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(54) **A METHOD OF TUNING CHORDOPHONES IN ALTERNATIVE MUSICAL SCALES WITH A REDUCED NUMBER OF STEPS COMPARED TO THE ORIGINAL TUNING BASED ON MONOTONIC SURJECTIVE MAPPINGS, A COMPUTER-IMPLEMENTED METHOD AND A TUNER FOR IMPLEMENTING SUCH A METHOD**

(57) The object of the invention is a method of tuning chordophones in alternative musical scales with a reduced number of degrees relative to the standard tuning based on monotonic surjective mappings. The tuning method is characterized in that when the original scale has N degrees and the alternative scale has M , where $M < N$, then when tuning an instrument in the alternative scale, $N-M$ degrees of the original scale are mapped to the same degree of the alternative scale as another degree of the original scale. The method allows for stable tuning of a chordophone (such as a piano) without the risk of breaking strings or damaging the instrument.

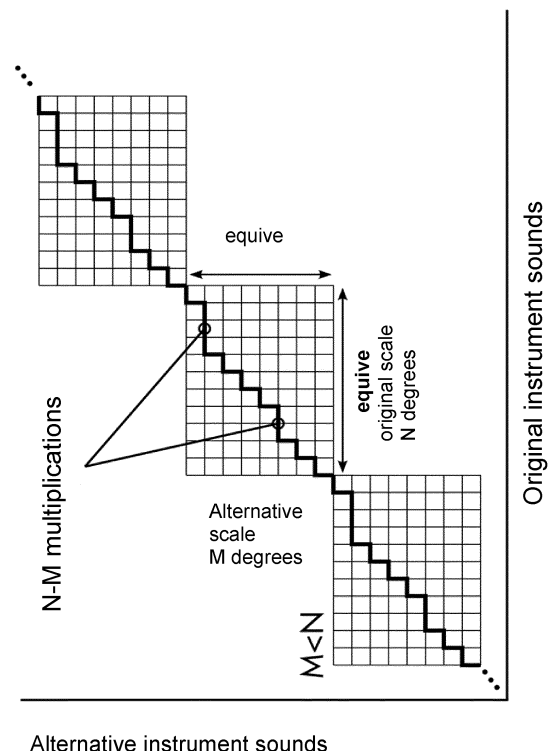


Fig.1

Description**[Technical Field]**

5 **[0001]** The object of the invention is a method of tuning chordophones in alternative musical scales with a reduced number of degrees relative to the original tuning based on monotonic surjective mappings. The method of tuning is characterized by the fact that if the original scale has N degrees and the alternative scale has M degrees, where $M < N$, then during the tuning of an instrument in the alternative scale, $N-M$ degrees of the original scale are mapped to the same degree of the alternative scale as another degree of the original scale. The present invention is applicable to the technique
 10 of construction and tuning of stringed acoustic instruments (chordophones) such as grand piano, piano, harpsichord, clavichord, lyre, harp, dulcimer, cantel, spinet, psalterium, virginium, zither.

[Prior art]

15 **[0002]** In the state of the art, the method suggested by Aron Andrew Hunt has been revealed in the preface to a collection of notes [*The Equal-Tempered Keyboard, Zwillinge Verlag (2021); ISBN: Not assigned*]. The foreword is available online at URL: https://zwillinge.zentral.zone/vorschau/etk_frontmatter.pdf. The method reveals how to tune an instrument with a typical piano keyboard tuned in the original scale of 12 TET to the alternative scales of 5 TET, 6 TET, 7 TET, 8 TET, 9 TET, 10 TET, 11 TET, 12 TET, 13 TET, 14 TET, 15 TET, 16 TET, 17 TET, 18 TET, 19 TET, and 20 TET, comprising assigning to
 20 successive keys (relative to a selected pinning point), successive sounds of a selected alternative scale. This method will be referred to in this application as a strictly monotonic. Strictly monotonic method applied to piano tuning from the original 12 TET scale to the alternative 10 TET scale increases the instrument's frequency range. In the original 12 TET scale, the piano has a frequency range of 27.5 Hz to 4186.01 Hz, while when tuned in the alternative 10 TET scale according to the strictly monotonic method, the piano has a range of frequencies from 23.12 Hz to 9616.92 Hz (for pinning point C2).
 25 Because of that fact, the application of this method to chordophones is extremely difficult or impossible, due to the risk of damaging to the instrument resulting from a significant change in the total tension of the strings of a chordophone tuned in the alternative scale, relative to the total tension of the strings of a chordophone tuned in the original scale (tuning the string to a higher frequency requires an increase in tension).

[0003] In addition, the strictly monotonic method disclosed by Aron Andrew Hunt involves the risk of breaking a string whose vibration frequency in the alternative scale significantly deviates from its intended vibration frequency on the original scale. Another unfavorable effect of the strictly monotonic method is a change in the instrument sound significant resulting from discrepancies in tension of individual strings of the chordophone relative to the tension in the original tuning (changing the operating point of the strings).
 30

[0004] Patent document [US6194646B1] proposes an alternative musical keyboard layout, with an increased number of keys within an octave relative to the layout of the piano keyboard. The embodiments show division of the octave into 20 or 16 degrees with the specific order of white and black keys. The document does not discuss whether it is possible to tune or otherwise modify an existing instrument to realize the presented keyboard layout with the frequencies corresponding to each key.
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[0005] The patent document [WO2003060872] presents a method of tuning the instrument in alternative (microtonal) scales relative to the equally tempered tuning. The suggested method requires intervening in the construction of a stringed instrument such as a piano, grand piano or dulcimer by adding a mechanism that shortens the active vibrating length of the string (*menzura*). Shortening the active vibration length of the strings modifies the frequency of the string's vibration.
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[0006] Patent document [US6559369B1] describes method for tuning piano involving the application of a dedicated voltage to each string, resulting in current flow and thermal expansion of the strings. This method requires significant interference in the structure of the instrument (including the need for electrical isolation of individual strings), allowing the piano to be precisely tuned in the selected tuning without the need for standard tuning techniques.
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[0007] Patent document [EP1153384A1] describes an alternative tuning system deviating from equally tempered that allows an instrument to be tuned in a scale of more than 12 degrees per octave.

[0008] In the publication [K. Hobby, W. A. Sethares, "Inharmonic strings and the hyperpiano", Applied Acoustics, 317-327, 114, 2016, <https://doi.org/10.1016/j.apacoust.2016.07.029>] it is disclosed a modification of piano involving the use of strings with heterogeneous structure (for example, with different thickness and length of a braid). String heterogeneity significantly modifies the harmonic series of the sound it generates. Thanks to this it is possible to control the timbre and pitch of the sound generated by the string. The use of specially prepared strings allows the tuning of the piano to any alternative tuning, however, it requires expensive and time-consuming replacement of a set of strings in the instrument.
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[A problem from the state of the art]

[0009] The problem from the state of the art is safe tuning method for the chordophones in alternative musical scales, in

which the number of degrees is less than the number of degrees in the original tuning provided for the instrument by the manufacturer. Chordophone tuning involves the risk of damage to the instrument caused by both a change in the overall tension of the strings (threatening, for example, with the mechanical damage to the instrument) as well as changes in the tension of individual strings (threatening to break the strings). In addition, changing the tuning of a chordophone can involve a deterioration in sound quality caused by a change in the operating point of each string. In particular, a problem from the state of the art is the tuning of a piano from the original tuning of twelve equally tempered degrees (12 TET) to a tuning of ten degrees evenly tempered (10 TET), without the risk of damage to the structural components of the piano such as strings, tuning board, soundboard, etc., and without deterioration of the sound quality.

[Solution to the problem]

[0010] The invention described in the present patent application consists in finding a monotonic surjective mapping between the degrees of the original scale and the degrees of the alternative scale. If the original scale has N degrees and the alternative scale has M , where $M < N$, then when tuning an instrument in the alternative scale, the $N-M$ degrees of the original scale are mapped to the same degree of the alternative scale as another degree of the original scale. This mapping makes it possible to solve the problem from the state of the art minimizing the risk of damage to the instrument caused by both changing the total tension of the strings as well as changing the tension of individual strings, which increases the life and durability of the strings in the instrument minimizing the possibility of damage to the structural components of the instrument.

[Summary of the of the invention]

[0011] The object of the present invention is a method of tuning chordophones in alternative musical scales with a reduced number of degrees relative to the original tuning, in which a monotonic surjective mapping is sought between the degrees of the original scale and the degrees of the alternative scale, characterized in that when the original scale has N degrees and the alternative scale has M degrees, where $M < N$, then the instrument tunes to the alternative scale so that $N-M$ degrees of the original scale is mapped to the same degree of the alternative scale as another degree of the original scale, and, in addition, the frequency range of the instrument tuned in the alternative scale is not greater than the frequency range of the instrument tuned in the original scale.

[0012] Preferably, among all monotonic surjective mappings a single one is selected for which the tension of each string of the chordophone tuned in the alternative scale does not exceed its breaking tension.

[0013] Preferably, the total tension strings chordophone tuned to alternative scale is as close as possible to the total string tension of the chordophone tuned to the original scale.

[0014] Preferably, the operating point of each of the strings tuned in alternative tuning does not extend beyond the area of tuning stability region.

