(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 262 286 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
15.12.2010 Bulletin 2010/50

(51) Int Cl.:
H04R 29/00 *(2006.01)*

(21) Application number: **09290447.3**

(22) Date of filing: **12.06.2009**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO SE SI SK TR
Designated Extension States:
AL BA RS

(71) Applicant: **Canon Kabushiki Kaisha**
Tokyo (JP)

(72) Inventors:
- **Kergourlay, Gérald**
  35250 Saint-Sulpice La Forêt (FR)
- **Lasserre, Sébastien**
  35000 Rennes (FR)

(74) Representative: **Petit, Maxime**
Santarelli
14, avenue de la Grande Armée
75017 Paris (FR)

(54) Method of estimating the position of the acoustic centre of a sound producing unit in a room

(57) The invention relates to a method of estimating the position of the acoustic centre of a sound producing unit in a room with a given Schroeder frequency, the method including the following steps:
■ generating acoustic waves at frequencies below the Schroeder frequency from the sound producing unit located at a first position (P1) in the room,
■ determining a first frequency response at a given fixed point in the room,
■ moving the sound producing unit from the first position (P1) to a second position (P2) through a geometric transformation so that the sound producing unit in the second position induces a second frequency response at said given fixed point that matches the first frequency response,
■ determining from the geometric transformation a first plane that is invariant with respect to this transformation and contains the acoustic centre of the sound producing unit .

EP 2 262 286 A1

Description

[0001] This invention relates to a method of estimating the position of the acoustic centre of a sound producing unit (referred to hereinafter as SPU) in a room.

[0002] In a known manner, when an SPU produces acoustic waves at high frequencies in a room the acoustic waves reflect diffusely off all the surfaces they encounter.

[0003] Under these circumstances, the sound perceived at a listening position in the room is of good quality, generally speaking.

[0004] On the other hand, when the SPU produces acoustic waves at low frequencies, below about 200Hz for a conventional room, the room acoustic modes (also called room resonant modes) are excited, thereby giving rise to standing waves and therefore to a stationary pressure field in the room.

[0005] The frequency response at a listening position in the room is thus disturbed by these room acoustic modes, which constitute one of the biggest obstacles to high fidelity sound reproduction.

[0006] Simulating the frequency response at different listening positions shows that the frequency responses include the room response at low frequencies. Further, the frequency response at low frequencies proves to be very sensitive to the positioning of the listening position.

[0007] The Applicant has also found that positioning the SPU is a key factor since it strongly influences the way the room acoustic modes are excited.

[0008] In particular, knowing the position of an SPU acoustic centre is of great interest since the acoustic centre is the specific point from which the sound that is emitted is the most isotropic.

[0009] An experimental method for determining the position of the acoustic centre of a conventional pistonic loudspeaker is known from the article entitled "Polar Plots at Low Frequencies: The Acoustic Centre", J. VanderKoy, AES convention paper 6784, 120th Convention, May 2006".

[0010] According to this method, a loudspeaker is installed on a turntable which is suitable for rotating through predetermined angles and therefore for imparting predetermined angular positions to the loudspeaker.

[0011] The turntable is placed in an anechoic room and frequency responses are measured in a frequency range situated above the anechoic room cut-off frequency, at a given location in the room respectively for a number of different angular positions of the loudspeaker.

[0012] Since the experiment takes place in an anechoic room, the frequency responses initially exhibit a clear rising slope up to the resonant frequency value of the loudspeaker, the so-called piston mode, and then a roughly flat curve.

[0013] According to the method, a plurality of rising slopes of the frequency response curves obtained at different rotation angles for a given position of the loudspeaker on the turntable are compared to each other.

[0014] Matching of the frequency response rising slopes may or may not be obtained. If matching is obtained the position of the acoustic centre of the loudspeaker is determined.

[0015] If not, the loudspeaker is translated on the turntable and a number of measurements are performed as already mentioned above until matching is obtained.

[0016] However, this method suffers from several drawbacks.

[0017] The method is implemented in an anechoic room that is, by definition, a very specific kind of room. Such a room is used with acoustic waves at frequencies above the cut-off frequency of the anechoic room in order to be sure that no acoustic waves reflected back will perturb the measurement.

[0018] Further, the method requires a great number of measurements to be performed, which proves to be time consuming. For instance, the turntable occupies 72 different angular positions for a given translation of the speaker on the turntable. This leads to a frequency response measuring step for each angular position and to a number of comparison steps in accordance therewith. In addition, the comparison between the different rising slopes obtained through a number of measurements turns out to be difficult and is not very accurate.

[0019] In view of the above, there exists a need for a new method for determining the position of the acoustic centre of an SPU in a room which alleviates at least one of the above-mentioned shortcomings.

[0020] When trying to reach this aim, the Applicant has found that it would be advantageous, in a first phase, to be able to roughly locate the acoustic centre in the SPU reference system thanks to a novel and inventive method before locating it more accurately.

[0021] To that end, an object of the invention is a method according to claim 1.

[0022] This method makes provision for determining a second position of the SPU by applying a geometric transformation to the latter.

[0023] The second position thus determined induces a second frequency response at the given fixed point in the room that matches the first frequency response. Thanks to the geometric transformation used, in particular its characteristics, it is possible to determine an invariant plane containing the acoustic centre of the SPU.

[0024] Thanks to this method, the acoustic centre of the SPU can therefore be localized in the SPU reference system. This means that the acoustic centre is roughly located with respect to the SPU which serves as a reference system and not the room.

[0025] This is advantageous since the position of the acoustic centre is therefore independent from the room.

[0026] Thus, the SPU may be placed in another room and the acoustic centre position will still be defined with respect to the SPU.

[0027] Further the method enables the approximate location of the acoustic centre to be estimated easily and rapidly.

[0028] The Schroeder frequency of a room denotes the boundary between reverberant room behaviour above and discrete room modes below.

[0029] Generating acoustic waves from the SPU at frequencies situated below the room Schroeder frequency implies that these waves interact with the room (e.g. walls, ceiling, etc.).

[0030] Due to the strong acoustic coupling between the SPU and the room, the room frequency responses exhibit salient characteristics or accidents over a wide frequency range.

[0031] These characteristics make it easier to compare the frequency responses to each other over a wide frequency range than to only compare rising slopes to each other before the SPU piston mode, over a small range.

[0032] Matching is therefore easier and faster to obtain.

[0033] According to one feature, the geometric transformation includes at least one rotation and at least one translation.

[0034] Such a simple geometric transformation is particularly easy to perform and makes it possible to reduce the number of measurements compared with the prior art methods.

[0035] According to another feature, the at least one rotation is performed before the at least one translation.

[0036] Starting with the rotation of the SPU enables its geometric orientation to be changed first. This approach increases the chance of getting quickly closer to the actual position of the acoustic centre than starting with the translation. Therefore, the determination of the invariant plane will be faster and easier than in the prior art.

[0037] Further, this approach enables the number of measurements and matching steps to be reduced.

[0038] In a preferred embodiment, the transformation includes one rotation only and at least one translation, which proves to be even easier.

[0039] According to another feature the method further includes the following operations:

i) performing at least once the following steps:

- moving the SPU from the first position (P1) to another position (Pn) through another geometric transformation so that the SPU in this other position (Pn) induces another frequency response at said given fixed point that matches the first frequency response,
- determining from this other geometric transformation another plane that is invariant with respect to this transformation and contains the acoustic centre of the SPU,

ii) determining an axis by intersecting the first plane and the other invariant plane or planes thus determined, said axis containing the acoustic centre of the SPU.

[0040] Thus, the number of steps to be performed is lower than in the prior art method. According to another feature, the SPU having a plane of symmetry, the method further includes a step of determining the position of the acoustic centre by intersecting the determined axis and the plane of symmetry.

[0041] Such a method enables the acoustic centre of the SPU to be determined with a relatively low number of steps.

[0042] In case the SPU has no plane of symmetry, the method further includes the following steps:

- rotating the SPU through 90˚,
- determining another axis containing the acoustic centre of the SPU by performing the operations i) and ii) with the rotated SPU, the rotated SPU being moved from its rotated position to another position through a geometric transformation in order to match the frequency responses respectively obtained for these two positions,
- determining the position of the acoustic centre by intersecting the two axes thus determined.

[0043] It is to be noted that the SPU is first rotated through 90˚ and a frequency response is determined from the thus rotated SPU. Next, the SPU undergoes a geometric transformation so that the SPU in the transformed (moved) position induces another frequency response at the given fixed point that matches the frequency response obtained for the rotated SPU.

[0044] These steps make it possible to search in another spatial direction and necessitate few operations for finding out the position of the acoustic centre.

[0045] In a particular case, the geometric transformation includes a rotation of 180˚. Such a rotation is particularly easy to implement. For instance, it is easy to find a reference in a room such as a wall of the enclosure in order to make a 180˚ rotation parallel to this wall.

[0046] When the SPU has a plane of symmetry, then the 180° rotation is performed about an axis of rotation that is contained in the plane of symmetry, the at least one translation being performed in a direction that is perpendicular to that axis of rotation and contained in the plane of symmetry.

[0047] Thus, the translation will then be performed in the plane of symmetry.

[0048] When the SPU has an axis of symmetry, then the 180° rotation is performed about an axis of rotation that is perpendicular to the axis of symmetry, the at least one translation being performed in a direction that is parallel to that axis of symmetry.

[0049] Thus, the translation will then be performed along the axis of symmetry. According to one feature, the method includes the following steps performed iteratively so as to match the frequency response obtained for the SPU before the geometric transformation and the frequency response induced by the moved SPU as well as possible:

- rotating the SPU,
- translating the SPU,
- determining the frequency response induced by the translated SPU,
- comparing the frequency response obtained for the SPU before the geometric transformation and the frequency response induced by the translated SPU to each other.

[0050] Thus, the method includes a step of translating the SPU and comparing the frequency response obtained for the SPU before the geometric transformation and the frequency response induced by the translated SPU in order to match the two frequency responses.

[0051] It is to be noted that the frequency response induced by the SPU in the translated position is compared to either the first frequency response (obtained for the SPU in the first position) or to the frequency response obtained for the SPU in the rotated position depending on the case.

[0052] Once the rotation has been performed, the iterative process involving translations is carried out until the matching is obtained. However, this iterative process leads quite easily and rapidly to the matching and with fewer operations than used in the prior art method.

