1s); - causing a change of a total acoustic output power produced by the first transducer (11) by initially applying an initial first control signal and subsequently applying a subsequent first control signal (S1s). In particular, the initial and subsequent first control signals (S1s) can have different signal shapes.

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CONTACTLESS MANIPULATION OF OBJECTS USING CONTROLLED ELECTROACOUSTIC TRANSDUCERS

The invention relates to the field of manipulation of objects in a contactless manner, based on acoustic pressure fields. It relates to methods and apparatuses according to the opening clauses of the claims. Such methods and devices can find application, e.g., in robotics or in various industries, such as in handling and placing of electronic components, or in various fields of science, where small objects or portions of material shall be handled in a contactless manner.

From J. Nakahara et al. “Contact-less Manipulation of Millimeter-scale Objects via Ultrasonic Levitation” (submitted to the 8th IEEE RAS/EMBS International Conference on Biomedical Robotics and Biomechatronics), a way of picking up objects is known, which is accomplished in a phase-controlled way, i.e. by modulating the phase of control signals applied to the transducers.

In O. Youssefi et at. “Contactless Robotic Micromanipulation in Air Using a Magneto-Acoustic System” (IEEE ROBOTICS AND AUTOMATION LETTERS, VOL. 4, NO. 2, APRIL 2019), a combination of magnetic and acoustic micromanipulation methods is described.

L. Cox et al. describe in “Acoustic Lock: Position and orientation trapping of non-spherical sub-wavelength particles in mid-air using a single-axis acoustic levitator” (Appl. Phys. Lett. 113, 054101 (2018)) ways of handling small particles using an acoustic pressure field.

The inventors did recognize that currently known techniques for contactless object manipulation have some shortcomings. For example, some degrees of freedom, such as rotation about some axes and movement along some (other) axes, are not accessible by known devices, at least not in combination with other rotations or movements. And furthermore, known manipulation techniques lack precision, in particular in terms of precision of an achieved alignment of the object. And still furthermore, known manipulation techniques apparently lack some desirable smoothness of provoked object movements.

The inventors not only recognized that these shortcomings do exist and should be remedied, but they also found a solution for them.

In prior art devices, transducers are usually connected to a power supply producing a square-shaped voltage of a fixed, high amplitude, as this usually results in maximum acoustic pressure or more particularly in a maximum total acoustic output power for each transducer. In order to accomplish object manipulations, it is known to vary the relative phase of some transducers with respect to the phase of other transducers of the device.

The inventors, however, found that changing, in particular decreasing for respective ones of the transducers the total acoustic output power produced by the respective ones of the transducers can open up new and useful possibilities in object manipulation.

One possible object of the invention is to create new ways of contactless object manipulation.

Another possible object of the invention is to provide a way of contactlessly manipulating objects which does not have the shortcomings mentioned above.

Another possible object of the invention is to make possible to contactlessly manipulate objects in a particularly stable or safe fashion.

Another possible object of the invention is to make possible to contactlessly manipulate objects in a particularly smooth fashion.

Another possible object of the invention is to make possible to contactlessly manipulate objects in a particularly precise fashion.

Another possible object of the invention is to enable contactless manipulation of objects including rotations about various different axes.

Another possible object of the invention is to enable contactless manipulation of objects including translations along various different axes.

Another possible object of the invention is to enable picking up an object from a surface, in particular in a safe and/or smooth fashion.

Another possible object of the invention is to enable placing an object on a surface, in particular in a safe and/or smooth fashion.

Another possible object of the invention is to enable changing a shape of a levitating amount of a liquid, in particular to produce shape changes of a levitating amount of a liquid in a well-controlled and/or precise and/or smooth fashion.

In particular, a corresponding method for operating a device for contactless manipulation of objects, a corresponding method for contactlessly manipulating an object, a corresponding device for contactless manipulation of objects and a corresponding robotics apparatus shall be provided.

Further objects and various advantages emerge from the description and embodiments below.

At least one of these objects is at least partially achieved by apparatuses and methods according to the patent claims.

In the method for operating a device for contactless manipulation of objects, the device comprises a plurality of electroacoustic transducers. And the method comprises:

— applying to each of the transducers an electrical control signal to produce an acoustic pressure field.

As is known from the art, such an acoustic pressure field can be used for manipulating one or more objects, such as letting the one or more objects levitate and meanwhile have them carry out a rotation and/or a translation.

A control signal applied to a first one of the transducers shall be referred to as first control signal.

The method furthermore comprises:

— causing a change of a total acoustic output power produced by the first transducer by initially applying an initial first control signal and subsequently applying a subsequent first control signal.

This way, the acoustic pressure field produced by the plurality of transducers of the device can be changed, which again can influence an object disposed within the acoustic pressure field. More particularly, location and/or orientation in space of the object can be changed. E.g., a translation and/or a rotation of the object can be produced or changed.

Of course, a control signal identical to the first control signal can be (simultaneously) applied to a first subset of the plurality of transducers, the first subset including the first transducer and one or more further transducers.

The changing the total acoustic output power can be a decreasing. In other embodiments, it can be an increasing.

For example, at some point, such as during an initial time span (t_i), the first transducer produces an initial total acoustic output power (P_i), and later, such as during a subsequent time span (t_s), the first transducer produces a subsequent total acoustic output power (P_s).

The initial and subsequent first control signals are not identical – of course, as that could not result in the described change of a total acoustic output power.

The control signals are usually control voltages.

Furthermore, usually neither the initial nor the subsequent first control signal is zero.