[0015] Preferably, a chordophone is a plucked chordophone or struck chordophone.

[0016] Preferably, a chordophone is an instrument selected from the group including: dulcimer, zither, piano, gusli, harp, kankle, kanun, harpsichord, clavichord, kokle, kora, lyre, kantele, grand piano, psalterium, stredici, spinet, virginals.

[0017] Preferably, the chordophone is a piano or a grand piano.

[0018] Preferably, the original scale is the N TET scale, while the alternative scale is the M TET.

[0019] Preferably, the original scale is the 12 TET scale, while the alternative scale is the 10 TET scale.

[0020] Preferably, the mapping of the original scale of 12 TET to the alternative scale of 10 TET is characterized by at least two fixed points within an octave.

[0021] Preferably, the mapping of the original 12 TET scale to the alternative 10 TET scale is characterized by two fixed points within one octave corresponding to the $D\#$ and A scale degrees.

[0022] Preferably, the mapping of the original scale of 12 TET to the alternative scale of 10 TET is characterized by the fact that the frequency range of a piano or grand piano tuned in scale the alternative 10 TET ranges from 27.50 Hz to 4043.42 Hz.

[0023] Another subject of the invention is also a method of tuning chordophones in alternative musical scales with a reduced number of degrees relative to the original tuning, in which a monotonic surjective mapping between scale of the original scale and degrees of the alternative scale is sought, characterized in that when the original scale has N degrees and the alternative scale has M degrees, where $M < N$, the instrument is tuned to the alternative scale in such a way that $N-M$ degrees of the original scale are mapped to the same degree of the alternative scale as another degree the original scale, characterized by at least two fixed points within one octave, in addition, the frequency range of the instrument tuned in the alternative scale is not greater than the frequency range of the instrument tuned in the original scale, where the method consists of the following steps:

(a) the corresponding signature of the mapping of the original scale N TET to the alternative scale M TET is selected,

the choice of signature defines which notes of the new scale will be repeated;

(b) the pinning point is selected between the original N TET scale and the alternative M TET scale;

(c) It is found what degree of the alternative scale (M TET) corresponds to the pinning point in the original scale (N TET), then to that degree of the scale 'm' it is assigned the vibration frequency corresponding to the pinning point f_m ;

(d) the remaining sounds in the alternative scale in a given equive (or octave) are calculated using the formula:

$$f_i = f_m \cdot 2^{\left(\frac{i-m}{M}\right)}$$

where 'M' denotes the number of degrees of the alternative scale, 'm' denotes the degree of the alternative scale corresponding to the pinning point, 'i' denotes the calculated degree of the alternative scale, and f_m denotes the frequency of the sound being the pinning point;

(e) for the other equives, the frequencies of the sound can be obtained by multiplying the obtained frequencies respectively by the corresponding equives frequency ratios (e.g., for octave factors 2, 2², 2⁴ for subsequent octaves), and by dividing the obtained frequencies by the corresponding equives frequency ratios, respectively (e.g., for octave factor 2, 2², 2⁴ for antecedent octaves).

[0024] Yet another subject of the invention is also a chordophone tuning method implemented by computer in an electronic tuner for determining the frequency of vibration of the string of a chordophone during the tuning of the instrument from the original N TET scale to the alternative M TET scale, including:

- recording of the sound signal generated by the string or strings of a single scale sound;
- extraction of the fundamental frequency of the recorded audio signal;
- comparing the obtained frequency of the audio signal with the reference data stored in the tuner's memory corresponding to the successive steps of the new M TET alternative scale and display information to the user about the difference of the measured frequency from the reference frequency.

[0025] In another aspect of the invention, there is also a frequency tuner adapted to confirm the correct frequency of vibration of a chordophone string or strings, using the reference data necessary to realize the method of computer assisted.

[Advantages effects of the invention]

[0026] The invention described in the claims features a number of advantages over solutions known in the state of the art. Firstly, the tuning of the chordophone using disclosed method minimizes the risk of damage to the instrument caused by the difference of the total string tension of strings instrument tuned in alternative tuning to the total string tension of an instrument tuned in the original tuning. Similarly, the risk of breaking a single string is minimized. In most cases, this allows the instrument to be re-using tuned without interfering with its construction. By keeping the operating point as similar as possible for each of the chordophone strings (depending on the original scale of the instrument and the selected alternative scale), there is no significant change in the instrument's timbre in the disclosed method. Chordophone tuning according to the disclosed method is characterized by the occurrence of more than one fixed point, allowing an increase in the number of common sounds between chordophones tuned in alternative tuning and any other instrument tuned in the original tuning, which facilitates joint performance of musical pieces in musical ensembles. In addition, in the disclosed method, the cycle of equive is preserved in the sequence of sounds allowing those experienced in playing in the original tuning to easily transfer the performance techniques learned so far to an instrument tuned to alternative scale using the method presented. The occurrence of N-M repetitions in the alternative scale opens up new performance possibilities based on rapid repetition sounds and other rhythmic effects.

[Possible areas of application of the invention]

[0027] The present invention finds application in musical arts, film arts and theater arts. Music composed for instruments tuned in alternative musical scales is now one of the directions of avant-garde modern music. Due to the lack of safe methods of tuning acoustic instruments such music is mainly created using electronic instruments or computer programs. Music performed on chordophones tuned in alternative scales can be used in film scores as well as in musicals for theatrical performances. Chordophones tuned in alternative scales can also be a valuable source of musical education about possible tunings of the instrument and the existence of other scales alternative to the most widely used equally-tempered tuning.

[Preferred embodiments of the invention]

[0028] The invention will now be further illustrated in a favorable embodiments with reference to the attached drawing, where:

Fig. 1 presents the concept of a method for tuning chordophones in alternative musical scales with a reduced number of degrees relative to the original tuning based on monotonic surjective mappings. Within one equive, the original scale consists of N degrees, while the alternative scale consists of $M < N$ degrees. The horizontal axis shows the sounds of the instrument's original scale, while the vertical axis shows the sounds of the alternative scale. Each scale degree is represented by using a single square. The mapping is periodic with respect to (with respect to the degree of scale) with a period of one equive. A characteristic feature of the mapping is the occurrence of $N-M$ multiplications (visible as horizontal segments of more than one square length).

Fig. 2 presents the link between keys of the piano and sound frequencies for Steinway acoustic piano model B tuned in the original scale of equally tempered 12 TET (white circles) and for a piano tuned to the scale of 10 TET using a strictly monotonic method (dashed line). The solid line shows the connection between the keys of the same piano tuned by the method proposed in the following disclosure to alternative scale 10 TET with signature $\{6, 10\}$ and the pinning point marked with a vertical dotted line. The area filled in with the dotted pattern indicates the difference between the frequency range of the instrument tuned by the strictly monotonic method and that of the frequencies of an instrument tuned by the method disclosed in the present invention. In order to illustrate more clearly the difference between original scale tuning and alternative scale tuning according to the disclosed method, a close-up view of the area between key 18 and 31 is shown in panel (a).

Fig. 3 presents a graph of the change of sound frequency in cents when tuning a Steinway model B acoustic piano from the original scale of 12 TET to the alternative scale of 10 TET. The horizontal axis shows the successive key numbers of the piano. The white dots denotes the values for the original scale, being zero (tuning to 12 TET scale does not require tuning the strings). The dashed line and the symbols " $\blacktriangle$ " denote the change in frequency of sounds using the strictly monotonic method known from the state of the art. The solid line and the symbols " x " denote the change in frequency of the tones with the tuning method obtained by the method according to this disclosure for signature $\{6, 10\}$ and pinning point A (440 Hz). The dotted line marks the pinning point. The gray area between the multi-point lines indicates the area of tuning stability corresponding to detuning the string no more than 100 cents up or down.

Fig. 4 presents the tension diagram of a string being vibrated with hit of a hammer of the corresponding key numbered from 1 to 88 in a Steinway model B acoustic piano. Tension is expressed as a percentage of the maximum allowable string tension for standard strings based on "Röslau steel wire for piano strings Blue Label." The white dots indicate the string tension values for the instrument tuned to the original scale of 12 TET. The dash line marks the tension values obtained when the instrument was tuned to the alternative scale of 10 TET using the strictly monotonic method known from the state of the art. The solid line denotes the values obtained when detuning the instrument to an alternative scale of 10 TET based on the method presented in this disclosure for signature $\{6, 10\}$ and pinning point A (440 Hz). The horizontal dotted line marks the string breakage threshold. The gray area between the multi-point lines denotes the tuning stability area corresponding to the tension resulting from detuning of the string by no more than 100 cents up or down.

Fig. 5 presents the maximum detuning value of a single sound (and thus the corresponding strings) expressed in cents for selected monotonic surjective mappings according to the method revealed for tuning Steinway acoustic piano model B and used "Röslau steel wire for piano strings Blue Label" strings from the original scale of 12 TET to the alternative scale of 10 TET. The value of the maximum detuning is represented on the chart as a shade of grey according to the color scalebar given on the chart. On vertical axis there are shown the names of the sounds corresponding to the individual pinning points (the names of the sounds follow the standard notation used in the 12 TET scale), where sound A corresponds to a frequency of 440.00 Hz, and sound C corresponds to 261.63 Hz. The horizontal axis shows the successive surjective monotonic mappings according to the present disclosure, numbered from 0 to 54. The bottom part of Fig. 5 shows a table tying the mapping number to the order of the notes of the 12 TET scale (1st column of the table) to the notes of the 10 TET scale on the piano keyboard (columns 2-54 of the table). The individual columns of the table excluding column number 1 denote successive mappings according to the method described in this submission. In the diagram, white circles indicate mappings for which the maximum detuning of a single sound (and thus the corresponding strings) towards higher frequencies does not exceed 60 cents.