[0053] According to another feature, the matching between the two frequency responses is performed automatically. This may be done by computation.

[0054] Thus, a user may be informed accordingly once the matching has been obtained, i.e. when the two corresponding curves match to a certain extent. The matching may be validated once a predetermined criterion or threshold has been met.

[0055] For instance, a user may be warned by an audio and/or a visual signal, the emission of which is triggered by the matching.

[0056] According to one feature, the position of the acoustic centre of the SPU is defined by three geometric coordinates of which one, two or three coordinates are unknown depending on the existence in the SPU of an axis of symmetry, a plane of symmetry or no symmetry respectively.

[0057] The steps of the method which has been briefly discussed above enable one, two or three geometric coordinates to be determined depending on the symmetry properties in the SPU.

[0058] According to another feature, the geometric transformation includes a translation along each axis that corresponds to an unknown geometric coordinate of the SPU.

[0059] According to one feature, the frequency responses each include a succession of bumps and dips, which make the comparison between the responses particularly easy.

[0060] According to another aspect, the invention also relates to a system according to claim 15. Such a system provides the same advantages as those provided by the method briefly disclosed above.

[0061] Additional advantages and features of the present invention will become apparent from the description that follows given by way of example only, with reference to the accompanying drawings, in which:

- Figure 1 is a schematic view of a room including elements of the system for carrying out the method of the present invention;
- Figure 2 represents an algorithm of the method according to one embodiment of the invention;
- Figures 3 and 4 schematically depict a geometric transformation applied to an SPU;
- Figure 5 is an algorithm detailing the step S3 in Figure 2;
- Figures 6 to 8 schematically depict the determination of an invariant plane according to the invention;
- Figure 9 schematically represents a geometric transformation applied to an SPU and which includes a 180° rotation;
- Figure 10 schematically represents an algorithm of a method according to another embodiment of the invention;
- Figure 11 schematically depicts the three geometric coordinates of the acoustic centre of an SPU;
- Figure 12 represents a geometric transformation applied to an SPU having an axis of symmetry;
- Figures 13 and 14 schematically depict a geometric transformation applied to an SPU having a plane of symmetry;

- Figure 15 schematically depicts the matching of two frequency response curves;
- Figures 16 to 18 schematically represent a geometric transformation applied to an SPU having no symmetry.

[0062] Figure 1 schematically depicts a room 10 that is enclosed by walls, ceiling and floor (not depicted) defining the limits of an enclosure 12. The room includes an SPU 14 such as a loudspeaker, e.g. of the diaphragm type. The room is represented in two dimensions in the drawing for the sake of clarity, although it is of course a three-dimensional room.

[0063] The SPU 14 comprises membrane connected in a conventional manner to known excitation means such as an electrodynamic motor (magnet/moving coil system) not depicted in the drawings.

[0064] When suitably excited, the SPU 14 is adapted to generate acoustic waves in the room over a predetermined range of frequencies.

[0065] The room 10 also includes sensing means 16 located at a given fixed point called listening point. Sensing means 16 is for example a microphone. Sensing means 16 is located away from the walls, the ceiling, the floor and any corner in the room in order to limit the interactions with the room enclosure.

[0066] Sensing means 16 is connected to a data processing unit 18 that can be located outside the enclosure 12 to avoid undesired interaction with the acoustic waves. The data processing unit includes display means for displaying data, a signal, several signals, a superimposition of several signals, etc.

[0067] Sensing means 16 is adapted to detect and capture acoustic waves during a time slot or several time slots, transform them into an electrical signal or signals and send them to the processing unit 18 for signal processing.

[0068] The received signal or signals are processed in the processing unit 18 so as to be displayed on display means 20 in the form of one or more curves.

[0069] This curve or curves represent the sound pressure level detected by sensing means 16 as a function of frequency.

[0070] More particularly, the processing unit 18 includes spectral analysis means which is able to digitally convert the received signal or signals and carry out a Fast Fourier Transform on the digitally converted signals in order to determine a frequency response curve.

[0071] It is to be noted that if several signals based on several time slots are provided by sensing means, an averaged frequency response is produced by the processing unit 18.

[0072] The frequency response of the room thus determined is displayed for further processing.

[0073] This room is characterized by a given Schroeder frequency which denotes the boundary between reverberant room behaviour above and discrete room modes below.

[0074] Generating acoustic waves from the SPU 14 at selected frequencies situated below the room Schroeder frequency causes the acoustic waves to acoustically couple with the enclosure 12.

[0075] The room whose frequency responses are illustrated in Figure 15 is of size 14x10x2.5m3. The lowest acoustic mode is 340/2/14=24Hz. Next, there are combinations with other room sizes that are distributed at discrete frequencies and that are clearly visible up to 300 Hz (estimated Schroeder frequency).

[0076] The room frequency responses or an averaged room frequency response taking account of this acoustic coupling exhibit salient characteristics or accidents over a wide frequency range.

[0077] More particularly, each room frequency response comprises a succession of bumps and dips which constitute useful landmarks for identifying each curve.

[0078] Such landmarks can be of great assistance to compare two curves to each other either by computation or visually.

[0079] The comparison between the two curves and the matching may be carried out automatically. For example, the difference or the error between the two curves may be compared to a predetermined threshold value. This value may be selected by a user from several values or fixed once end for all. If the difference between the curves (this difference may be expressed in terms of amplitude or power) is less than the threshold, then the matching has been obtained. Thus, an audio and/or a visual warning signal may be produced by the unit 18 in Figure 1 when matching is obtained.

[0080] For instance, when the SPU is being translated in a direction and the two frequency response curves are compared to each other, a minimum difference between the curves is reached when the matching has been obtained.

[0081] One could envisage that an audio signal be emitted while the comparison is in process.

[0082] Further, when the matching is about to be obtained, the noise level of the audio signal or the frequency of the succession of audible sounds may increase, thereby informing the user of the matching to come.

[0083] In practice, sensing means 16 is placed in the room at a location where the dips and bumps of the frequency response are clearly identified.

[0084] The position of the SPU unit in the room, in particular in terms of its acoustic centre, is of the utmost importance.

[0085] This is because the SPU acoustic centre is a point from which the sound that is emitted is the most isotropic.

[0086] Finding this position and locating the SPU at this position guarantees very good acoustic performance in the room.

[0087] In a general manner, the present invention aims at estimating/determining the position of the acoustic centre of an SPU in a room that is not an anechoic room.

[0088] In this connection, a system for estimating/determining this position has just been described with reference to Figure 1. An embodiment of a method according to the invention is depicted in Figure 2 in the form of an algorithm.

[0089] It is to be noted that the acoustic centre, denoted AC, of the SPU 14 is defined by three spatial geometric coordinates which, theoretically, are all unknown. However, in some cases one or more coordinates can be already known when taking account of the existence of a plane of symmetry or an axis of symmetry in the SPU configuration.

[0090] The algorithm includes several steps whose the execution enables the implementation of the method.

[0091] The description of the Figure 2 algorithm will be made with reference to Figures 3 to 8.

[0092] The algorithm includes a first step S1 of generating acoustic waves from the SPU 14 that is located in a first position P1 in the room.

[0093] The acoustic waves generated at frequencies below the Schroeder frequency propagate in the room and interact with the boundaries of the enclosure (walls, ceiling, floor).

[0094] Subsequent step S2 provides for determining at a given fixed point in the room a first frequency response of the room.

[0095] The fixed point is the location of sensing means 16 in the room and the first frequency response is determined in accordance with the above description. An example of a frequency response is given in Figure 15 which will be described later on.

[0096] During next step S3 the SPU 14 is moved from the first position P1 to a second position P2 by applying a geometric transformation to the SPU.

[0097] Generally speaking, the geometric transformation includes at least one rotation (e.g. a three-dimensional rotation) and at least one translation.

[0098] The geometric transformation is chosen so that the SPU 14 in the resulting second position P2 induces a second frequency response at sensing means 16 that matches the first frequency response. The matching of the first and second frequency responses will be described subsequently with reference to Figure 15.

[0099] Practically, the geometric transformation comprises a rotation characterized by a centre of rotation and an angle of rotation and a translation characterized by a direction and a length.

[0100] More generally, the rotation is defined by a rotation matrix M whose rotation centre O is the coordinate system centre (Figure 3).

[0101] The translation is defined by a translation vector $\vec{t}$ that corresponds to the translation enabling the first and second frequency responses to be matched (Figure 4).

[0102] It is to be noted that means for moving SPU 14 is not depicted in Figure 1 for the sake of clarity.

[0103] However, such means may take the form of a rotating support that is further able to be translated on the floor of the room from one position to another, e.g. thanks to casters or wheels.

[0104] Such a support has to be as small as possible so as not to interact (or to interact as little as possible) with the SPU.

[0105] Step S3 is further detailed in Figure 5.

[0106] The algorithm in Figure 5 begins with step S31 which makes provision for rotating the SPU as illustrated in Figure 3.

[0107] Next, step S32 is carried out for translating the rotated SPU into a translated position.

[0108] Then, step S33 is carried out for determining the frequency response induced by the thus translated SPU at the above given fixed point (location of sensing means 16).

[0109] A further step S34 makes provision for comparing the first frequency response (obtained for the position P1 of the SPU) with the frequency response determined at step S33.

[0110] If matching between the two frequency responses is not achieved then steps S32, S33 and S34 are reiterated as many times as necessary in order for the matching to be obtained.

[0111] In the embodiment depicted in figure 5, the three steps are carried out several times before matching the frequency responses as well as possible.

[0112] In the course of the last iteration (Nth iteration), the SPU is further translated into a position referred to as P2 (Figure 4) at step S3n-3. This position P2 results from the combination of a rotation M and a translation $\vec{t}$.

[0113] The induced frequency response is determined at the same given fixed point (Step S3n-2) and compared to the first frequency response (step S3n-1).

[0114] The frequency response induced by the SPU thus translated into position P2 is called second frequency response and matches the first frequency response as well as possible (step S3n).

[0115] The algorithm of Figure 5 terminates at step S3n, which completes the execution of step S3 in Figure 2.

[0116] In Figures 3 and 4 the unknown position of the acoustic centre AC of the SPU 14 is represented by a circle in front of the SPU.