Furthermore, usually neither the total acoustic output power produced in reaction to application of the initial first control signal nor the total acoustic output power produced in reaction to application of the subsequent first control signal is zero.

In some embodiments, the change caused in the total acoustic output power produced by the first transducer is a gradual change. Thus, it is not a qualitative change, as would be the case if before or after the change (upon application of the initial or the subsequent first control signal) the total acoustic output power would be zero.

In some embodiments, the initial first control signal differs from the subsequent first control signal in at least one of

— its amplitude;

— its frequency;

— its signal shape.

Said two control signals can also differ with respect to their phase; however they do not differ from one another merely with respect to their phase, as merely changing the phase of a control signal does not create a change in total acoustic output power produced by the respective transducer; even though the acoustic pressure field can change in reaction to such a mere phase change.

Referring the the “frequency” of a signal here can in particular mean to refer to a fundamental frequency of the signal. For example, a periodic signal can be composed of various frequency components (harmonics) which are integer multiples of the lowest (=first) harmonic, said first harminic constituting in this case the fundamental frequency of the signal.

In some embodiments, the initial first control signal differs from the subsequent first control signal in their respective amplitudes, in particular while their frequencies and optionally also their signal shapes are identical.

In some embodiments, the initial first control signal differs from the subsequent first control signal in their respective frequencies, in particular while their amplitudes and optionally also their signal shapes are identical. A total acoustic output power can depend on the frequency of the control signal. This is the case, e.g., for piezoelectric transducers, showing a resonance: moving the frequency of the control signal away from the resonance frequency lowers the total acoustic output power, even at constant signal shape and amplitude.

In some embodiments, the initial first control signal differs from the subsequent first control signal in their respective signal shapes. Such embodiments where the initial and the subsequent first control signals have different signal shapes can be particularly simple to realize. Herein, it can be provided that the frequency of the initial and the subsequent first control signal is identical. And it can be provided (alternatively or in addition) that the initial and the subsequent first control signals have an identical amplitude.

In particular, in some embodiments, the initial first control signal differs from the subsequent first control signal in their respective signal shapes, and the respective amplitudes and frequencies of the initial and of the subsequent first control signal are identical.

In the particular aspect regarding differences in signal shape, the method can be a method for operating a device for contactless manipulation of objects, the device comprising a plurality of electroacoustic transducers, wherein the method comprises:

— applying to each of the transducers an electrical control signal to produce an acoustic pressure field, wherein a control signal applied to a first one of the transducers is referred to as first control signal; and

— modifying a signal shape of the first control signal.

The modifying the signal shape of the first control signal can in particular mean that the initial first control signal has a signal shape which is different from the signal shape of the subsequent first control signal; and by the modifying, the signal form of the first control signal is changed from a signal form of the initial first control signal to the signal form of a subsequent first control signal.

The signal shape of a control signal can also be considered, e.g., the waveform of a control signal.

In some embodiments, the first control signal is a pulse wave, in particular wherein the control signal applied to any of the transducers is a pulse wave. Pulse waves are also referred to as rectangular waves.

Referring to "the first control signal" means to refer to both, the initial and the subsequent the first control signal.

Changing the waveform of a pulse wave is particularly simple – and can readily result in a change in total acoustic output power of the respective transducer.

The pulse wave can be, e.g., a pulse wave with zero-sequence. In other embodiments, the pulse wave is a pulse wave without zero-sequence.

In some embodiments, the signal shape of the first control signal – and optionally of the control signals applied to any of the transducers – is a signal shape which assumes (dwells on) exactly two (and not more than two) different values, such as a minimum value and a maximum value. These two values can be, e.g., zero and a non-zero value. In other embodiments, these two values are a positive and a negative value, in particular wherein the negative value equals a negative of the positive value.

In some embodiments, the signal shape of the first control signal – and optionally of the control signals applied to any of the transducers – is a signal shape which assumes (dwells on) exactly three (not more than three) different values, such as a minimum value and zero and a maximum value. For example, the negative of the maximum value can equal the minimum value.

In some embodiments, a duty cycle of the initial first control signal is different from a duty cycle of the subsequent first control signal. Accordingly, modifying the signal shape comprises changing a duty cycle of the first control signal. The duty cycle of a signal can in particular denote the ratio of the time duration during which the signal is non-zero to the time duration during which the signal is zero, in particular considering one period of the signal.

In some embodiments, a pulse width of the initial first control signal is different from a pulse width of the subsequent first control signal. Accordingly, modifying the signal shape can comprise modulating a pulse width of the first control signal.

In some embodiments, the method comprises causing a continuous or quasi-continuous change of the total acoustic output power produced by the first transducer by continuously or quasi-continuously changing the first control signal from the initial first control signal to the subsequent first control signal.

This way, the acoustic pressure field can be modified in a continuous or quasi-continuous way. This can enable smooth changes in the acoustic pressure field and thus can facilitate particularly smooth manipulations of objects.

For example, the signal form of the first control signal can be continuously or quasi-continuously changed, e.g., by gradually changing its duty cycle and/or by gradually changing a pulse width of the first control signal.

Quasi-continuous changes are changes taking place in a plurality of (small) steps, approximating a continuous change.

In some embodiments, a control signal applied to a second one of the transducers is referred to as second control signal, and the second control signal is different from the first control signal during application of the initial first control signal and/or during application of the subsequent first control signal. In particular, the difference can comprise that the second control signal has a signal shape which is different from the signal shape of the first control signal.