Fig. 6 presents a diagram for assigning successive scale tones to the consecutive keys of the piano in the case of the original tuning 12 TET (upper part). Enharmonic sounds names have been omitted for readability. The bottom part of the diagram shows the assignment to the keys of a piano designed for tuning in the original

12 TET, successive degrees of alternative scale 10 TET using the mapping with the signature {6,10} according to the present invention.

[0029] The figure uses the terms according to the definitions in the glossary of this patent document.

[Glossary and definitions of phrases used in the description]

[0030] Undefined terms herein shall have the meanings as given and understood by one skilled in the art in light of the best knowledge possessed, the present disclosure and the context of the patent application description. Unless stated otherwise, the following term conventions are used in this description, which have the indicated meanings as in the definitions below. In this description terms used have the following meanings.

[0031] The term "cent" means the change in frequency relative to the original frequency expressed as

$$1200 \times \log_2 \left(\frac{f_{alt}}{f_{org}} \right)$$

, where means the new sound frequency and f_{org} means the original sound frequency. The change expressed in the aforementioned form is denoted by the symbol ϕ .

[0032] The term "equive" means - in periodic scales - a musical interval in which sounds are perceived as equivalent. Otherwise known as an equivalent interval. In most Western musical scales (such as the 12 TET), the equivalent interval is the octave. In the Bohlen-Pierce scale, the role of the octave is the tritave of frequency ratio of 3:1. In scales based on equal divisions of fifths (so-called. EDF from *equal division of fifth*) the role of the *equive* is played by the *fifth* with a frequency ratio of 3:2.

[0033] The term "number of scale steps" means the number of scale tones within the range of one *equive*.

[0034] The term "monotonic surjective mapping" in the case of this disclosure means surjective mapping characterized by the fact that it preserves the order of scale degrees i.e. two consecutive degrees of the original scale are mapped to two consecutive degrees of the alternative scale or to the same degree of the alternative scale.

[0035] The term "*N* TET," where *N* is a natural number, refers to the musical scale in which an octave is divided into *N* tones for which the ratio of the frequencies of two consecutive tones (the higher frequency sound to the lower frequency sound) is $2^{1/N}$. Alternative names for the *N* TET (*tone equal temperament*) scale are the *N* EDO (*equal division of octave*) scale, and the *N* ET (*equal temperament*) scale.

[0036] The term "tuning stability area" means the range of string operating points for which no significant change in timbre and tuning instability is observed. In practice, the area of tuning stability is considered to be in the range from -100 cents to +100 cents relative to the original tuning.

[0037] The term "surjective mapping" means a mapping that takes as its values all elements of the counter-domain. In the case of the present invention, this means a mapping in which each degree of the alternative scale is assigned at least one degree of the original scale.

[0038] The term "octave" means the musical distance corresponding to the ratio of the 2:1 sound frequencies.

[0039] The term "instrument tuning" means changing the tuning of the original instrument to the alternative tuning of the instrument.

[0040] The term "pinning point" means the sound for which the frequency in the original tuning is identical to the frequency in the alternative tuning, both when the tuning of the instrument is carried out by a strictly monotonic method as well as when the instrument is tuned by the method described in this application. The choice of this point is one of the characteristics of the mapping.

[0041] The term "fixed point" means the degree of the original scale, the frequency of which sound is the same as alternative scale degree at which it is mapped.

[0042] The term "string operating point" means the percentage tension of the string relative to the breaking tension specified by the string manufacturer. The optimal operating point of each string for the original tuning is set by the manufacturer. Deviation from optimal operating point results in a change in the timbre of the sound emitted by the string.

[0043] The term "original tuning" means the tuning of the instrument predicted by the manufacturer's specifications for which the instrument was designed. For example, in the case of a modern piano and harpsichord, this is an equally tempered tuning in the 12 TET scale.

[0044] The term "alternative tuning" means an instrument tuning different from the original tuning, distinguished by a lower number of scale degrees than the original tuning.

[0045] The term "mapping signature" is a unique set of alternative scale degrees specific to a given mapping between the original scale instrument, and the alternative scale. If the original scale has *N* degrees, and the alternative scale *M* degrees, where $M < N$, then when tuning the instrument in the alternative scale according to the disclosed method, *N-M* degrees of the original scale are mapped to the same degree of the alternative scale as another degree of the original scale. For this reason, the mapping can be described by the characteristic sequence of characters of length *N-M* indicating which degrees of the alternative scale are assigned more than one degree of the original scale. The aforementioned

sequence of characters is referred to as the mapping signature in this application. In order to standardize the length of the signature, it is permissible for the same degree of alternative scale to appear several times in the signature. For example, if the original scale has a length of 7: [OR1, OR2, OR3, OR4, OR5, OR6, OR7], where OR_n is the n -th step of the original scale and the alternative scale has length 4: [A1, A2, A3, A4], where A_m denotes the m -th degree of the alternative scale, the signature of the monotonic surjective mapping [OR1→A1, OR2→A1, OR3→A2, OR4→A3, OR5→A3, OR6→A4, OR7→A4], where $OR_n \rightarrow A_m$ denotes the assignment of the n -th degree of the original scale m -th degree of the alternative scale, will be {A1, A3, A4}. Also, for example The signature of the surjective mapping [OR1→A1, OR2→A1, OR3→A1, OR4→A1, OR5→A2, OR6→A3, OR7→A4], where $OR_n \rightarrow A_m$ means assigning the n th degree of the original scale to the m -th degree of the alternative scale, will be {A1, A1, A1}.

[0046] The term "tritava" is a musical distance corresponding to the 3:1 ratio of frequencies sounds.

[0047] The term "instrument frequency range" means the frequency range of sounds that can be played on an instrument expressed in Hz.

[0048] The term "change in string tension" means the difference of a string tuned in alternative tuning, relative to the tension of a string tuned in the original tuning. The change in string tension shown in Tables 1, 3, and 4 and expressed as a

percentage was calculated according to the equation
$$\left[\frac{(f_{alt})^2}{(f_{org})^2} - 1 \right] \times 100\%$$
, where f_{alt} denotes the new sound frequency of the tuned string according to the alternative tuning, and f_{org} denotes the original sound frequency produced by the string according to the original specifications of the instrument (consistent with the original tuning).

[Embodiments of the invention]

[0049] The following examples are included only to illustrate the invention and to explain particular aspects of the invention, and not for its limitations and should not be equated with its entire scope, which are defined in the accompanying claims. In the following examples, unless otherwise indicated, standard materials and methods used in the technical field were used manufacturers' recommendations were followed for specific materials and methods.

EMBODIMENT 1

[0050] A method of tuning a chordophone from the original tuning in the Bohlen-Pierce even-tempered scale (13 EDT) to the alternative tuning in the 12 EDT scale based on monotonic surjective mappings

[0051] The Bohlen-Pierce scale is cyclic, with the tritave taking the place of the standard octave. The frequencies of successive scale steps correspond to the frequency ratio resulting from dividing the tritave into 13 equal parts, i.e. $f_1/f_0 = 3^{1/13}$. This scale is referred to in the literature as 13 EDT, from the *equal division of tritave*. The sounds of such a scale are customarily called: [C, C#, D, E, F, F#, G, H, H#, J, A, A#, B]. One possible keyboard layout adapted to the Bohlen-Pierce scale (http://ziaspace.com/NYU/BP-Scale_research.pdf) is the BT-tar layout presented by Elaine Walker. An acoustic instrument that allows the use of the method presented in this submission is the chordophone "Stredici" designed by David Lieberman (<http://bohlen-pierce-conference.org/bohlen-pierce-instruments/stredici>). The tuning method presented in this patent application based on monotonic surjective mappings results in 12 possible mappings to an alternative scale of 12 EDT in which the individual scale steps are called: [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]. These mappings are characterized by the one-element signatures {1}, {2}, {3}, {4}, {5}, {6}, {7}, {8}, {9}, {10}, {11}, each of these provides a lower total instrument string tension than the strictly monotonic method known from the state of the art. If an instrument originally designed for the Bohlen-Pierce scale has a frequency range covering two tritaves, and the common sound between the two scales (the pinning point) is the middle C sound (261.63 Hz), then the individual sounds and their corresponding frequencies will be as shown in the first three columns of the table below.