[0117] The spatial coordinates of AC in position P1 are represented by vector $\vec{r}$, whereas the spatial coordinates of AC in position P2 after application of the geometric transformation are represented by vector $\vec{R} = M\vec{r} + \vec{t}$.

[0118] As depicted in figure 4, the AC coordinates in position P2 are also represented by $\vec{R} = \vec{r} + \alpha\vec{v}$, where $\vec{v}$ is a unitary vector that is perpendicular to the direction of the translation $\vec{t}$ and α is a coefficient representing the distance between AC in position P2 and AC in position P1.

[0119] This other expression of $\vec{R}$ depending on $\vec{v}$ comes from the fact that the two frequency responses best match when the distance between the two AC coordinates $\vec{R}$ and $\vec{r}$ is minimum.

Combining the two equations $\begin{cases} \vec{R} = M\vec{r} + \vec{t} \\ \vec{R} = \vec{r} + \alpha\vec{v} \end{cases}$ leads to $\vec{r} = \vec{U} + \alpha\vec{V}$ where $\begin{cases} \vec{U} = [I - M]^{-1}\vec{t} \\ \vec{V} = -[I - M]^{-1}\vec{v} \end{cases}$

Expressing M as follows $M = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$, the transformation$[I - M]^{-1}$ can be written as

$[I - M(\theta)]^{-1} = k[I - M(-\theta)]$ with $k = \dfrac{1}{2(1-\cos\theta)}$, $\theta \neq 0^\circ$

[0120] Thus, it is possible to determine the two normal vectors $\vec{U}$ and $\vec{V}$ and the invariant plane $P(\alpha) = \vec{U} + \alpha\vec{V}$ (that is reduced to an invariant straight line in the plane of Figures 3 and 4 to which the acoustic centre AC belongs. At this stage, α is not known so that there are a plurality of possibilities for positioning AC in the invariant plane.

[0121] As depicted in Figure 6 the vector $\vec{U}$ is determined from translation vector $\vec{t}$ and matrix of rotation M.

[0122] Figure 7 illustrates the determination of the vector $\vec{V}$ from vector $\vec{v}$ defined above with reference to figure 4 and matrix of rotation M.

[0123] As depicted in Figure 8, a plane P, called first plane, that is invariant with respect to the geometric transformation of concern (M, $\vec{t}$) is determined from vectors $\vec{U}$ and $\vec{V}$ defined above with reference to Figures 6 and 7. This plane contains the acoustic centre AC of the SPU.

[0124] Determining such a plane in accordance with step S4 in Figure 2 is not sufficient to precisely locate the position of AC in the room, i.e. to know its three geometric coordinates. It is to be noted that the position of AC is determined in the geometric reference system of the SPU, not that of the room. For instance, if the SPU has a spherical shape (e.g. see Figure 12), the reference system may be based on the geometric centre of the SPU and the position of the AC will be determined from this geometric centre.

[0125] If the SPU has a parallelepipedic shape, the reference system may be based on the front face of the SPU. Thus, the position of the AC will be determined from the front face of the SPU.

[0126] However, determination step S4 reduces the space in the room 10 where AC has to be localized and, therefore, renders easier the further task of determining its position.

[0127] The algorithm of Figure 2 includes other steps enabling the position of AC to be determined.

[0128] Thus, next step S5 makes provision for moving the SPU from the first position P1 to another position Pn by applying a geometric transformation to the SPU. In a general manner, this geometric transformation includes at least one rotation and at least one translation and has the same properties as those mentioned above with reference to step S3.

[0129] As for step S3, step S5 is broken down into several steps S31 to S3n as illustrated in Figure 5.

[0130] Thus, the aim of step S5 is to determine another position, obtained through a geometric transformation, so that the SPU in this other position induces a frequency response at sensing means 16 that matches the first frequency response.

[0131] The algorithm in Figure 2 includes a further step S6 similar to step S4 described above.

[0132] According to step S6, another plane which is invariant with respect to the geometric transformation applied at step S5 and which contains the acoustic centre of the SPU is determined.

[0133] This determination is based on the geometric transformation used at step S5 and defined by a rotation matrix M and a translation $\vec{t}$.

[0134] This invariant plane is determined as explained in step S4 already described. Step S6 yields another plane different from the first one determined at step S4 and which includes the acoustic centre AC of the SPU.

[0135] Steps S5 and S6 can be carried out several times as indicated in Figure 2 in order to obtain several invariant planes each including the acoustic centre AC of the SPU.

[0136] Subsequent step S7 provides for determining an axis by intersecting the different planes determined at each step S6 carried out as explained above. The axis intersecting the invariant planes contains the acoustic centre AC of the SPU.

[0137] It is to be noted that the determination of such an axis can be made by intersecting the first plane determined at step S4 and a second plane determined at the first execution of step S6.

[0138] However, it is to be noted that more than two invariant planes can be determined and used for locating the axis intersecting all these planes and containing the acoustic centre.

[0139] If the second determined invariant plane is perpendicular or nearly perpendicular to the first determined invariant plane, it is not necessary to determine further invariant planes.

[0140] Nevertheless, if the second plane is parallel or nearly parallel to the first plane, it is useful to search for at least one additional invariant plane.

[0141] This is because the intersection of the first and second invariant planes thus determined would not be very accurate.

[0142] Next, the algorithm includes step S8 which is a step for testing whether two axes have been determined through the execution of the above steps.

[0143] In the negative, step S8 is followed by another test step S9.

[0144] According to step S9, a step is carried out in order to determine whether the SPU has a plane of symmetry.

[0145] In the affirmative, step S9 is followed by step S10.

[0146] An SPU having a symmetrical configuration with respect to a plane is depicted in Figures 13 and 14.

[0147] Step S10 is a step of intersecting the axis found at step S7 and the plane of symmetry of the SPU.

[0148] It is to be noted that the plane of symmetry of the SPU contains the acoustic centre thereof.

[0149] This intersection is represented by a point which corresponds to the position of the acoustic centre AC of the SPU.

[0150] If the result of the test carried out at step S9 is negative, a further step S11 is performed.

[0151] This step provides for rotating the SPU through 90° around an axis passing through itself in order to search for another unknown geometric coordinate of the acoustic centre position.

[0152] The SPU in the rotated position is then subjected to steps S5 and S6 already described in order to determine one or several invariant planes.

[0153] Step S7 is then carried out in order to determine a second axis intersecting the first invariant plane determined at step S5 and the other invariant plane or planes determined at step S6 executed once or several times.

[0154] Following step S7 the test carried out at step S8 is therefore positive since two axes each containing the acoustic centre have been determined.

[0155] This step is followed by step S12 which makes provision for intersecting the two axes thus determined.

[0156] These two axes intersect at a point which corresponds to the acoustic centre AC of the SPU.

[0157] Thus, whatever the symmetry properties of the SPU configuration (no symmetry, a symmetry plane, a symmetry axis), the algorithm of Figure 2 enables determination of the position of the acoustic centre AC of the SPU 14. It is to be noted that if the symmetry configuration of the SPU 14 is taken into account, then the method according to the invention is easier and faster to implement.

[0158] Figure 9 illustrates a more specific embodiment in which the geometric transformation involved at step S3 of the algorithm of Figure 2 includes a rotation of 180° and the SPU has no symmetry properties (in that case $k = \dfrac{1}{2(1-\cos\theta)} = \dfrac{1}{2}$)

[0159] This Figure illustrates how the invariant plane determined at step S4 of the algorithm is obtained in this specific embodiment.

[0160] In this case, the mathematical formulas expressed above with respect to the description of step S4 can be simplified as follows:

$$\theta = 180^\circ \quad M = \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} = -I \qquad \begin{cases} \vec{U} = \dfrac{1}{2}\vec{t} \\ \vec{V} = -\dfrac{1}{2}\vec{v} \end{cases}$$

$$[I - M]^{-1} = \frac{1}{2} I$$

[0161] According to Figure 9, SPU 14 is firstly moved through a 180° rotation starting from the first position P1 and ending at an intermediate position P1'.

[0162] Then, SPU 14 is translated from this intermediate position to the second position P2 through a translation defined by vector $\vec{t}$ (perpendicular to the front face of the SPU).

[0163] This combination of movements is particularly easy to perform as is each movement per se.

[0164] As already explained above with respect to Figures 3 to 8, the translation is performed in accordance with the steps S32 to S3n represented in Figure 5.

[0165] The matching between the first frequency response (when the SPU 14 is in the first position P1) and the second frequency response (when the SPU 14 is in the second position P2) determines the length of the translation.

[0166] Once the second position P2 is fixed, then the plane P that is invariant with respect to the geometric transformation described above can be determined.

[0167] In particular, this plane is determined from vectors $\vec{U}$ and $\vec{V}$ which are defined as expressed above.

[0168] In this particular embodiment, this invariant plane is located midway between the positions P1 and P2.

[0169] As depicted in Figure 9, the acoustic centre is positioned in the invariant plane thus determined.

[0170] The algorithm depicted in Figure 10 will now be described. This algorithm illustrates particular embodiments of the method according to the invention.

[0171] In particular, this algorithm explains how the symmetry properties of the SPU configuration can be taken into account when determining the position of the acoustic centre of the SPU.

[0172] The Figure 10 algorithm starts with step S40 according to which acoustic waves are generated from SPU 14 and the first frequency response based on the first position P1 of SPU 14 is determined.

[0173] Figure 11 schematically illustrates the three geometric coordinates, the depth, the laterality and the elevation that have to be known in order to determine the position of the acoustic centre of SPU 14.

[0174] S40 is followed by S42 which is a test step.

[0175] During step S42, a step is carried out in order to know whether the SPU has any symmetry properties.

[0176] The first case corresponds to the existence of an axis of symmetry in the SPU configuration.

[0177] Such a symmetry property is illustrated in Figure 12 representing a spherical SPU having a geometric axis of revolution.

[0178] This case corresponds to the left part of the Figure 10 algorithm.

[0179] Where an axis of symmetry denoted As exists, step S42 is followed by step S44.

[0180] According to step S44, a rotation of 180° is performed about an axis of rotation Ar that is perpendicular to the axis of symmetry As.

[0181] The SPU in the first position and in the rotated position are represented face to face in Figure 12.

[0182] Next, step S46 is executed.