Of course, a control signal identical to the second control signal can be (simultaneously) applied to a second subset of the plurality of transducers the second subset including the second transducer and one or more further transducers. This second subset does not include the first transducer; and it does not include the first subset mentioned further above.

In some embodiments, the transducers are piezoelectric transducers. In particular, for a subset of the transducers, more particularly for each of the transducers, a frequency of the control signal applied to the respective transducer coincides with a resonance frequency of this respective transducer.

In some embodiments, the control signals have a frequency (in particular fundamental frequency) in the ultrasonic range, e.g., in a range between 25 kHz and 100 kHz, more particular each of which is in a range between 30 kHz and 60 kHz.

In some embodiments, the transducers are nominally identical, i.e. have nominally identical properties.

Also a method for contactlessly manipulating an object by means of a device for contactless manipulation of objects is described. Therein, the device comprises a plurality of electroacoustic transducers, and the method comprises operating the device according to a method as herein described, in particular as described above.

In some embodiments, the change in total acoustic output power (and a respective change of the first control signal) is accomplished in such a way that a movement of the object can follow the changes. In other words, the changes can be carried out relatively slowly, and not so fast that the object, due to inertia, cannot follow them and thus effectively provoking no change of motional state of the object.

In some embodiments, the change from the initial to the subsequent first control signal takes at least as long as one period of the initial first control signal.

The method can facilitate picking and/or placing objects, in particular picking objects from and/or placing objects on an acoustically reflective surface. For example:

In some embodiments, the method comprises increasing the total acoustic output power produced by the first transducer by changing, in particular by continuously or quasi-continuously changing the first control signal from the initial first control signal to the subsequent first control signal in order to facilitate picking said object from an acoustically reflective surface. In particular, the changing of the first control signal can comprise modifying a signal shape of the first control signal.

For example, the first control signal can be a pulse wave without zero-sequence, and a duty cycle of the pulse wave is increased from a first value in a range from 0% to 10% (or 100% to 90%); to a second value in a range from 40% to 50% (or 60% to 50%); or the first control signal is a pulse wave with zero-sequence, and a duty cycle of the pulse wave is increased from a first value in a range from 0% to 20% to a second value in a range from 80% to 100%.

In some embodiments, the method comprises decreasing the total acoustic output power produced by the first transducer by changing, in particular by continuously or quasi-continuously changing the first control signal from the initial first control signal to the subsequent first control signal in order to facilitate placing said object on an acoustically reflective surface. In particular, the changing of the first control signal can comprise modifying a signal shape of the first control signal.

For example, the first control signal can be a pulse wave without zero-sequence, and a duty cycle of the pulse wave is increased from a first value in a range from 40% to 50% (or 60% to 50%) to a second value in a range from 0% to 10% (or 100% to 90%); or the first control signal is a pulse wave with zero-sequence, and a duty cycle of the pulse wave is increased from a first value in a range from 80% to 100% to a second value in a range from 0% to 20%.

In some embodiments, the method comprises

— decreasing the total acoustic output power produced by the first transducer by changing, in particular by continuously or quasi-continuously changing the first control signal from the initial first control signal to the subsequent first control signal; and

thereafter

— increasing the total acoustic output power produced by the first transducer by changing, in particular by continuously or quasi-continuously changing the first control signal from the subsequent first control signal to a final first control signal.

Such ways of proceeding can be used, e.g., in order to facilitate producing a smooth and/or precise tilt or rotation movement of said object about an axis.

This way, a change from the initial to the final first control signal can be accomplished which involves a fade-out-and-fade-in-type of transition. This can be useful, e.g., when the acoustic pressure field shall not undergo a sudden change, but shall be changed in a rather smooth way. For example, when a phase shift of the first control signal needs to be accomplished, e.g., a phase shift of 180°, a sudden change of the acoustic pressure field can be avoided this way: Fading down to a first control signal close to zero, accomplish the phase shift and fade in again to a final first control signal, which may, e.g., be identical to the initial first control signal.

For example, the total acoustic output power of the first transducer produced during application of the subsequent first control signal can amount to at most 20%, more particularly to at most 5% of the total acoustic output power of the first transducer produced during application of the initial first control signal. And/or the total acoustic output power of the first transducer produced during application of the final first control signal amounts to at least 80%, more particularly to at least 95% of the total acoustic output power of the first transducer produced during application of the initial first control signal.

Of course, the changing of the first control signal can be comprise doing so in one or more of the described ways, such as by modifying its signal shape of the first control signal.

In some embodiments, the plurality of transducers comprises a second transducer, wherein a control signal applied to a second transducer is referred to as second control signal. Furthermore, a phase of the initial first control signal relative to a phase of the second control signal is referred to as initial phase, and a phase of the final first control signal relative to the phase of the second control signal is referred to as final phase. And the initial phase is different from the final phase. In particular, the initial phase can differ from the final phase by at least 90°, more particularly by between 150° and 210°. For example, the initial phase differs from the final phase by 180°.

Therein, it can be provided that the phase of the second control signal remains unchanged (during the change of the first control signal from the initial first control signal to the final first control signal).