Table 1

original scale of the instrument			strictly monotonic mapping (state of the art)			mapping according to the invention		
degree name in 13	No degree in 13	frequency (Hz)	No degree in 12 EDT	frequency (Hz)	change in string tension	No degree in 12 EDT	frequency (Hz)	change in string tension
EDT	EDT							

(continued)

5	original scale of the instrument			strictly monotonic mapping (state of the art)			mapping according to the invention		
	degree name in 13	No degree in 13	frequency (Hz)	No degree in 12 EDT	frequency (Hz)	change in string tension	No degree in 12 EDT	frequency (Hz)	change in string tension
10	C	1	87,21	12	79,58	-17%	1	87,21	0%
	C#	2	94,90	1	87,21	-16%	2	95,57	1%
	D	3	103,27	2	95,57	-14%	3	104,73	3%
15	E	4	112,38	3	104,73	-13%	4	114,77	4%
	F	5	122,28	4	114,77	-12%	5	125,78	6%
	F#	6	133,07	5	125,78	-11%	6	137,84	7%
20	G	7	144,80	6	137,84	-9%	7	151,05	9%
	H	8	157,57	7	151,05	-8%	8	165,53	10%
	H#	9	171,47	8	165,53	-7%	8	165,53	-7%
25	J	10	186,59	9	181,40	-5%	9	181,40	-5%
	A	11	203,04	10	198,80	-4%	10	198,80	-4%
	A#	12	220,95	11	217,85	-3%	11	217,85	-3%
30	B	13	240,43	12	238,74	-1%	12	238,74	-1%
	C	1	261,63	1	261,63	0%	1	261,63	0%
	C#	2	284,70	2	286,71	1%	2	286,71	1%
35	D	3	309,81	3	314,20	3%	3	314,20	3%
	E	4	337,13	4	344,32	4%	4	344,32	4%
	F	5	366,85	5	377,34	6%	5	377,34	6%
40	F#	6	399,20	6	413,51	7%	6	413,51	7%
	G	7	434,41	7	453,16	9%	7	453,16	9%
	H	8	472,71	8	496,60	10%	8	496,60	10%
45	H#	9	514,40	9	544,21	12%	8	496,60	-7%
	J	10	559,76	10	596,39	14%	9	544,21	-5%
	A	11	609,12	11	653,56	15%	10	596,39	-4%
50	A#	12	662,84	12	716,22	17%	11	653,56	-3%
	B	13	721,29	1	784,89	18%	12	716,22	-1%
	C	1	784,89	2	860,14	20%	1	784,89	0%
				average of the absolute value		10%	average of the absolute value		0%

[0052] Table 1. Tone frequencies corresponding to each degree of the Bohlen-Pierce original 13 EDT scale (columns 1, 2, 3) and the 12 EDT alternative scale (columns 4, 5, 6, 7, 8, 9), for the chordophone tuned according to the strictly monotonic method (columns 4, 5, 6) and for the chordophone tuned according to the disclosed method (columns 7, 8, 9). The gray color indicates the pinning point. The rows of the table assign sounds of the alternative scale to individual sounds of the original scale. The selected mapping is characterized by a one-element signature {8}. In addition, columns 6 and 9 show the numerically calculated percentage change in tension for each string of the tuned chordophone relative to the original tuning.

[0053] In Table 1 selects one of the 12 possible surjective monotonic mappings preserving tritava, in which both 8th and

9th degrees of scale 13 EDT are mapped to the 8th degree of the 12 EDT scale. Minimizing the risk of damage to the instrument when changing tuning requires both minimizing the difference between the total tension of the strings before and after tuning and minimizing the difference in tension of each string separately before and after tuning. In contrast to strictly monotonic method tuning the instrument in the alternative scale according to the disclosed method, does not increase the frequency range of the instrument tuned in the alternative scale compared to the frequency range of the instrument tuned in the original scale. For alternative scale tuning consistent with the strictly monotonic method, the range is from 79.58 Hz to 860.14 Hz, while for alternative scale tuning consistent with the disclosed method the range is from 87.21 Hz to 784.89 Hz and is the same as the range of the instrument tuned in the original scale. The disclosed method is clearly more favorable than the state-of-the-art method as reflected by both the average of the absolute value of the percentage change in string tension (10% for the state-of-the-art method technique, 0% for the disclosed method) as well as the maximum value of percentage change in the tension of a single string (20% for the state of the art method, 10% for the disclosed method). The risk of damaging the instrument when changing the tuning according to the disclosed method is therefore significantly lower.

EMBODIMENT 2

Method of tuning the harp from the original tuning of a seven-step diatonic scale to alternative tuning in 4 TET scale based on monotonic surjective mappings

[0054] Another example of the implementation of the disclosed method is the tuning of a 29-string diatonic harp to an alternative tuning in the 4 TET scale. The diatonic harp under consideration has 29 nylon strings, tuned in the cyclic scale where the names of the 7 degrees in the cycle are [C, D, E, F, G, A, H]. There are 4 degrees in the 4 TET scale, which can be called [x, y, z, W]. Using the disclosed tuning method based on monotonic surjective mappings, 20 possible mappings are obtained with the signatures shown in the Table 2:

1: {x, x, x}	2: {x, x, y}	3: {x, x, z}	4: {x, x, W}	5: {x, y, y}
6: {x, y, z}	7: {x, y, W}	8: {x, z, z}	9: {x, z, W}	10: {x, W, W}
11: {y, y, y}	12: {y, y, z}	13: {y, y, W}	14: {y, z, z}	15: {y, z, W}
16: {y, W, W}	17: {z, z, z}	18: {z, z, W}	19: {z, W, W}	20: {W, W, W}

[0055] Table 2: All possible signatures of monotonic surjective mappings that allow tuning a diatonic harp from the 7 step original diatonic tuning to the 4 TET alternative tuning according to the disclosed method.

Table 3

original scale of the instrument			strictly monotonic mapping (state of the art)			mapping according to the invention		
string number	sound name	frequency (Hz)	sound name	frequency (Hz)	change in string tension	sound name	frequency (Hz)	change in string tension
1	C	130,81	W	55,00	-82%	x	130,81	0%
2	D	146,83	x	65,41	-80%	y	155,56	12%
3	E	164,81	y	77,78	-78%	y	155,56	-11%
4	F	174,61	z	92,50	-72%	z	185,00	12%
5	G	196,00	W	110,00	-69%	z	185,00	-11%
6	A	220,00	x	130,81	-65%	W	220,00	0%
7	H	246,94	y	155,56	-60%	W	220,00	-21%
8	C	261,63	z	185,00	-50%	x	261,63	0%
9	D	293,66	W	220,00	-44%	y	311,13	12%
10	E	329,63	x	261,63	-37%	y	311,13	-11%
11	F	349,23	y	311,13	-21%	z	369,99	12%
12	G	392,00	z	369,99	-11%	z	369,99	-11%
13	A	440,00	W	440,00	0%	W	440,00	0%
14	H	493,88	x	523,25	12%	W	440,00	-21%
15	C	523,25	y	622,25	41%	x	523,25	0%
16	D	587,33	z	739,99	59%	y	622,25	12%
17	E	659,26	W	880,00	78%	y	622,25	-11%
18	F	698,46	x	1046,50	124%	z	739,99	12%
19	G	783,99	y	1244,51	152%	z	739,99	-11%
20	A	880,00	z	1479,98	183%	W	880,00	0%
21	H	987,77	W	1760,00	217%	W	880,00	-21%
22	C	1046,50	x	2093,00	300%	x	1046,50	0%
23	D	1174,66	y	2489,02	349%	y	1244,51	12%
24	E	1318,51	z	2959,96	404%	y	1244,51	-11%
25	F	1396,91	W	3520,00	535%	z	1479,98	12%
26	G	1567,98	x	4186,01	613%	z	1479,98	-11%
27	A	1760,00	y	4978,03	700%	W	1760,00	0%
28	H	1975,53	z	5919,91	798%	W	1760,00	-21%
29	C	2093,00	W	7040,00	1031%	x	2093,00	0%
			average of the absolute value		401%	average of the absolute value		9%

[0056] Table 3. Tone frequencies corresponding to each degree of the original scale, i.e. the seven-step diatonic scale (columns 1, 2, 3) and the alternative scale 4 TET (columns 4, 5, 6, 7, 8, 9), for a 29-string harp tuned according to the strictly monotonic method (columns 4, 5, 6) and for a 29-string harp tuned according to the disclosed method (columns 7, 8, 9). The gray color indicates the pinning point. The rows of the table assign sounds of the alternative scale to individual sounds of the original scale. The selected mapping is characterized by three-element signature {y, z, W}. In addition, columns 6 and 9 show the numerically calculated percentage change in tension for each string of the tuned harp relative to the original tuning.

[0057] An example of harp tuning according to the disclosed method, for the selected signature {y, z, W} shown in Table 2, is shown in Table 3. The tuning method based on strictly monotonic mapping (disclosed in the state of the art) leads to a tension difference for a single string reaching 1031% of the original string tension which would lead to the breaking of most strings. The tuning method based on the disclosed method leads to a tension difference for a single string reaching only 21%. Similarly, the average of the absolute value of the percentage change in tension of individual strings for the strictly monotonic method is 401%, while for the revealed method it is 9%. The risk of damaging the instrument when changing the tuning is therefore significantly reduced by using the disclosed method. In contrast to the strictly monotonic method, tuning the harp in alternative scale tuning according to the disclosed method does not increase the frequency range of the harp tuned in the alternative scale compared to the frequency range of the harp tuned in the original scale. For alternative scale tuning according to the strictly monotonic method, this range is from 55.00 Hz to 7040.00 Hz, while for tuning to alternative scale consistent with the disclosed method, the range is from 130.81 Hz to 2093.00 Hz and is the same as the frequency range of the harp tuned in the original scale.