[0183] According to this step, the SPU is translated along the axis of symmetry As and the steps S32 to S3n illustrated in the algorithm of Figure 5 are carried out so that the first frequency response and the frequency response induced by the translated position of the SPU match as well as possible.

[0184] When matching is obtained the SPU is in the second position P2.

[0185] In this particular case where an axis of symmetry exists in the SPU configuration there is only one unknown geometric coordinate to find in order to determine the position of the acoustic centre.

[0186] This coordinate is the depth of the acoustic centre along the axis of symmetry (Figures 11 and 12).

[0187] When the first and second frequency responses match at step S46 (second position P2 is determined), the following step S48 is carried out.

[0188] During this step the depth of the acoustic centre along the axis of symmetry As is determined from the first position P1 and the second position P2.

[0189] The acoustic centre is here located halfway between the positions P1 and P2.

[0190] It is to be noted that steps S44, S46 and S48 correspond to step S3 in the algorithm of Figure 2.

[0191] Returning to test step S42, when the SPU configuration has a plane of symmetry, then the right part of the Figure 10 algorithm will be executed.

[0192] Such a plane of symmetry is illustrated in Figure 13 and denoted Ps.

[0193] The SPU is different from the one depicted in Figure 12 since it has a parallelepipedic shape and includes a lower elongated aperture.

[0194] Taking into account this plane of symmetry, two unknown geometric coordinates have to be determined for locating the position of the acoustic centre of the SPU, namely the depth and the elevation (Figure 11).

[0195] Having regard to the existence of a plane of symmetry, step S42 is followed by step S50.

[0196] According to step S50, a 180° rotation of the SPU illustrated in Figure 13 is made about an axis of rotation Br which is contained in the plane of symmetry Ps.

[0197] Next, step S52 is carried out for translating the rotated SPU along the plane of symmetry Ps and perpendicularly to the rotation axis Br.

[0198] This iterative translation process is performed as described with reference to Figure 5.

[0199] When the second frequency response induced by the translated SPU matches the first frequency response obtained at step S40 as well as possible, the second position P2 of the SPU is determined.

[0200] The depth of the acoustic centre is therefore determined at following step S54 by defining the median plane located halfway between the first and second positions of the SPU.

[0201] Figure 15 schematically illustrates the matching process between the first and second frequency responses.

[0202] Left part in Figure 15 illustrates at the top the first position of the SPU and the rotated position (180°) of the SPU superimposed together with the location of the acoustic centre AC.

[0203] At the bottom of the left part, two curves are represented, one denoted FR1 and the other denoted FR.

[0204] These curves represent the frequency response determined by sensing means 16 in Figure 1 for the two positions of the SPU.

[0205] In particular, FR1 illustrates the first frequency response determined when the SPU is in the first position P1 and the frequency response FR corresponds to the frequency response induced when the SPU is in the rotated position.

[0206] Each of these curves represents the variation of the sound level produced in dB as a function of a wide range of frequencies.

[0207] It is to be noted that the frequency response has a particular configuration due to the coupling between the acoustic waves generated by the SPU and the room in which the SPU is located.

[0208] As illustrated each curve represents a succession of bumps and dips over a relatively extended range of frequencies which make particularly easy the comparison between two curves.

[0209] Right part in Figure 15 represents at the top two positions of the SPU that are spaced apart after performing a translation from the superimposed positions illustrated in top left part in Figure 15.

[0210] At the bottom of Figure 15 right part, the same diagram representing the sound level produced as a function of frequencies is represented.

[0211] However, this diagram shows the superimposition of both the first frequency response curve FR1 and the second frequency response curve FR2 and their matching (when the SPU is in the second position P2).

[0212] Since the curves exhibit salient characteristics or accidents it is easy to compare them to each other by simply superimposing both curves over the same range of frequencies.

[0213] Thus, in Figure 15 left part it is quite easy to understand that the frequency responses do not match since the bumps and dips of one curve do not correspond, even approximately, to those of the other curve.

[0214] However, when translating the SPU from its rotated position illustrated at the top left part in Figure 15 the curve FR undergoes transformations and takes another form for each translated position of the SPU.

[0215] The comparison of the frequency response curve FR obtained from a translated position with the first frequency response FR1 is performed on a step by step basis as explained with reference to Figure 5 already described. When the superimposition of the two curves is of the type represented in right part in Figure 15, then one can consider that matching between the two curves is obtained.

[0216] This is because not only does the overall shape of the curves correspond but also the different accidents such as the bumps and dips.

[0217] It is to be noted that the matching is particularly satisfactory over the range of frequencies lying from 30 to 55Hz.

[0218] This is because in this range a particularly significant bump appears whose rising and decreasing slopes enable an easy and quick comparison to be made between two curves having this kind of bump.

[0219] Further, the matching between the curves can be checked over an even wider range of frequencies as depicted in Figure 15 (right part).

[0220] When this matching is obtained (visually by a user or by computation) and viewed on the display means 20 in Figure 1, this means that the SPU has been translated sufficiently and attained the second position P2.

[0221] It is to be noted that the comparison and matching may be made alternatively in an automated manner, merely through computation between the curves. The user may then be warned visually or audibly upon matching.

[0222] From this second position, the rough location of the acoustic centre can then be determined as explained in steps S50 to S54 described above.

[0223] Reverting to the Figure 10 algorithm step S54 is followed by several steps enabling determination of the missing geometric coordinate of the acoustic centre, which is the elevation.

[0224] Subsequent step S56 provides for rotating the SPU around an axis passing through itself on its support 30 as represented in Figure 14 and denoted by arrow R.

[0225] The SPU thus rotated is in a new position P3.

[0226] During next step S58, the SPU thus rotated is moved to another position P4 spaced apart from the position P3 by the depth previously determined at step S54.

[0227] More particularly, the SPU undergoes a rotation of 180˚ about an axis of rotation Cr to move from position P3 to position P4 (Figure 14).

[0228] This axis of rotation is chosen outside the SPU so that the rotated SPU is positioned at a distance from position P3, while being away from the walls, the ceiling, the floor and any corner in the room.

[0229] This makes it possible to distinguish the acoustic room modes from each other. Once the SPU is in this newly rotated position P4 defined at step S58, following step S60 is carried out.

[0230] During this step the SPU is translated sideways in the direction given by arrow L.

[0231] This lateral movement is performed while keeping the front face of the SPU parallel to the position P4 it had at the end of step S58.

[0232] More particularly, iterative lateral translations are made as shown in Figure 5.

[0233] In a corresponding manner, the frequency response induced by the translated position of the SPU is determined and a comparison between this frequency response and the frequency response of the SPU in the rotated position P3 is made.

[0234] These steps are reiterated as many times as possible in order to match the frequency responses as explained with reference 15.

[0235] When matching is obtained (position P5 is determined), the algorithm proceeds to step S62 for determining the elevation of the SPU.

[0236] The elevation is determined from the two positions of the SPU, i.e. P3 and the laterally translated position P5..

[0237] More particularly, the elevation is determined from the two positions of the same face of the SPU, e.g. the front face 14a.

[0238] In practice, the two faces in the respective two positions P3 and P5 are projected onto each other, thereby leading to an intersected part of the SPU faces.

[0239] Next, the geometrical centre of this intersected part is determined and defined as the elevation of the acoustic centre.

[0240] Thus, determining the depth at step S54 and the elevation at step S62 enables the position of the acoustic centre AC of the SPU to be defined.

[0241] Returning to test step S42, when no symmetry exists in the SPU configuration, the three geometric coordinates depicted in Figure 11 have to be determined. The middle part of the Figure 10 algorithm will now be described with reference to Figures 16 to 18.

[0242] The first three steps S64, S66 and S68 aim at determining the depth of the acoustic centre.

[0243] This determination is based on a geometric transformation including a 180˚ rotation and a translation along an axis which corresponds to the axis of the unknown geometric coordinate (depth).

[0244] These three steps are carried out in the same manner as steps S44, S46 and S48, as well as steps S50, S52 and S54, in order to determine the depth of the acoustic centre.

[0245] The only difference between all these steps lies in the definition of the axis for the rotation and the translation.

[0246] In the no symmetry case, the axis of rotation of step S64 and the axis of translation have to be chosen so that the moved SPU will be located away from the limits of the enclosure.

[0247] Figure 16 illustrates the first three steps S64, S66 and S68.

[0248] As depicted the axis of rotation is external to the SPU.

[0249] The following two steps S70 and S72 aim at determining the laterality of the acoustic centre.

[0250] These steps are illustrated in Figure 17.

[0251] These steps are identical to steps S60 and S62 illustrated in Figure 14 except for the starting position of the SPU.

[0252] In particular, in Figure 17 the SPU is spaced apart from the first position P1 of the SPU according to the depth defined at step S68. In particular, it reaches the position P2 after being rotated through 180˚ as in step S64.

[0253] Laterality of the acoustic centre is therefore obtained by determining the geometrical centre of the intersection (intersected part) of the front face of the SPU in the first position P1 projected onto the front face of the SPU in the laterally translated position P3.

[0254] The algorithm includes further steps S74 to S80, the aim of which is to determine the elevation of the acoustic centre.

[0255] Steps S74, S76, S78 and S80 are illustrated in Figure 18 and correspond respectively to steps S46, S48, S60 and S62 already described with reference to Figure 14.

[0256] More particularly, the 90˚ rotation R, the 180˚ rotation Cr and the lateral translations L are performed likewise.

[0257] The SPU rotated through 90˚ occupies position P4 and then undergoes the 180˚ rotation about axis Cr to reach position P5.

[0258] The lateral translations L are next carried out so as to match the frequency response induced by the translated SPU with the frequency response of the SPU in the position P4.

[0259] Once matching is obtained, new position P6 of the SPU is thus determined. The elevation of the acoustic centre is next determined at step S80.

[0260] This determination consists in determining the geometric centre of the intersected part of the SPU front face in position P4 projected onto the SPU front face in position P6.

[0261] Thus, steps S74 to S80 achieve the determination of the SPU acoustic centre location.

[0262] It is to be noted that this algorithm begins with the determination of the depth of the acoustic centre since it is easier to determine first.

[0263] The matching is easier to obtain and this will then yield a better result for subsequent determination of the elevation and/or the laterality.

[0264] Although determining the depth first as in Figure 10 algorithm is most efficient, this does not preclude another order of determination.