For example, when an object shall be tilted or rotated an about axis, it can be useful to apply 180° phase changes to single ones of the transducers. E.g., when two subsets of transducers are provided, and a control signal applied to each transducer of the first subset has phase difference of 180° relative to a control signal applied to each transducer of the second subset, it can be useful for the desired object movement to make one or more of the transducers change to the other subset (in terms of their phases). In other words, for one or more of the transducers, the phase of the respective applied control signal shall be changed by 180°. Instead of doing so quasi instantaneously, possibly resulting in undesired object movements due to the sudden changes of the acoustic pressure field, the described method makes possible to accomplish such changes in a smooth way, in a well-controlled way. Firstly, the influence of the respective one or more transducers (which initially logically belong to the first subset) on the acoustic pressure field is reduced, then the phase is changed by 180°, and then the influence of the respective one or more transducers of the first subset on the acoustic pressure field is increased again. Finally, the respective one or more transducers (logically) belong to the second subset.

We also describe a corresponding device, In particular, we describe a device for contactless manipulation of objects, comprising a plurality of electroacoustic transducers and a control unit for applying to each of the transducers an electrical control signal to produce an acoustic pressure field, wherein a control signal applied to a first one of the transducers is referred to as first control signal, and wherein the device is operable to cause a change of a total acoustic output power produced by the first transducer by initially applying an initial first control signal and subsequently applying a subsequent first control signal.

As will be readily understood, features mentioned herein with respect to a method can analogously apply for a described apparatus as well, such as to the device. And, vice versa, features mentioned herein with respect to an apparatus can analogously apply for a described method as well. The achievable effects correspond to each other.

The control unit is operable to produce at least two different control signals, namely the initial first control signal and the subsequent first control signal. More particularly, the control unit can be operable to initially apply an initial first control signal and subsequently apply a subsequent first control signal. The control unit can still more particularly be configured to automatically initially apply an initial first control signal and subsequently apply a subsequent first control signal. For example, the control unit can be programmable to produce different first control signals at different times.

The control unit can be programmable, e.g., to accomplish a modification of the signal shape of at least the first control signal.

The control unit can be configured to automatically accomplish a change from an application of the initial first control signal to an application of the subsequent first control signal.

In some embodiments, the device comprises a common transducer holder, wherein each one of the plurality of transducers is held in the common transducer holder. In particular, the mutual position and orientation of the transducers is fixed by the transducer holder; thus remaining unchanged because of the transducer holder.

The control unit can comprise, e.g., at least one of: a signal shape modulator, an amplitude modulator, a freqency modulator.

With respect to the particular aspect regarding differences in signal shape, the device for contactless manipulation of objects can comprise a plurality of electroacoustic transducers and a control unit for applying to each of the transducers an electrical control signal to produce an acoustic pressure field, wherein the control unit is operable to modify a signal shape of the control signal applied to at least one of the transducers. Being structured and configured to modify the first control signal, the control unit can be considered to comprise a signal shape modulator.

For example, the control unit can comprise a pulse width modulator. And/or the control unit can comprise a duty cycle modulator.

Furthermore, we describe a robotics apparatus. In particular, the robotics apparatus can comprise a device acording as herein described. In particular, it comprises a robotics arm including the device.

Further embodiments and advantages emerge from the following description and the enclosed figures and from the dependent claims.

Below, the invention is described in more detail by means of examples and the included drawings. In the drawings, same reference numerals refer to same or analogous elements. The figures show schematically:

Fig. 1A a conceptual illustration of a device in an initial state;

Fig. 1B a conceptual illustration of the device of Fig. 1A in a subsequent state;

Fig. 2 a diagram illustrating the interrelation between control signals of different signal shapes and a resulting normalized acoustic pressure;

Figs. 3A-3C a diagram of rectangular wave signals without zero-sequence, having different duty cycles;

Figs. 4A-4C a diagram of rectangular wave signals with zero-sequence, having different duty cycles;

Fig. 5 a cross-sectional side view of a device comprising a transducer arrangement;

Figs. 6A-6E a symbolic illustration of control signals applied to transducers of the transducer arrangement of Fig. 5, in a top view.

The described embodiments are meant as examples or for clarifying the invention and shall not limit the invention.

Figs. 1A and 1B show illustrations of a device 1 for for contactless manipulation of objects, in an initial state and in a subsequent state, respectively, in a strongly schematized way.

The device 1 comprises a plurality of electroacoustic transducers 11, 12, 13, 14, such as piezoelectric transducers, which may be held in a common transducer holder 19. Usually, there are more transducers, and the transducers are arranged in a specific way with respect to each other. A more realistic transducer arrangement will be shown further below.

The transducers are connected to a control unit 15 providing a control signal, such as a control voltage, to each of the transducers, for example, as sketched in Figs. 1A and 1B, rectangular signals.

Accordingly, the transducers produce acoustic waves, e.g., in the ultrasonic range, and an acoustic pressure field is produced this way. An object 5 present in the acoustic pressure field can be manipulated, e.g., translated and/or rotated, by changing the acoustic pressure field from an initial state 2i to a subsequent state 2s by changing the control signals from initial control signals S1i, S2i, S3i, S4i to subsequent control signals S1s, S2s, S3s, S4s.

In the initial state (Fig. 1A), the signals applied to transducers 11 to 14 are identical, e.g., square waves (pulse waves of 50% pulse width). From the initial to the subsequent state, the control signals applied to transducers 12, 13, 14 remain unchanged, whereas the control signal applied to transducer 11 is changed – it is then a pulse wave with a pulse width of only about 20%. Such a reduced duty cycle results in a reduced total acoustic output power of transducer 11. This results in a change of the acoustic pressure field (2i becomes 2s).

As has been described herein above, other signal shapes and other ways of changing the control signals and/or the total acoustic output power of transducer are possible.