EMBODIMENT3

A method of tuning a piano in 10 TET scale based on monotonic surjective mappings.

[0058] An alternative example of the implementation of the method according to the invention is a method of tuning a Steinway model B acoustic piano from the original scale of 12 TET (equally-tempered tuning) to the alternative scale of 10 TET. The tuning has been realized by means of a monotonic surjective mapping consistent with the invention, which is shown in Table 4. The selected mapping is characterized by the signature {6,10} and the pinning point A (440 Hz) - marked in gray in Table 4 below.

Table 4

original scale of the instrument			strictly monotonic mapping (state of the art)			mapping according to the invention		
string number	sound name	frequency (Hz)	sound name	frequency (Hz)	change in string tension	sound name	frequency (Hz)	change in string tension
1	A	27,50	2	15,79	-67%	9	27,50	0%
2	A#	29,14	3	16,93	-66%	10	29,47	2%
3	H	30,87	4	18,14	-65%	10	29,47	-9%
4	C	32,70	5	19,45	-65%	1	31,59	-7%
5	C#	34,65	6	20,84	-64%	2	33,86	-5%
6	D	36,71	7	22,34	-63%	3	36,29	-2%
7	D#	38,89	8	23,94	-62%	4	38,89	0%
8	E	41,20	9	25,66	-61%	5	41,68	2%
9	F	43,65	10	27,50	-60%	6	44,67	5%
10	F#	46,25	1	29,47	-59%	6	44,67	-7%

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11	G	49,00	2	31,59	-58%	7	47,88	-5%
12	G#	51,91	3	33,86	-57%	8	51,32	-2%
13	A	55,00	4	36,29	-56%	9	55,00	0%
14	A#	58,27	5	38,89	-55%	10	58,95	2%
15	H	61,74	6	41,68	-54%	10	58,95	-9%
16	C	65,41	7	44,67	-53%	1	63,18	-7%
17	C#	69,30	8	47,88	-52%	2	67,71	-5%
18	D	73,42	9	51,32	-51%	3	72,57	-2%
19	D#	77,78	10	55,00	-50%	4	77,78	0%
20	E	82,41	1	58,95	-49%	5	83,36	2%
21	F	87,31	2	63,18	-48%	6	89,35	5%
22	F#	92,50	3	67,71	-46%	6	89,35	-7%
23	G	98,00	4	72,57	-45%	7	95,76	-5%
24	G#	103,83	5	77,78	-44%	8	102,63	-2%
25	A	110,00	6	83,36	-43%	9	110,00	0%
26	A#	116,54	7	89,35	-41%	10	117,90	2%
27	H	123,47	8	95,76	-40%	10	117,90	-9%
28	C	130,81	9	102,63	-38%	1	126,36	-7%
29	C#	138,59	10	110,00	-37%	2	135,43	-5%
30	D	146,83	1	117,90	-36%	3	145,15	-2%
31	D#	155,56	2	126,36	-34%	4	155,56	0%
32	E	164,81	3	135,43	-32%	5	166,73	2%
33	F	174,61	4	145,15	-31%	6	178,70	5%
34	F#	185,00	5	155,56	-29%	6	178,70	-7%
35	G	196,00	6	166,73	-28%	7	191,52	-5%
36	G#	207,65	7	178,70	-26%	8	205,27	-2%
37	A	220,00	8	191,52	-24%	9	220,00	0%
38	A#	233,08	9	205,27	-22%	10	235,79	2%
39	H	246,94	10	220,00	-21%	10	235,79	-9%
40	C	261,63	1	235,79	-19%	1	252,71	-7%

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41	C#	277,18	2	252,71	-17%	2	270,85	-5%
42	D	293,66	3	270,85	-15%	3	290,29	-2%
43	D#	311,13	4	290,29	-13%	4	311,13	0%
44	E	329,63	5	311,13	-11%	5	333,46	2%
45	F	349,23	6	333,46	-9%	6	357,39	5%
46	F#	369,99	7	357,39	-7%	6	357,39	-7%
47	G	392,00	8	383,04	-5%	7	383,04	-5%
48	G#	415,30	9	410,53	-2%	8	410,53	-2%
49	A	440,00	10	440,00	0%	9	440,00	0%
50	A#	466,16	1	471,58	2%	10	471,58	2%
51	H	493,88	2	505,43	5%	10	471,58	-9%
52	C	523,25	3	541,70	7%	1	505,43	-7%
53	C#	554,37	4	580,58	10%	2	541,70	-5%
54	D	587,33	5	622,25	12%	3	580,58	-2%
55	D#	622,25	6	666,92	15%	4	622,25	0%
56	E	659,26	7	714,78	18%	5	666,92	2%
57	F	698,46	8	766,08	20%	6	714,78	5%
58	F#	739,99	9	821,07	23%	6	714,78	-7%
59	G	783,99	10	880,00	26%	7	766,08	-5%
60	G#	830,61	1	943,16	29%	8	821,07	-2%
61	A	880,00	2	1010,85	32%	9	880,00	0%
62	A#	932,33	3	1083,41	35%	10	943,16	2%
63	H	987,77	4	1161,17	38%	10	943,16	-9%
64	C	1046,50	5	1244,51	41%	1	1010,85	-7%
65	C#	1108,73	6	1333,83	45%	2	1083,41	-5%
66	D	1174,66	7	1429,56	48%	3	1161,17	-2%
67	D#	1244,51	8	1532,17	52%	4	1244,51	0%
68	E	1318,51	9	1642,14	55%	5	1333,83	2%
69	F	1396,91	10	1760,00	59%	6	1429,56	5%
70	F#	1479,98	1	1886,32	62%	6	1429,56	-7%

5	71	G	1567,98	2	2021,71	66%	7	1532,17	-5%
	72	G#	1661,22	3	2166,81	70%	8	1642,14	-2%
	73	A	1760,00	4	2322,33	74%	9	1760,00	0%
	74	A#	1864,66	5	2489,02	78%	10	1886,32	2%
10	75	H	1975,53	6	2667,66	82%	10	1886,32	-9%
	76	C	2093,00	7	2859,13	87%	1	2021,71	-7%
	77	C#	2217,46	8	3064,34	91%	2	2166,81	-5%
15	78	D	2349,32	9	3284,28	95%	3	2322,33	-2%
	79	D#	2489,02	10	3520,00	100%	4	2489,02	0%
	80	E	2637,02	1	3772,64	105%	5	2667,66	2%
20	81	F	2793,83	2	4043,42	109%	6	2859,13	5%
	82	F#	2959,96	3	4333,63	114%	6	2859,13	-7%
25	83	G	3135,96	4	4644,67	119%	7	3064,34	-5%
	84	G#	3322,44	5	4978,03	124%	8	3284,28	-2%
	85	A	3520,00	6	5335,32	130%	9	3520,00	0%
30	86	A#	3729,31	7	5718,26	135%	10	3772,64	2%
	87	H	3951,07	8	6128,68	141%	10	3772,64	-9%
	88	C	4186,01	9	6568,55	146%	1	4043,42	-7%
35				average of the absolute value		103%	average of the absolute value		4%

[0059] Table 4. Tone frequencies corresponding to each degree of the original scale that is, the equally-tempered 12 TET system (columns 1, 2, 3) and alternative scale 10 TET (columns 4, 5, 6, 7, 8, 9), for Steinway piano Model B tuned according to the strictly monotonic method (columns 4, 5, 6) and for the same piano tuned according to the disclosed method (columns 7, 8, 9). The gray color indicates the pinning point. The rows of the table assign to each sound of the original scale, the sound of the alternative scale. The selected mapping is characterized by the signature {6,10}. In addition, column 6 and 9 shows the numerically calculated percentage change in tension for each string of the tuned piano relative to the original tuning.

[0060] Fig. 2 shows the relationship between the piano keys and the frequencies of the sounds for piano tuned in original scale equally tempered 12 TET (white circles) and for a piano tuned in the 10 TET scale by a strictly monotonic method (dashed line). The solid line shows the relationship between the keys and sounds frequencies of the same piano tuned by the disclosed method in the application to the alternative scale 10 TET with the signature {6, 10} and the pinning point marked by the vertical dot line. The area filled with dotted pattern indicates the difference between the frequency range of an instrument tuned by the strictly monotonic method and the method proposed in this disclosure. In order to more clearly illustrate the difference between the original scale tuning and the alternative scale tuning according to the disclosed method, panel Fig.2(a) shows a close-up view of the area between the key 18 a 31. In contrast to the strictly monotonic method, tuning the piano to the alternative scale according to the disclosed method does not increase the frequency range of the alternative scale tuned piano compared to the frequency range of the original scale tuned piano. For alternative scale tuning according to the strictly monotonic method, the range is from 15.79 Hz to 6568.55 Hz, while for alternative scale tuning consistent with disclosed method the range is from 27.50 Hz to 4043.42 Hz and is smaller than the frequency range of a piano tuned in the original scale.