Claims

1. Method of estimating the position of the acoustic centre of a sound producing unit in a room (10) with a given Schroeder frequency, the method including the following steps:

   ■ generating (S1) acoustic waves at frequencies below the Schroeder frequency from the sound producing unit located at a first position (P1) in the room,
   ■ determining (S2) a first frequency response at a given fixed point in the room,
   ■ moving (S3) the sound producing unit from the first position (P1) to a second position (P2) through a geometric transformation so that the sound producing unit in the second position induces a second frequency response at said given fixed point that matches the first frequency response,
   ■ determining (S4) from the geometric transformation a first plane that is invariant with respect to this transformation and contains the acoustic centre of the sound producing unit.

2. Method according to Claim 1, **characterized in** it further includes the following operations :

   i) performing at least once the following steps:

      - moving (S5) the sound producing unit from the first position (P1) to another position (Pn) through another geometric transformation so that the sound producing unit in this other position (Pn) induces another frequency response at said given fixed point that matches the first frequency response,
      - determining (S6) from this other geometric transformation another plane that is invariant with respect to this transformation and contains the acoustic centre of the sound producing unit,

   ii) determining (S7) an axis by intersecting the first plane and the other invariant plane or planes thus determined, said axis containing the acoustic centre of the sound producing unit.

3. Method according to Claim 2, **characterized in that**, the sound producing unit having a plane of symmetry, the method further includes a step (S10) of determining the position of the acoustic centre by intersecting the determined axis and the plane of symmetry.

4. Method according to Claim 2, **characterized in that**, the sound producing unit having no plane of symmetry, the method further includes the following steps:

   - rotating (S11) the sound producing unit through 90˚,
   - determining another axis containing the acoustic centre of the sound producing unit by performing the operations i) and ii) with the rotated sound producing unit , the rotated sound producing unit being moved from its rotated position to another position through a geometric transformation in order to match the frequency responses respectively obtained for these two positions,
   - determining (S12) the position of the acoustic centre by intersecting the two axes thus determined.

5. Method according to any one of Claims 1 to 4, **characterized in that** the geometric transformation includes at least one rotation and at least one translation.

6. Method according to Claim 5, **characterized in that** the at least one rotation is performed before the at least one translation.

7. Method according to Claim 5 or 6, **characterized in that** the geometric transformation includes a rotation of 180˚.

8. Method according to Claim 7, **characterized in that**, the sound producing unit having a plane of symmetry, the rotation is performed about an axis of rotation that is contained in the plane of symmetry, the at least one translation being performed in a direction that is perpendicular to that axis of rotation and contained in the plane of symmetry.

9. Method according to Claim 7, **characterized in that**, the sound producing unit having an axis of symmetry, the rotation is performed about an axis of rotation that is perpendicular to the axis of symmetry, the at least one translation being performed in a direction that is parallel to that axis of symmetry.

10. Method according to anyone of Claims 5 to 9, **characterized in that** it includes the following steps performed

iteratively so as to match the frequency response obtained for the sound producing unit before the geometric transformation and the frequency response induced by the moved sound producing unit as well as possible:

- rotating the sound producing unit,
- translating the sound producing unit,
- determining the frequency response induced by the translated sound producing unit,
- comparing the frequency response obtained for the sound producing unit before the geometric transformation and the frequency response induced by the translated sound producing unit to each other.

11. Method according to any one of Claims 1 to 10, **characterized in that** the frequency responses each include a succession of bumps and dips.

12. Method according to any one of Claims 1 to 11, **characterized in that** the matching between the two frequency responses is performed automatically.

13. Method according to any one of Claims 1 to 12, **characterized in that** the position of the acoustic centre of the sound producing unit is defined by three geometric coordinates of which one, two or three coordinates are unknown depending on the existence in the sound producing unit of an axis of symmetry, a plane of symmetry or no symmetry respectively.

14. Method according to Claim 13, **characterized in that** the geometric transformation includes a translation along each axis that corresponds to an unknown geometric coordinate of the sound producing unit.

15. System for estimating the position of the acoustic centre of a sound producing unit in a room (10) with a given Schroeder frequency, the system including :

■ means for generating acoustic waves at frequencies below the Schroeder frequency from the sound producing unit located at a first position (P1) in the room,
■ means for determining a first frequency response at a given fixed point in the room,
■ means for moving the sound producing unit from the first position (P1) to a second position (P2) through a geometric transformation so that the sound producing unit in the second position induces a second frequency response at said given fixed point that matches the first frequency response,
■ means for determining from the geometric transformation a first plane that is invariant with respect to this transformation and contains the acoustic centre of the sound producing unit.