Fig. 2 illustrates the interrelation between control signals of different signal shapes and a resulting normalized acoustic pressure – which is closely proportional to the total acoustic output power of the transducer.

The y-axis shows a respective normalized amplitude, and the x-axis shows the duty cycle.

The solid line represents a calculated voltage for a rectangular-wave control signal (cf. Figs. 3A-3C); the crosses represent a measured voltage for a rectangular-wave control signal; the dashed line represents a calculated output pressure resulting from a rectangular-wave control signal; and the dotted line represents a calculated output pressure for a rectangular-wave control signal with zero-sequence (cf. Figs. 4A-4C); all in dependence of the duty cycle.

Figs. 3A-3C are a diagrammatical representations of rectangular wave signals without zero-sequence, having different duty cycles. And Figs. 4A-4C are diagrammatical representations of rectangular wave signals with zero-sequence, having the same different duty cycles as in Figs. 3A-3C.

In Figs. 3A-3C and 4A-4C, the x-axis represents the time, in arbitrary units, and the y-axis represents the signal height such as, e.g., a signal voltage.

In Figs. 3A, 4A, the duty cycle is D = 0.25.

In Figs. 3B, 4B, the duty cycle is D = 0.5.

In Figs. 3C, 4C, the duty cycle is D = 0.9.

Fig. 5 shows a cross-sectional side view of a device 1 comprising a transducer arrangement comprising a plurality of transducers, such as transducers 11 to 14. A control unit and connection lines between the transducers and the control unit are not shown. Figs. 6A-6E each show a top view of the transducer arrangement of Fig. 5. The transducers of the arrangement are arranged so as to form four circles of 12 transducers each, which are equidistantly distributed over the circumference, thus having an angular next-neighbor distance of 30°.

Inside the transducer arrangement, an acoustic pressure field is produced upon application of control signals to the transducers, and an object 5 inside the acoustic pressure field can be manipulated, e.g., rotated by changing the acoustic pressure field which is accomplished by modifying the control signals, e.g., by changing the waveform of the control signals – for at least one or more of the transducers.

Figs. 6A-6E comprise a symbolic illustration of control signals applied to the transducers, wherein only a single one of the four rings is shown in Figs. 6A-6E, but the control signals can be identical for each respective one of the four transducers (of the four rings) which have the same angular position.

As symbolized in Fig. 6A, to the transducers on the left of a plane illustrated by the thick line, 50% pulse waves of the same phase (0°) are applied, whereas on the right side of the plane, 50% pulse waves are applied to the transducers which have a phase differing therefrom by 180°. This way, a vertical twin trap can be established.

In order to rotate the object present in the acoustic pressure field, the plane can be rotated – by changing the control signals applied to the transducers adjacent to the plane.

In prior art, this is done by applying the control signals according to Fig. 6E as a next step subsequently to applying the control signals according to Fig. 6A. However, this is a strong step which can result in undesired object movements.

Herein, it is suggested to enable a much smoother transition from the state according to Fig. 6A to the state according to Fig. 6E. This can be accomplished by fading out the transducers adjacent to the plane, then changing the phase (from 0° to 180° or vice versa) and then fading the transducers in again. The fading in and out is accomplished by decreasing and increasing, respectively, the total acoustic power produced by the respectitve transducers. This again is accomplished by modifying the respective control signals, such as by modifying their duty cycle. By the modifying of the control signal and changing the phase, the plane is rotated.

Figs. 6B, 6C, 6D show merely three intermediate states between the states of Fig. 6A and 6E, but of course, a signal shape variation may be accomplished in a continuous fashion, or in a quasi-continuous fashion, such as in case of a digital pulse width control.

In Fig. 6B, the pulse widths of the control signals applied to the transducers adjacent the (rotating) plane is reduced; the plane is rotated 7.5° with respect to the state illustrated in Fig. 6A.

In Fig. 6C, the plane is rotated 15° with respect to the state illustrated in Fig. 6A; the pulse width of the transducers through which the plane is running is zero corresponding to a zero signal and, accordingly, to a zero total acoustic power of these transducers.

Fade-out is accomplished.

Furthermore, the phase of the transducers adjacent the (still further rotating) plane is changed, from 0° to 180° and vice versa, respectively.

Fade-in begins.

In Fig. 6D, plane is rotated 22.5° with respect to the state illustrated in Fig. 6A; the pulse width of the control signals applied to the transducers adjacent the (rotating) plane is reduced. Notably, the phase is changed with respect to the phase in Figs. 6A, 6B.

In Fig. 6E finally, a 50% pulse wave is applied to all transducers, like in Fig. 6A, but the plane separating the transducers with a 0° phase control signal from those with a 180° phase control signal is rotated by 30° with respect to the initial state illustrated in Fig. 6A.

The rotation of the object can thus be accomplished in a much smoother way than in prior art. And also an angular position of the object can be selected with a much higher precision, as states like in Figs. 6B or 6C or 6D and any of many other intermediate states can be selected – and not only states which are angularly more distant from one another (as given by the angular distance between next-neighbor transducers).

Patent Claims:

1. A method for operating a device for contactless manipulation of objects, the device comprising a plurality of electroacoustic transducers, the method comprising:

— applying to each of the transducers an electrical control signal to produce an acoustic pressure field, wherein a control signal applied to a first one of the transducers is referred to as first control signal;

— causing a change of a total acoustic output power produced by the first transducer by initially applying an initial first control signal and subsequently applying a subsequent first control signal.