[0061] Fig. 3 shows a graph of the change in sound frequency expressed in cents when tuning a Steinway model B acoustic piano from the original scale 12 TET to alternative scale 10 TET according to the selected mapping with signature {6, 10}. The horizontal axis shows consecutive piano key numbers. White dots indicate the values for the original scale, which is zero (tuning in the 12 TET scale does not require detuning the strings). The dashed line and the symbols "A" indicate the change in the frequency of sounds according to state of the art, strictly monotonic method techniques. The solid line and the symbols "x" are indicating changes in the frequency of the sound with the tuning obtained with the selected mapping according to the disclosed method. Tuning a piano according to the selected mapping requires detuning the strings from -80 cents to +60 cents preserving their operating point in the area of the stability of the tuning. In addition, the selected mapping is characterized by two fixed points within one octave corresponding to D# and A scale degrees (according to typical 12 TET scale degree designations). Tuning a piano according to the strictly monotonic method moves the operating point of most strings outside the area of tuning stability.

[0062] Fig. 4 shows a diagram of the tension of the string being vibrated by pressing the corresponding key numbered from 1 to 88 on a Steinway model B acoustic piano. Tension is expressed as a percentage of the maximum allowable string tension for standard strings based on "Röslau steel wire for piano strings Blue Label" wire. White dots indicate string tension values for an instrument tuned in the original scale of 12 TET. By line The dashed line indicated the tensions values obtained when the instrument is tuned to the alternative scale of 10 TET using the strictly monotonic method known from the state of the art. For keys with numbers greater than 80, the dash line significantly exceeds the string breakage threshold. Tuning according to the strictly monotonic method also results in a significant change in the instrument's timbre and tuning instability caused by the fact that the operating point of most strings is outside the area of the tuning stability. The solid line indicates the values obtained when the instrument is tuned to the alternative scale of 10 TET. The horizontal dotted line denotes the string breakage threshold. The gray area between the multi-point lines denotes the tuning stability area corresponding to the tension corresponding to the detuning of the string by no more than 100 cents up or down. The disclosed method allows the piano to be tuned to the 10 TET alternative scale without the risk of string breakage caused by exceeding the maximum string tension allowed by the manufacturer. In addition, the tension of each string after tuning is within the tuning stability area.

[0063] In general, such a tuning can be accomplished with any of the mappings shown in Fig. 5. Each of these mappings has a distinct advantage over the strictly monotonic method due to the smaller difference in the total string tension of the piano tuned in the alternative tuning relative to the total string tension of the piano tuned in the original tuning. Similarly, each of these mappings has a distinct advantage over the method of strictly monotonic due to the fact that the maximum detuning of any string toward higher frequencies in the disclosed method is lower than the maximum detuning of any string towards higher frequencies in the strictly monotonic method. This avoids string breakage during the tuning. Of all the mappings shown in Fig. 5, the best stability of tuning after tuning to the alternative scale is offered by the mappings marked with white circles. For these mappings, the maximum detuning of any string in the direction of higher frequencies does not exceed 60 cents.

[0064] Fig. 6 shows a diagram of the assignment of successive scale tones to the consecutive keys of the piano in the case of the original tuning 12 TET (upper part). Enharmonic of sound names have been omitted for readability. The lower part of the diagram shows the assignment to the keys of a piano designed for the tuning in the original 12 TET successive degrees of the alternative scale 10 TET using a mapping with signature {6, 10} according to this implementation example.

EMBODIMENT 4

A method of tuning any chordophone in the 10 TET scale based on monotonic surjective mappings using a professional tuner or acoustic spectrum analyzer

[0065] Alternative example of method according to invention is the method of tuning a Steinway model B acoustic grand piano from the original scale of 12 TET (equally tempered tuning) to the alternative scale of 10 TET. The tuning was implemented using a monotonic surjective mapping in accordance with the invention, which is shown in Table 4. The selected mapping is characterized by a signature {6, 10} and the pinning point A (440 Hz) - marked in gray in the Table 4 below. In general, tuning an instrument requires the following steps. The piano technician chooses a mapping signature from among the possibilities shown under the map presented in Figure 5. The choice of particular signature may be related to the decision of the instrumentalist, whose playing comfort depends on, which keys of the instrument will produce the same sounds of the alternative scale. In the embodiment, the selected signature {6, 10} = 1,2,3,4,5,6,6,7,8,9,10,10 (number 44 on the horizontal axis) means that within one octave the same sounds will be produced by the sixth and seventh keys of the piano as well as the eleventh and twelfth keys. Then, using Figure 5, the technician selects the pinning point (vertical axis). Of all the pinning points shown on the vertical axis, the tuner should select such a pinning point for which the maximum value of detuning of a single sound expressed in cents is as small as possible. In particular, it is advantageous to choose the pinning points marked with white circles in Figure 5. In this example, the A sound of the original scale with a frequency of 440 Hz is chosen as the pinning point. In the next step, the technician determines which

degree of the new scale corresponds to the pinning point of the old scale. In this example, the A sound is the 10th sound of the old 12TET scale, while in the new 10TET scale it is the 9th sound, so the frequency of the ninth sound of the new scale f_9 is 440 Hz. The frequencies of the other sounds of the 10TET scale are calculated by the technician using the formula:

$$f_i = f_m \cdot 2^{\left(\frac{i-m}{M}\right)}$$

Where i is the sound number of the alternative scale (i belongs to the set of 1-10). For the other octaves, the frequencies of the sounds can be obtained by multiplying the obtained frequencies by factors of 2,4,8... respectively for the next higher octaves and by dividing the resulting frequencies by a factor of 2,4,8 respectively... for previous lower octaves. In this embodiment, in the final stage it is necessary to use a professional frequency tuner or an acoustic spectrum analyzer to verify the correct frequency of the chordophone string vibration, which was previously calculated from the formula above. The aforementioned tuner or spectrum analyzer can be realized in electronic or analog version. Other methods of verifying the correct frequency of string vibration are also known, which can be used in the embodiments of the present invention (e.g., comparing beat frequency). It is good tuning practice to repeat the complete tuning procedure several times, depending on the technical condition of the instrument.

EMBODIMENT 5

A method to tune any chordophone using a professional tuner programmed for a scale of 10 TET - based on monotonic surjective mappings

[0066] An alternative embodiment of the method shown in Example 4 is a method of tuning a Steinway model B acoustic grand piano from the original scale of 12 TET (equally tempered tuning) to the alternative scale of 10 TET. The tuning was implemented using a monotonic surjective mapping according to the invention, which is shown in Table 4. Selected mapping is characterized by the signature {6,10} and the pinning point A (440 Hz) - marked in gray in Table 4, shown in Example 3. In this embodiment, it is necessary to use a professional frequency tuner or acoustic spectrum analyzer at the tuning stage to verify the correct frequency of the chordophone string vibration. Used device has pre-defined chordophone strings vibration frequencies preloaded in memory chordophone defined according to Table 4 for the 10TET scale. The piano technician uses the aforementioned tuner or spectrum analyzer, which, thanks to the stored frequencies, do not require the technician to calculate the frequency of vibration of individual strings corresponding to the keys of the instrument in the new 10TET scale. The technician selects only the starting point of the instrument's tuning (the key from which he/she starts tuning), and then proceeds up and down the keyboard, tuning the instrument's successive strings accordingly as indicated by the tuner. It is good tuning practice to repeat the full tuning procedure several times depending on the condition of the instrument.

Claims

1. A method of tuning chordophones in alternative musical scales with a reduced number of degrees relative to the original tuning, in which a monotonic surjective mapping is sought between the degrees of the original **scale** and the degrees of the alternative scale, **characterized in that** when the original scale has N degrees and the alternative scale has M degrees, where $M < N$, the instrument is tuned to the alternative scale in such a way that $N-M$ degrees of the original scale are mapped to the same degree of the alternative scale as another degree of the original scale, and, in addition, the frequency range of the instrument tuned to the alternative scale is not greater than the frequency range of the instrument tuned to the original scale.
2. The method according to claim. 1, **characterized in that** among all monotonic surjective mappings a single one is selected for which the tension of each string of the chordophone tuned in the alternative scale does not exceed its breaking tension.
3. The method according to claim. 2, **characterized in that** the total tension of the strings of the chordophone tuned to the alternative scale is as close as possible to the total tension of the strings of the chordophone tuned to the original scale.
4. The method according to claim. 3 **characterized in that** the operating point of each of the strings tuned in alternative tuning does not extend beyond the tuning stability region.