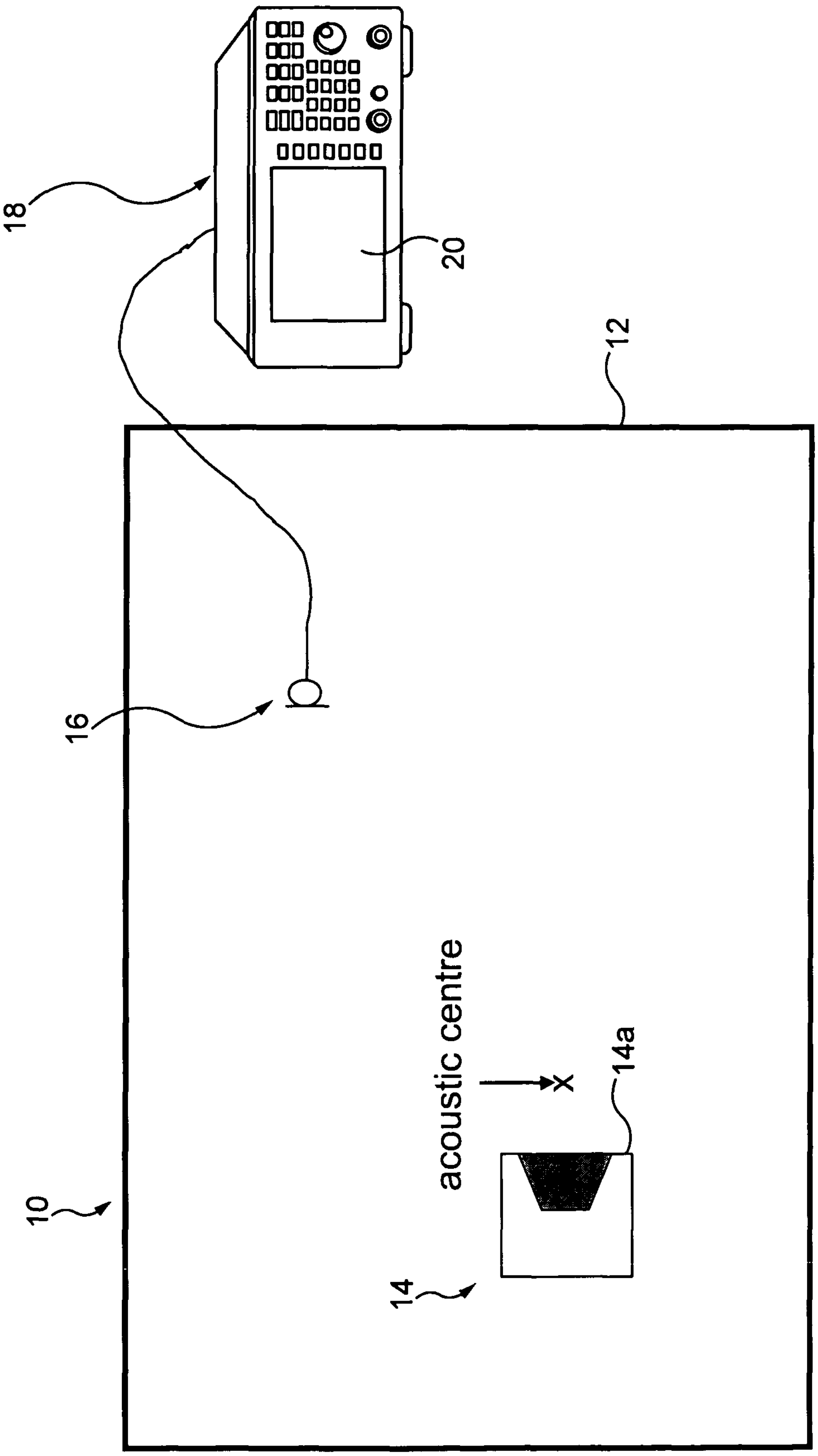


Fig. 1

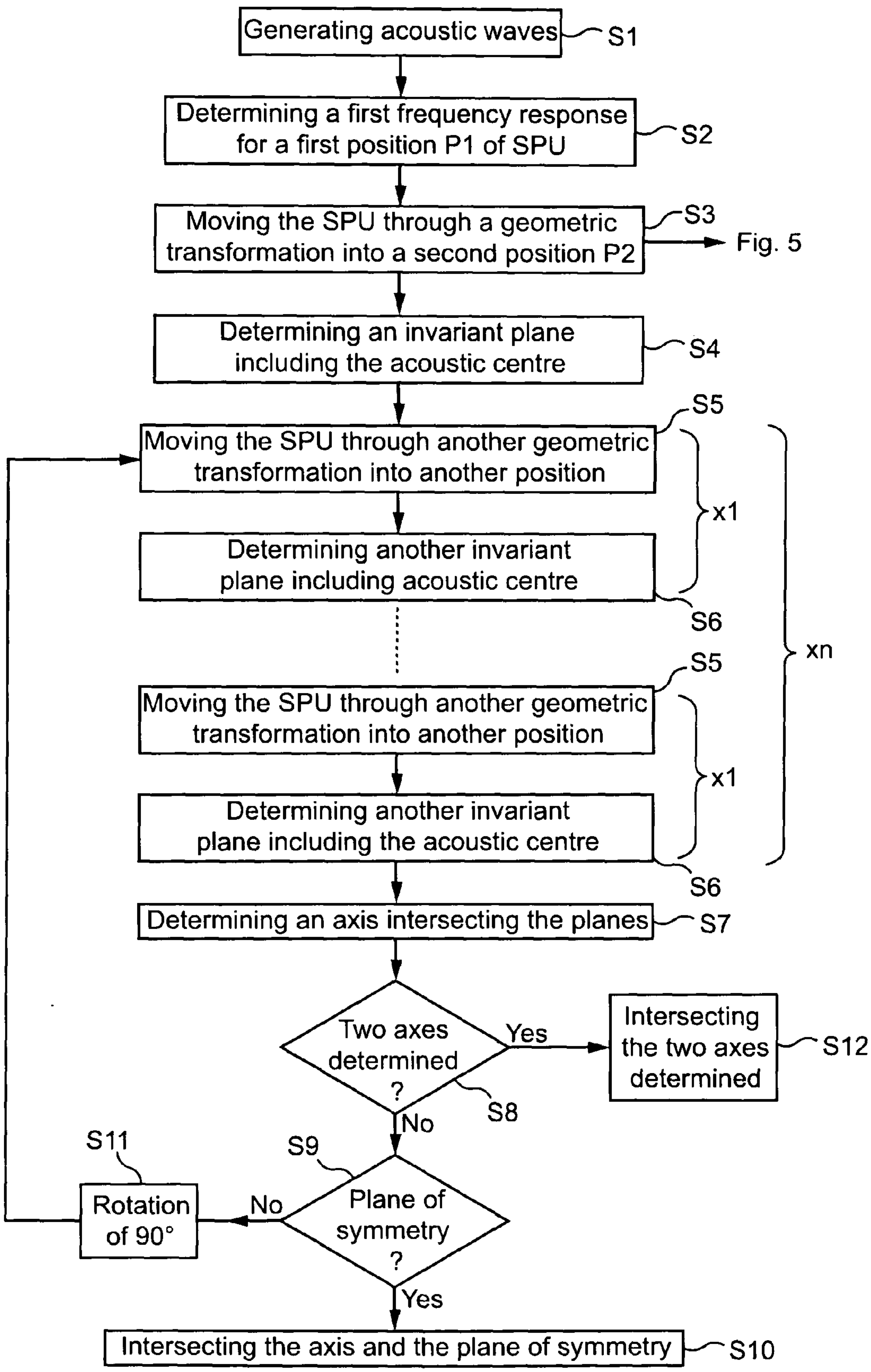

Generating acoustic waves
S1
Determining a first frequency response for a first position P1 of SPU
S2
Moving the SPU through a geometric transformation into a second position P2
S3
Fig. 5
Determining an invariant plane including the acoustic centre
S4
S5
Moving the SPU through another geometric transformation into another position
x1
Determining another invariant plane including acoustic centre
S6
xn
S5
Moving the SPU through another geometric transformation into another position
x1
Determining another invariant plane including the acoustic centre
S6
Determining an axis intersecting the planes
S7
Two axes determined ?
Yes
Intersecting the two axes determined
S12
S8
No
S11
S9
Rotation of 90°
No
Plane of symmetry ?
Yes
Intersecting the axis and the plane of symmetry
S10

Fig. 2

Fig. 4

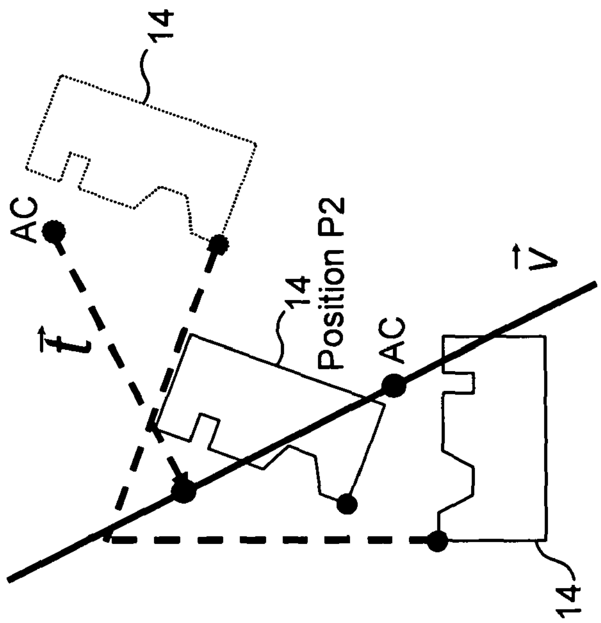
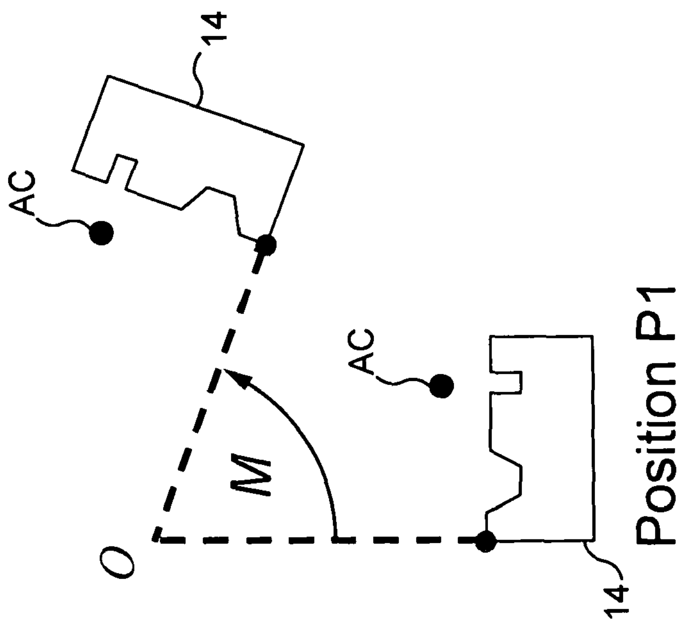


Fig. 3



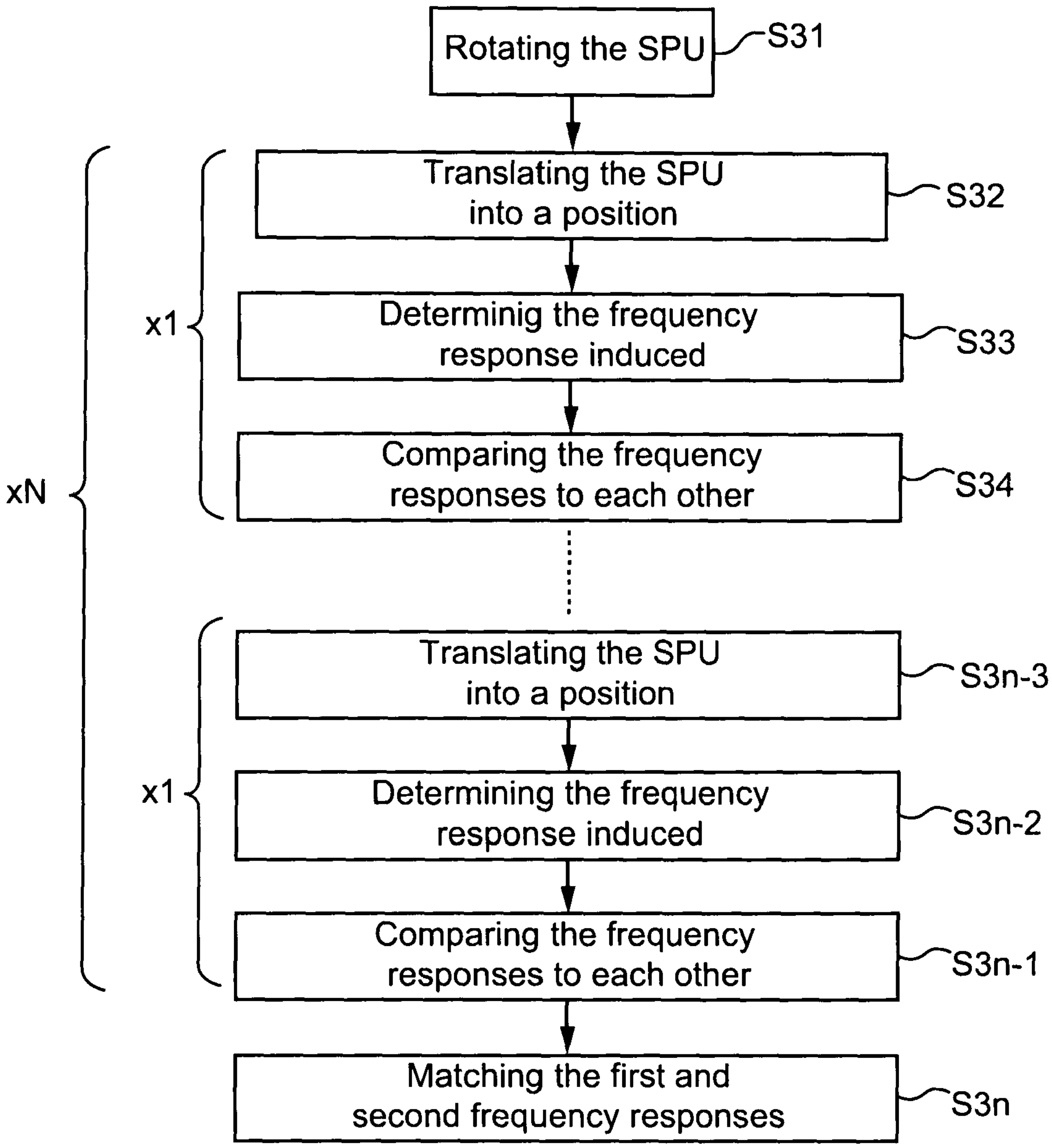

Rotating the SPU
S31
Translating the SPU into a position
S32
Determinig the frequency response induced
S33
Comparing the frequency responses to each other
S34
x1
xN
Translating the SPU into a position
S3n-3
Determining the frequency response induced
S3n-2
Comparing the frequency responses to each other
S3n-1
x1
Matching the first and second frequency responses
S3n