2. The method according to claim 1, wherein the first control signal is a pulse wave, in particular wherein the control signal applied to any of the transducers is a pulse wave.

3. The method according to claim 1 or claim 2, wherein a duty cycle of the initial first control signal is different from a duty cycle of the subsequent first control signal and/or a pulse width of the initial first control signal is different from a pulse width of the subsequent first control signal.

4. The method according to one of claims 1 to 3, comprising causing a continuous or quasi-continuous change of the total acoustic output power produced by the first transducer by continuously or quasi-continuously changing the first control signal from the initial first control signal to the subsequent first control signal.

5. The method according to one of claims 1 to 4, wherein a control signal applied to a second one of the transducers is referred to as second control signal, and the second control signal is different from the first control signal during application of the initial first control signal and/or during application of the subsequent first control signal, in particular wherein a signal shape of the second control signal is different from a signal shape of the first control signal during application of the initial first control signal and/or during application of the subsequent first control signal.

6. The method according to one of claims 1 to 5, wherein the transducers are piezoelectric transducers, in particular wherein for a subset of the transducers, more particularly for each of the transducers, a frequency of the control signal applied to the respective transducer coincides with a resonance frequency of this respective transducer.

7. A method for contactlessly manipulating an object by means of a device for contactless manipulation of objects, the device comprising a plurality of electroacoustic transducers, the method comprising operating the device according to a method as claimed in one of claims 1 to 6.

8. The method according to claim 7, comprising increasing the total acoustic output power produced by the first transducer by changing, in particular by continuously or quasi-continuously changing the first control signal from the initial first control signal to the subsequent first control signal in order to facilitate picking said object from an acoustically reflective surface; in particular wherein the changing of the first control signal comprises modifying a signal shape of the first control signal.

9. The method according to one of claims 7 to 8, comprising decreasing the total acoustic output power produced by the first transducer by changing, in particular by continuously or quasi-continuously changing the first control signal from the initial first control signal to the subsequent first control signal in order to facilitate placing said object on an acoustically reflective surface; in particular wherein the changing of the first control signal comprises modifying a signal shape of the first control signal.

10. The method according to one of claims 7 to 9, comprising

— decreasing the total acoustic output power produced by the first transducer by changing, in particular by continuously or quasi-continuously changing the first control signal from the initial first control signal to the subsequent first control signal; and

thereafter

— increasing the total acoustic output power produced by the first transducer by changing, in particular by continuously or quasi-continuously changing the first control signal from the subsequent first control signal to a final first control signal;

in order to facilitate producing a tilt or rotation movement of said object about an axis; in particular wherein the total acoustic output power of the first transducer produced during application of the subsequent first control signal amounts to at most 20%, more particularly to at most 5% of the total acoustic output power of the first transducer produced during application of the initial first control signal, and more particularly wherein the total acoustic output power of the first transducer produced during application of the final first control signal amounts to at least 80%, more particularly to at least 95% of the total acoustic output power of the first transducer produced during application of the initial first control signal.

11. The method according to claim 10, the plurality of transducers comprises a second transducer, wherein a control signal applied to a second transducer is referred to as second control signal, and wherein a phase of the initial first control signal relative to a phase of the second control signal is referred to as initial phase, and a phase of the final first control signal relative to the phase of the second control signal is referred to as final phase, and wherein the initial phase is different from the final phase, in particular wherein the initial phase differs from the final phase by at least 90°, more particularly by between 150° and 210°, still more particularly by 180°.

12. A device for contactless manipulation of objects, comprising a plurality of electroacoustic transducers and a control unit for applying to each of the transducers an electrical control signal to produce an acoustic pressure field, wherein a control signal applied to a first one of the transducers is referred to as first control signal, and wherein the device is operable to cause a change of a total acoustic output power produced by the first transducer by initially applying an initial first control signal and subsequently applying a subsequent first control signal.

13. The device according to claim 12, comprising a common transducer holder, wherein each one of the plurality of transducers is held in the common transducer holder.

14. Robotics apparatus comprising a device according to one of claims 12 to 13, in particular comprising a robotics arm including the device.