5. The method according to any of the claims. 1-4, **characterized in that** the chordophone is a plucked chordophone or a struck chordophone.
6. The method according to any of the claims. 1-5, **characterized in that** the chordophone is an instrument selected from the group including: dulcimer, zither, piano, gusli, harp, kankle, kanun, harpsichord, clavichord, kokle, kora, lyre, kantele, grand piano, psalterium, stredici, spinet, virginals.
7. The method according to claim. 6 **characterized in that** the chordophone is a piano or a grand piano.
8. The method according to any of the claims. 1-7, **characterized in that** the original scale is the N TET scale, and the alternative scale is the M TET scale.
9. The method according to any of the claims. 1-8, **characterized in that** the original scale is a 12 TET scale, and the alternative scale is a 10 TET scale.
10. The method according to any of the claims. 1-9, **characterized in that** the mapping of the original scale 12 TET to the alternative scale 10 TET is **characterized by** at least two fixed points within one octave.
11. The method according to any of the claims 1-10, **characterized in that** the mapping of the original scale 12 TET to the alternative scale 10 TET is **characterized by** two fixed points within one octave corresponding to the scale degrees D# and A.
12. The method according to any of the claims 1-11, **characterized in that** the mapping of the original scale 12 TET to the alternative scale 10 TET is **characterized in that** the frequency range of the piano or grand piano tuned in the alternative scale 10 TET is from 27.50 Hz to 4043.42 Hz.
13. A method of tuning chordophones in alternative musical scales with a reduced number of degrees relative to the original tuning, in which a monotonic surjective mapping between scale degrees of the original scale and the degrees of the alternative scale is sought, **characterized in that** when the original scale has N degrees and the alternative scale has M degrees, where $M < N$, the instrument is tuned to the alternative scale in such a way that $N-M$ degrees of the original scale are mapped to the same degree of the alternative scale as another degree of the original scale, **characterized by** at least two fixed points within one octave, in addition, the frequency range of the instrument tuned in the alternative scale is not greater than the frequency range of the instrument tuned in the original scale, wherein the method comprises the following steps:
 - a) the corresponding signature of the mapping of the original scale N TET to the alternative scale M TET is selected, the choice of signature defines which notes of the new scale will be repeated;
 - b) a pinning point was selected between the original N TET scale and the alternative M TET scale;
 - c) it is found what degree of the alternative scale (M TET) corresponds to the pinning point in the original scale (N TET), then to that degree of the scale m is assigned the vibration frequency corresponding to the pinning point f_m ;
 - d) the remaining tones in the new alternative scale in a given equive (or octave) are calculated using the formula:

$$f_i = f_m \cdot 2^{\left(\frac{i-m}{M}\right)}$$

where 'M' denotes the number of degrees of the alternative scale, 'm' denotes the degree of the alternative scale corresponding to the pinning point, 'i' denotes the calculated degree of the alternative scale, and f_m denotes the frequency of the sound being the pinning point;

e) for the other equives, the frequencies of the sounds can be obtained by multiplying the obtained frequencies respectively by the corresponding equives frequency ratios (e.g., for the octave, factors 2, 2², 2⁴ for the subsequent octaves) and by dividing the obtained frequencies respectively by the corresponding equives frequency ratios (e.g., for the octave, factors 2, 2², 2⁴... for the antecedent octaves).

14. A method of tuning a chordophone implemented by computer in an electronic tuner for determining the frequency of vibration of the strings of a chordophone during tuning of the instrument from the original N TET scale to the alternative M TET scale, comprising:

- recording the sound signal generated by the string or strings of a single scale sound;

- extraction of the fundamental frequency of the recorded audio signal;
- comparing the obtained frequency of the audio signal with the reference data stored in the tuner's memory corresponding to the successive steps of the new *MTET* alternative scale and displaying information to the user about the difference of the measured frequency from the reference frequency.

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- 15.** A frequency tuner adapted to confirm the correct frequency of vibration of a chordophone string or strings, using the reference data necessary to realize the method according to any of claims 1 to 14.

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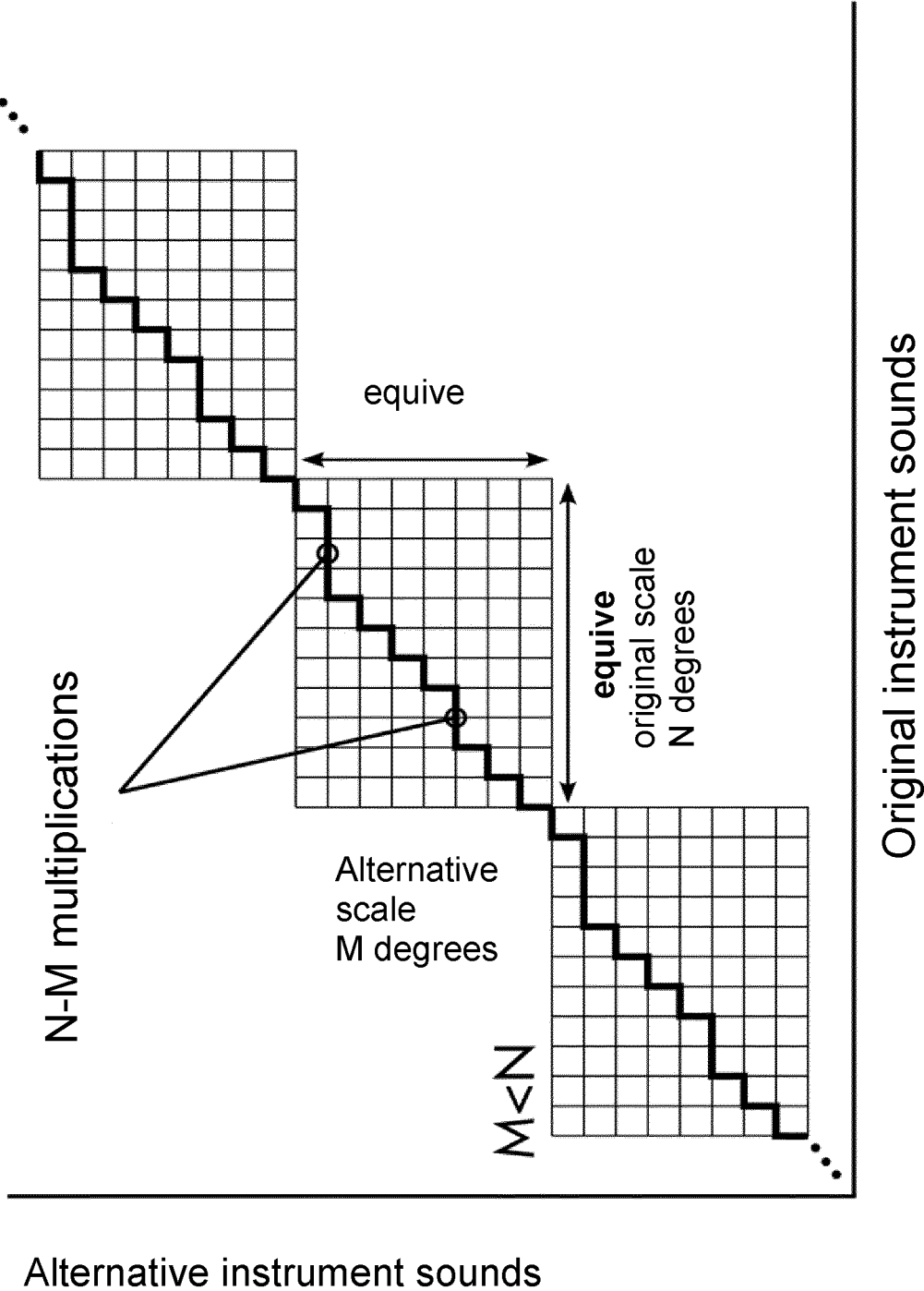