Fig. 5

Fig. 6

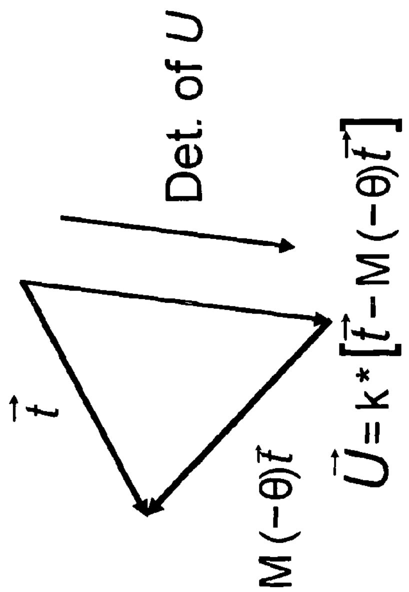


Fig. 7

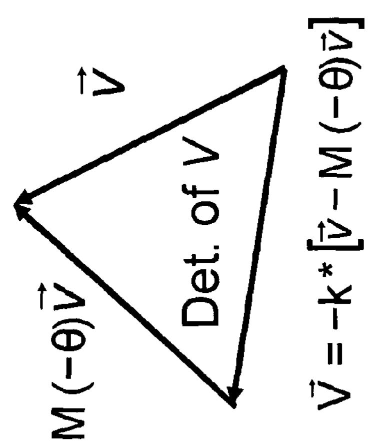


Fig. 8

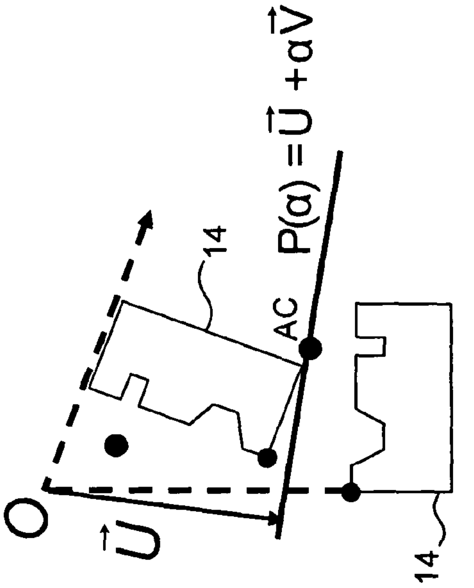
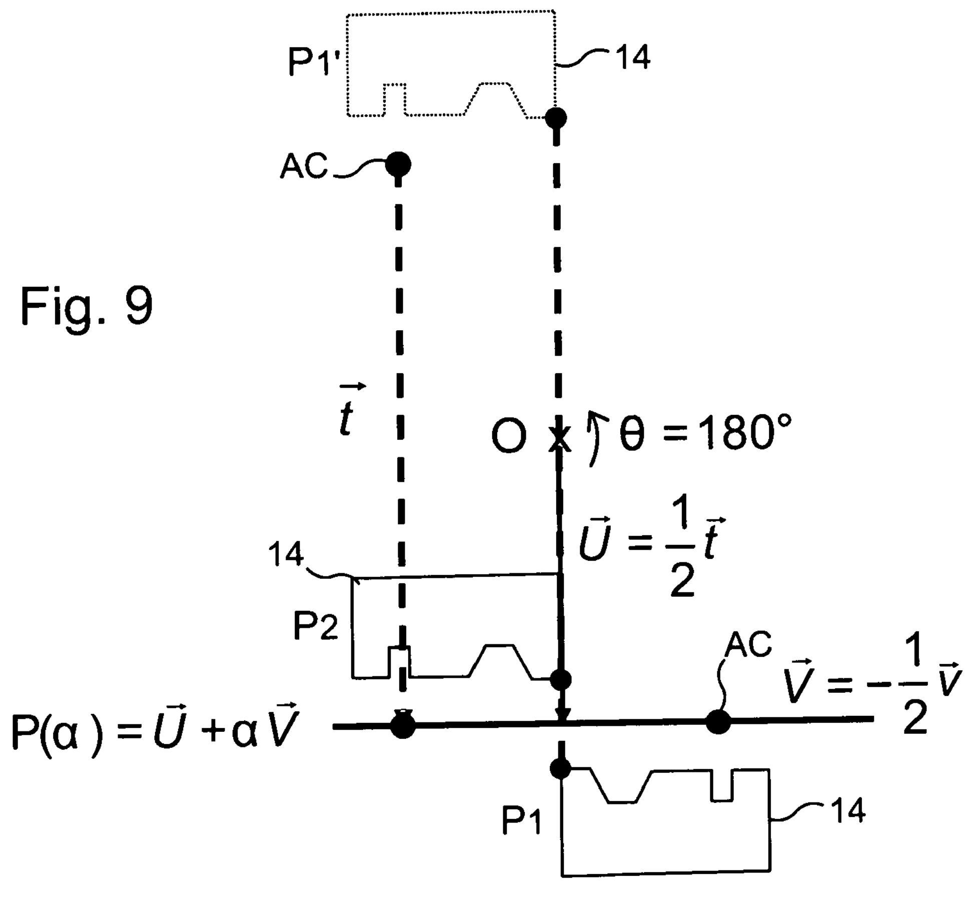


Fig. 9


P1'
14
AC
$\vec{t}$
O
$\theta = 180°$
$\vec{U} = \frac{1}{2}\vec{t}$
14
P2
AC
$\vec{V} = -\frac{1}{2}\vec{v}$
$P(\alpha) = \vec{U} + \alpha\vec{V}$
P1
14

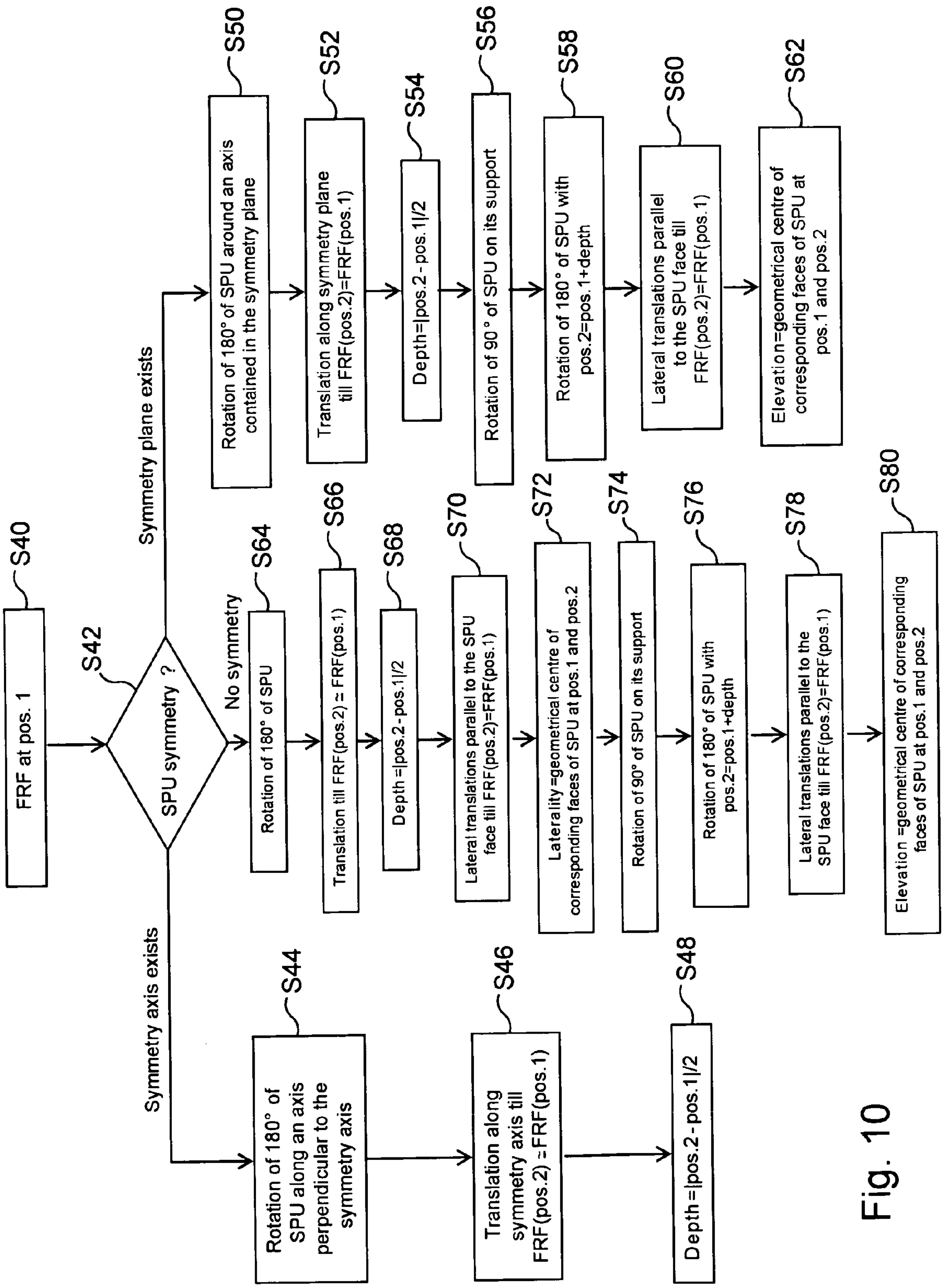

FRF at pos. 1
S40
SPU symmetry ?
S42
Symmetry axis exists
No symmetry
Symmetry plane exists
Rotation of 180° of SPU along an axis perpendicular to the symmetry axis
S44
Translation along symmetry axis till FRF(pos.2) ≃ FRF(pos.1)
S46
Depth =|pos.2 - pos.1|/2
S48
Rotation of 180° of SPU
S64
Translation till FRF(pos.2) ≃ FRF(pos.1)
S66
Depth =|pos.2 - pos.1|/2
S68
Lateral translations parallel to the SPU face till FRF(pos.2)=FRF(pos.1)
S70
Laterality =geometrical centre of corresponding faces of SPU at pos.1 and pos.2
S72
Rotation of 90° of SPU on its support
S74
Rotation of 180° of SPU with pos.2=pos.1+depth
S76
Lateral translations parallel to the SPU face till FRF(pos.2)=FRF(pos.1)
S78
Elevation =geometrical centre of corresponding faces of SPU at pos.1 and pos.2
S80
Rotation of 180° of SPU around an axis contained in the symmetry plane
S50
Translation along symmetry plane till FRF(pos.2)=FRF(pos.1)
S52
Depth=|pos.2 - pos.1|/2
S54
Rotation of 90° of SPU on its support
S56
Rotation of 180° of SPU with pos.2=pos.1+depth
S58
Lateral translations parallel to the SPU face till FRF(pos.2)=FRF(pos.1)
S60
Elevation=geometrical centre of corresponding faces of SPU at pos.1 and pos.2
S62