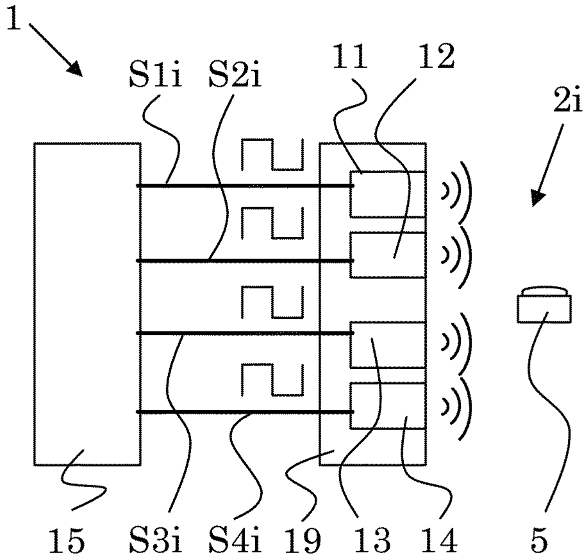

Fig. 1A

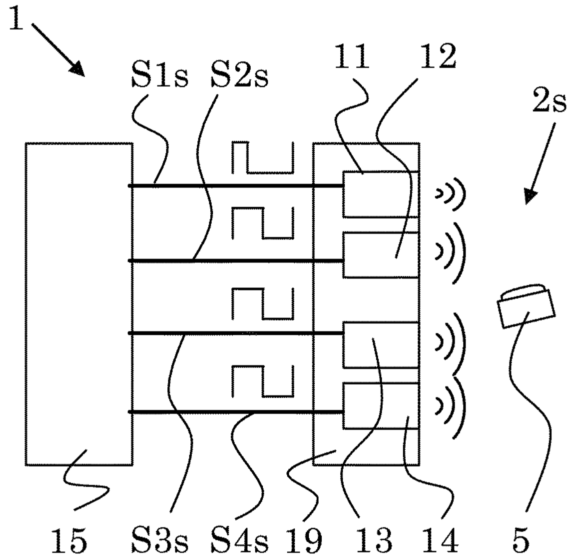

Fig. 1B

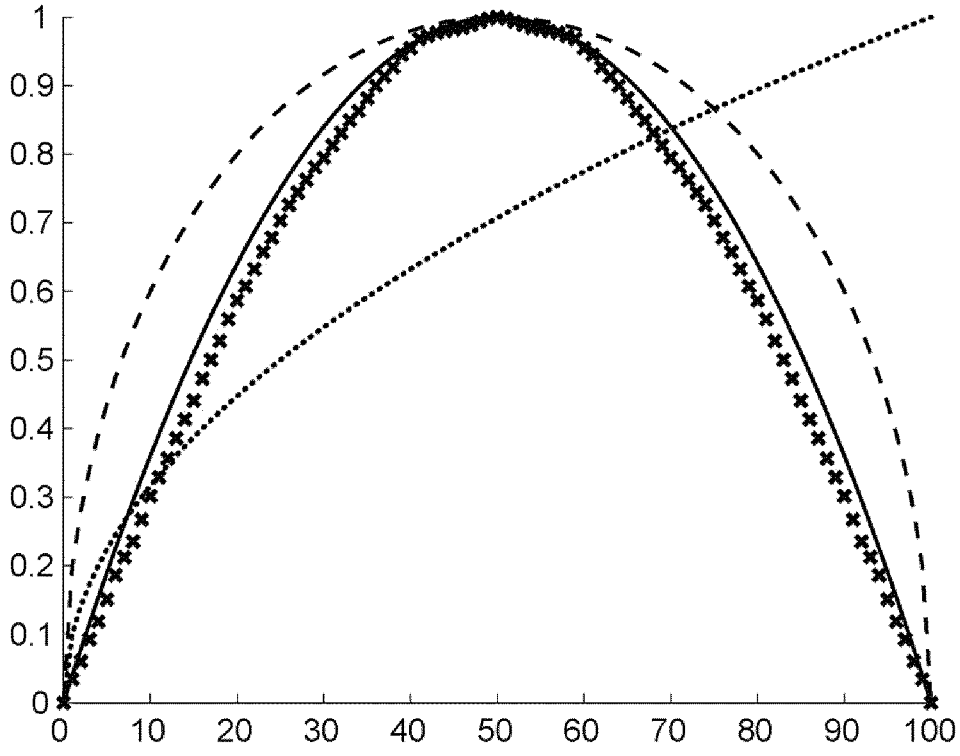

Fig. 2

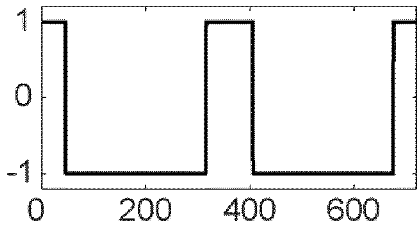

Fig. 3A

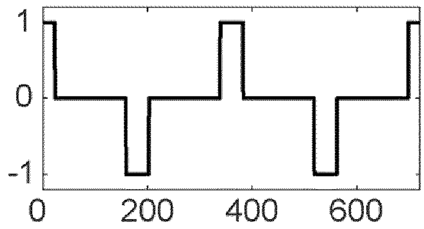

Fig. 4A

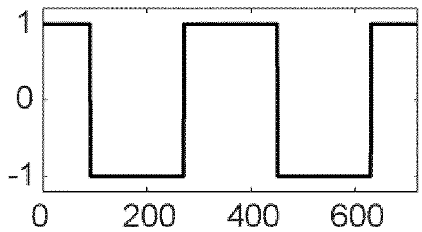

Fig. 3B

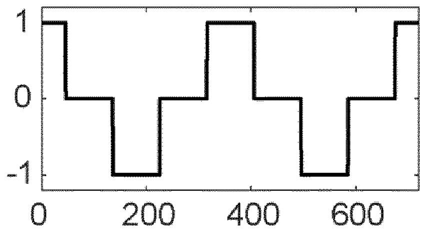

Fig. 4B

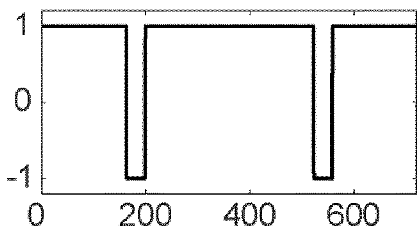

Fig. 3C

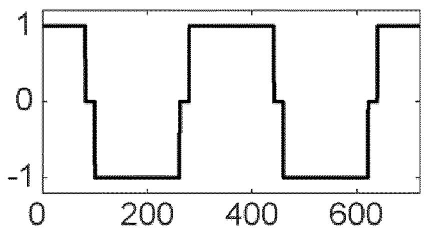

Fig. 4C

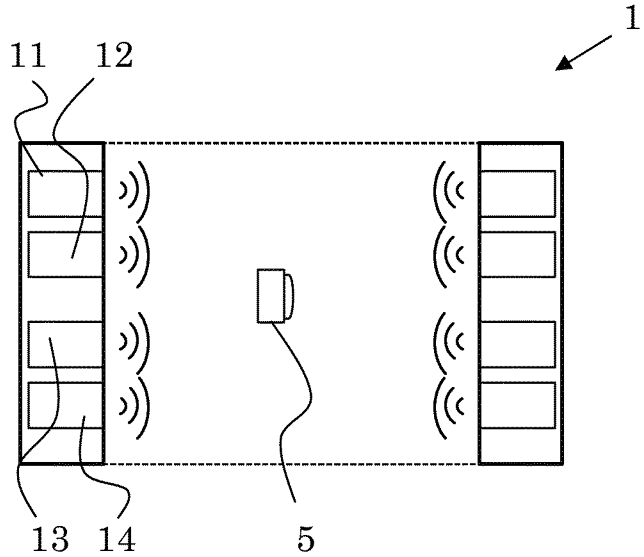

Fig. 5

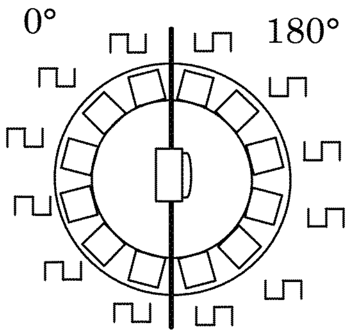

Fig. 6A

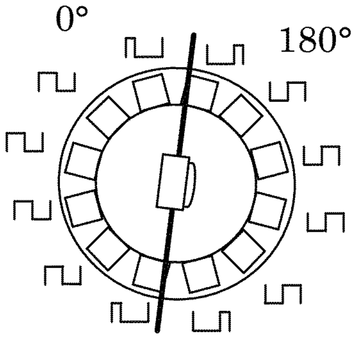

Fig. 6B

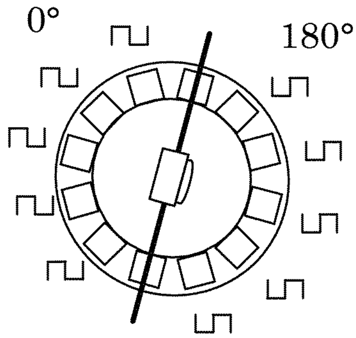

Fig. 6C

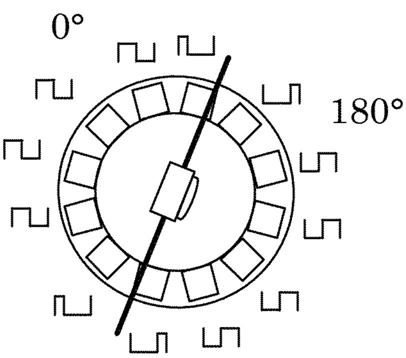

Fig. 6D

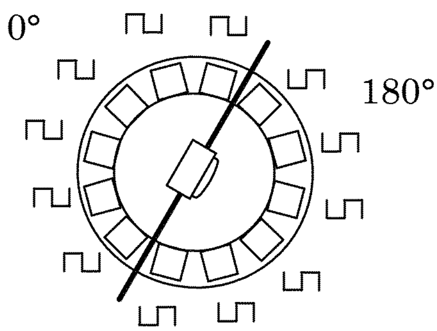

Fig. 6E

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2021/067638

A. CLASSIFICATION OF SUBJECT MATTER
INV. G10K11/34 G10K15/00
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G10K B06B B01L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	WO 2019/207143 A1 (MYVOX AB [SE]) 31 October 2019 (2019-10-31) page 7, lines 7-14 page 7, line 33 - page 8, line 1 page 11, lines 26-33 page 14, line 14 - page 15, line 7 page 19, lines 7-8 page 22, lines 15-16 page 23, lines 10-32 page 23, line 31 - page 24, line 2 page 24, lines 2-8 -----	1-10, 12-14 11

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 October 2021	15/10/2021

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	Mirkovic, Olinka

2

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	M. PRISBREY ET AL: "Ultrasound Noncontact Particle Manipulation of Three-dimensional Dynamic User-specified Patterns of Particles in Air", PHYSICAL REVIEW APPLIED, vol. 10, no. 3, 1 September 2018 (2018-09-01), XP055751526, DOI: 10.1103/PhysRevApplied.10.034066	1-3,5, 7-10,12
Y	abstract Sections: II. Methods and materials (A. Ultrasound wave field simulation, B. Acoustic trap locations, C. Dynamic manipulation of 3D patterns of particles, D. Experimental setup); III. Results and discussions figures 2, 5 -----	11
Y	GREENHALL J ET AL: "Continuous and unconstrained manipulation of micro-particles using phase-control of bulk acoustic waves", APPLIED PHYSICS LETTERS, vol. 103, no. 7, 12 August 2013 (2013-08-12), pages 74103-1, XP055848209, US ISSN: 0003-6951, DOI: 10.1063/1.4819031 Retrieved from the Internet: URL:https://aip.scitation.org/doi/pdf/10.1063/1.4819031> the whole document -----	11

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2021/067638

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2019207143 A1	31-10-2019	EP 3600696 A1	05-02-2020
		SE 1850519 A1	28-10-2019
		US 2021162457 A1	03-06-2021
		WO 2019207143 A1	31-10-2019