Fig. 10

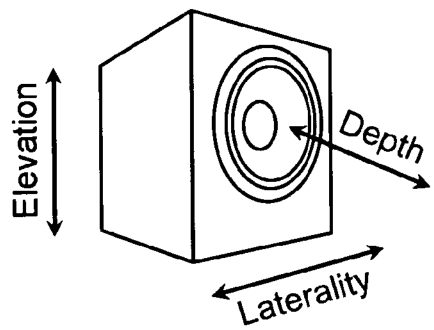


Fig. 11

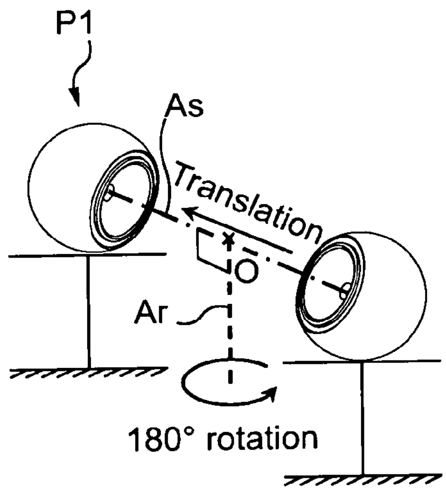


Fig. 12

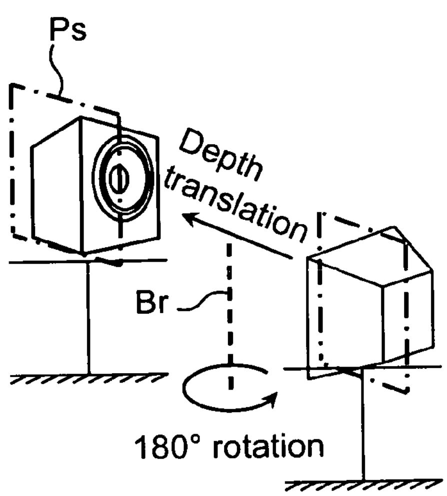


Fig. 13

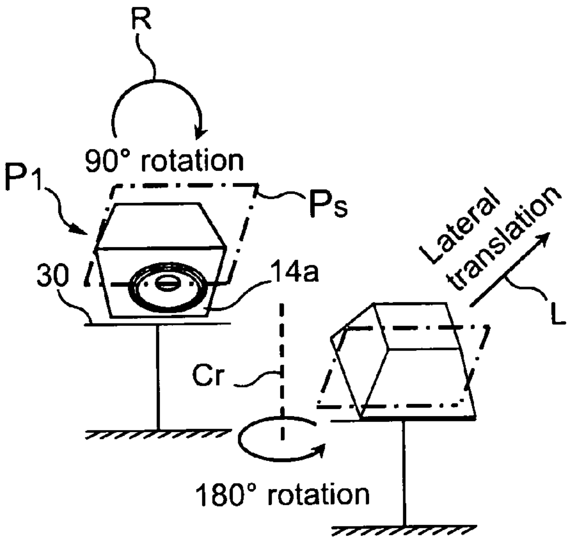


Fig. 14

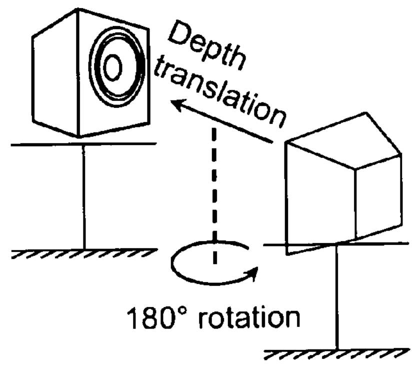


Fig. 16

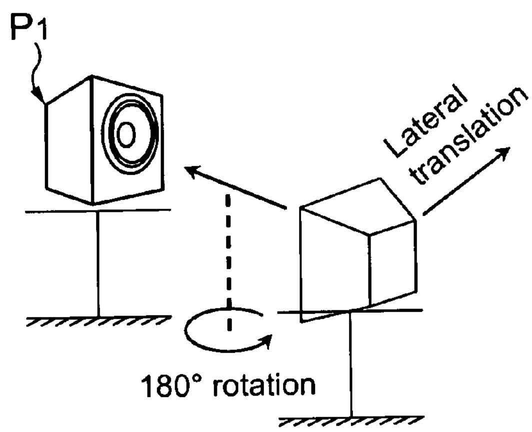


Fig. 17

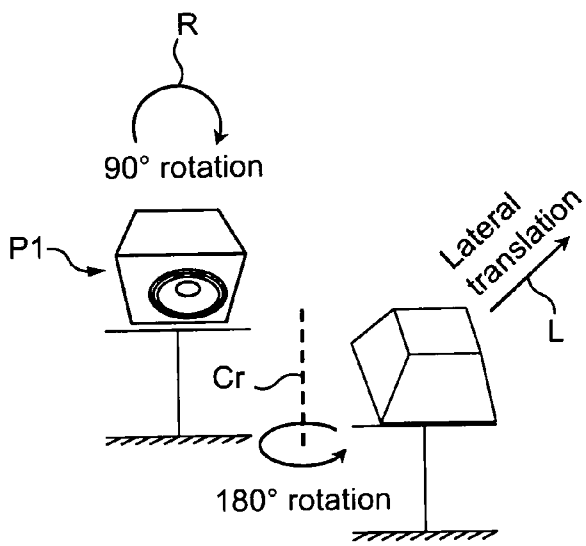


Fig. 18

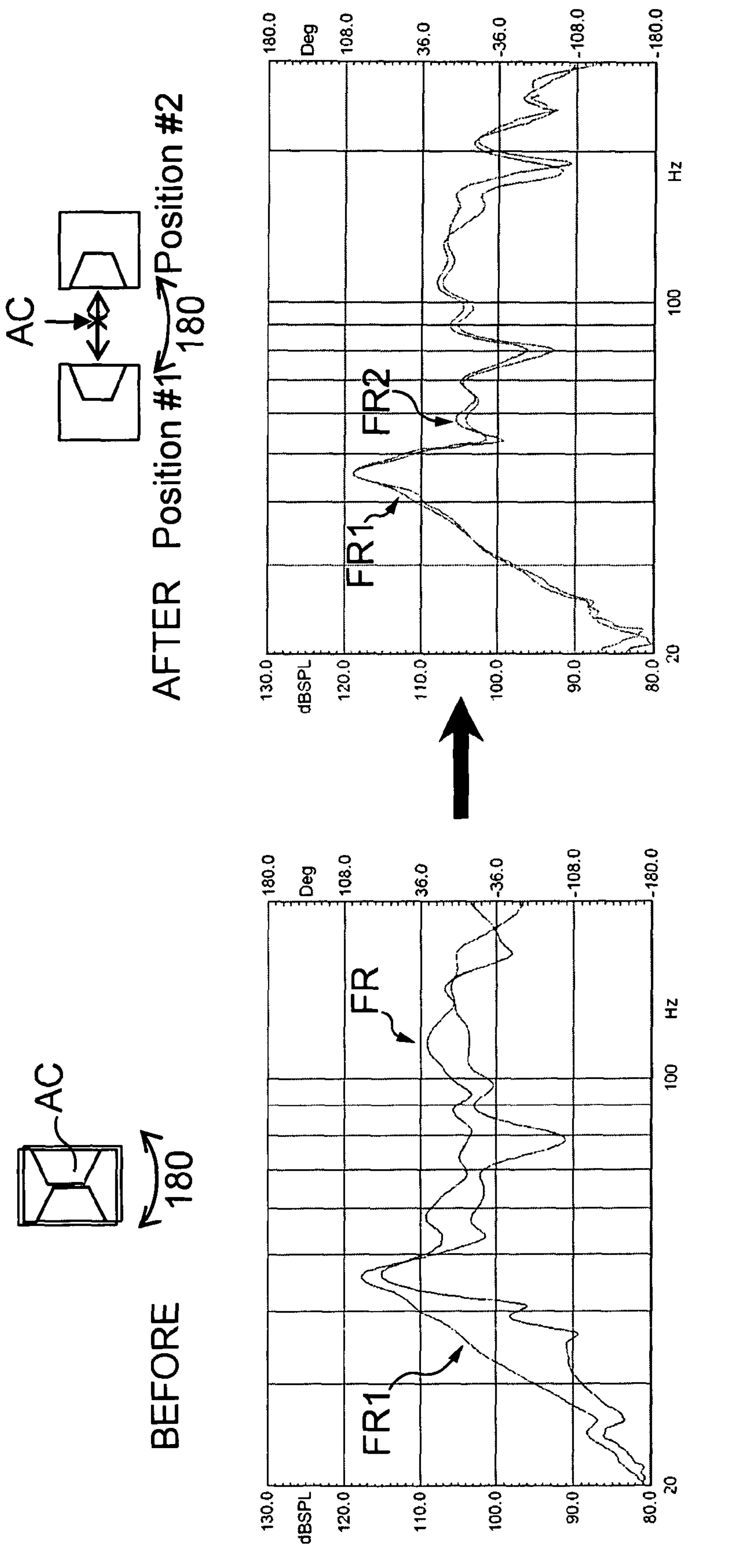

BEFORE
AC
180
FR1
FR
AFTER
Position #1
Position #2
FR1
FR2
130.0
dBSPL
120.0
110.0
100.0
90.0
80.0
180.0
Deg
108.0
36.0
-36.0
-108.0
-180.0
20
100
Hz

Fig. 15

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 09 29 0447

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	VANDERKOOY J ET AL: "Polar plots at low frequencies: the Acoustic Center" PREPRINTS OF PAPERS PRESENTED AT THE AES CONVENTION, XX, XX, vol. 2, no. 6784, 1 May 2006 (2006-05-01), pages 781-790, XP008117710 * the whole document * -----	1-15	INV. H04R29/00
A	US 2005/185797 A1 (KLEIN JERRY G [US] ET AL) 25 August 2005 (2005-08-25) * the whole document * -----	1-15	

TECHNICAL FIELDS SEARCHED (IPC)

H04R
H04S

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	5 March 2010	Timms, Olegs

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 09 29 0447

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

05-03-2010

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005185797 A1	25-08-2005	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

Non-patent literature cited in the description

- **J. VanderKoy.** Polar Plots at Low Frequencies: The Acoustic Centre. *AES convention paper 6784, 120th Convention,* May 2006 **[0009]**