Fig.1

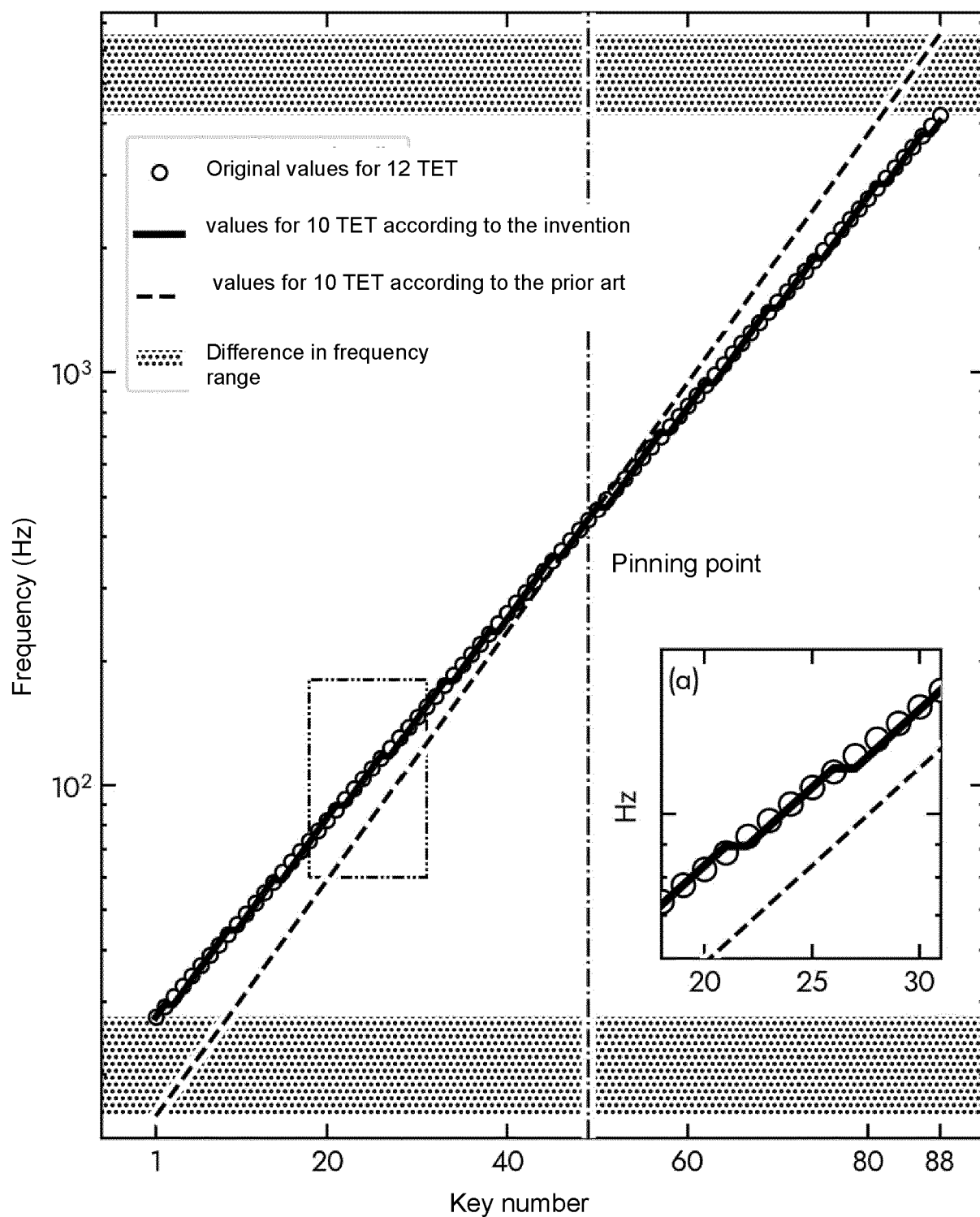


Fig.2

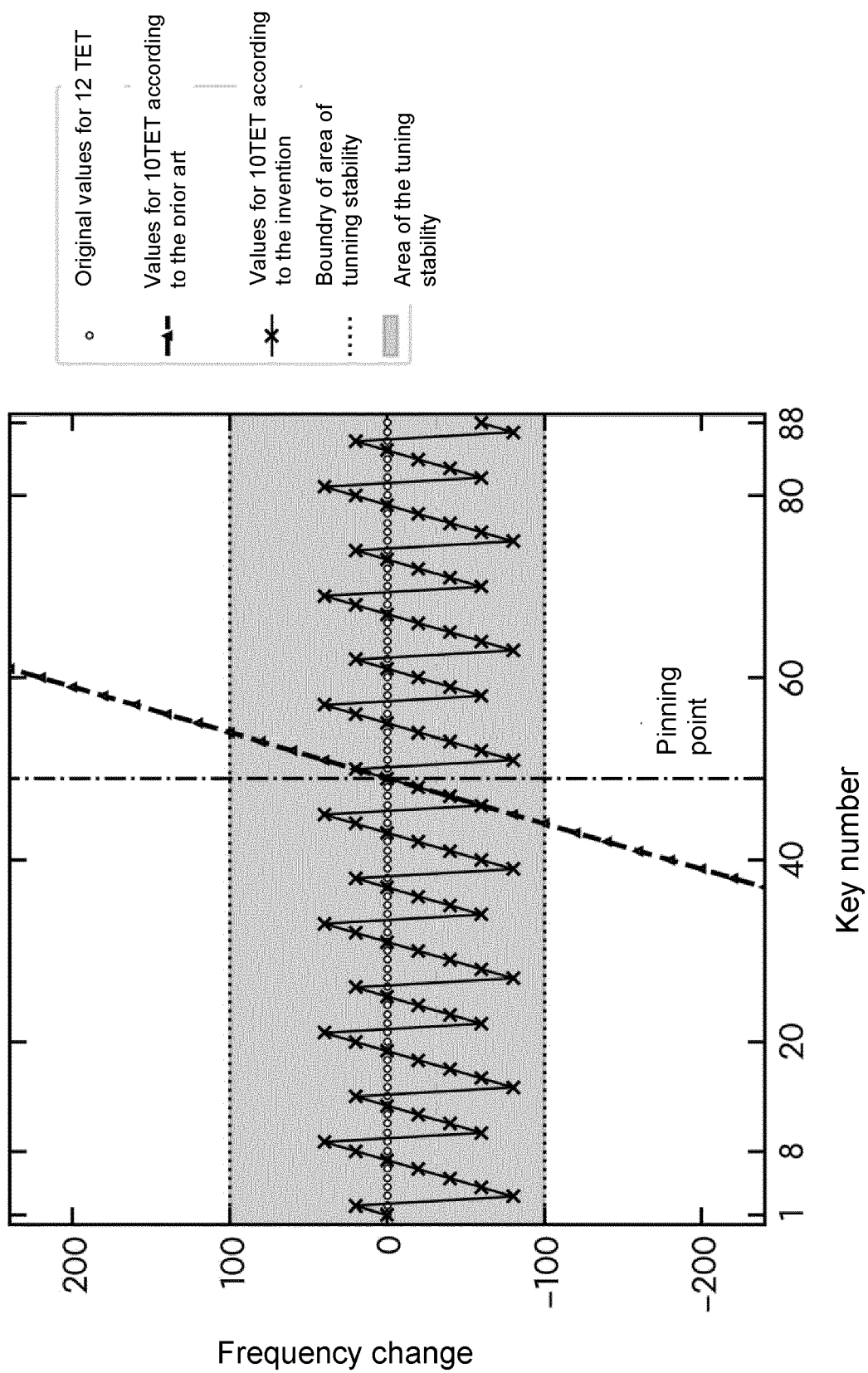


Fig. 3

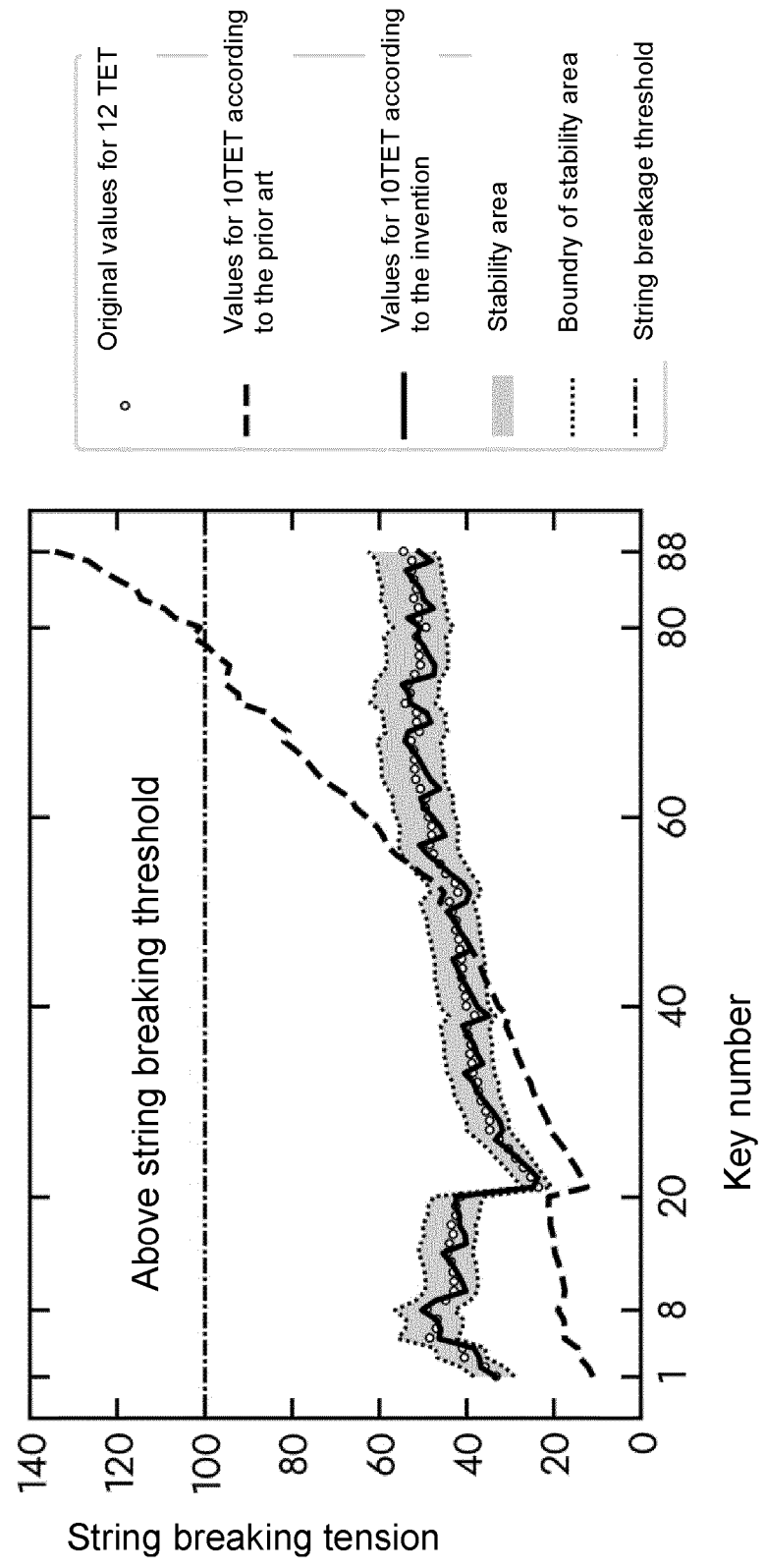


Fig. 4

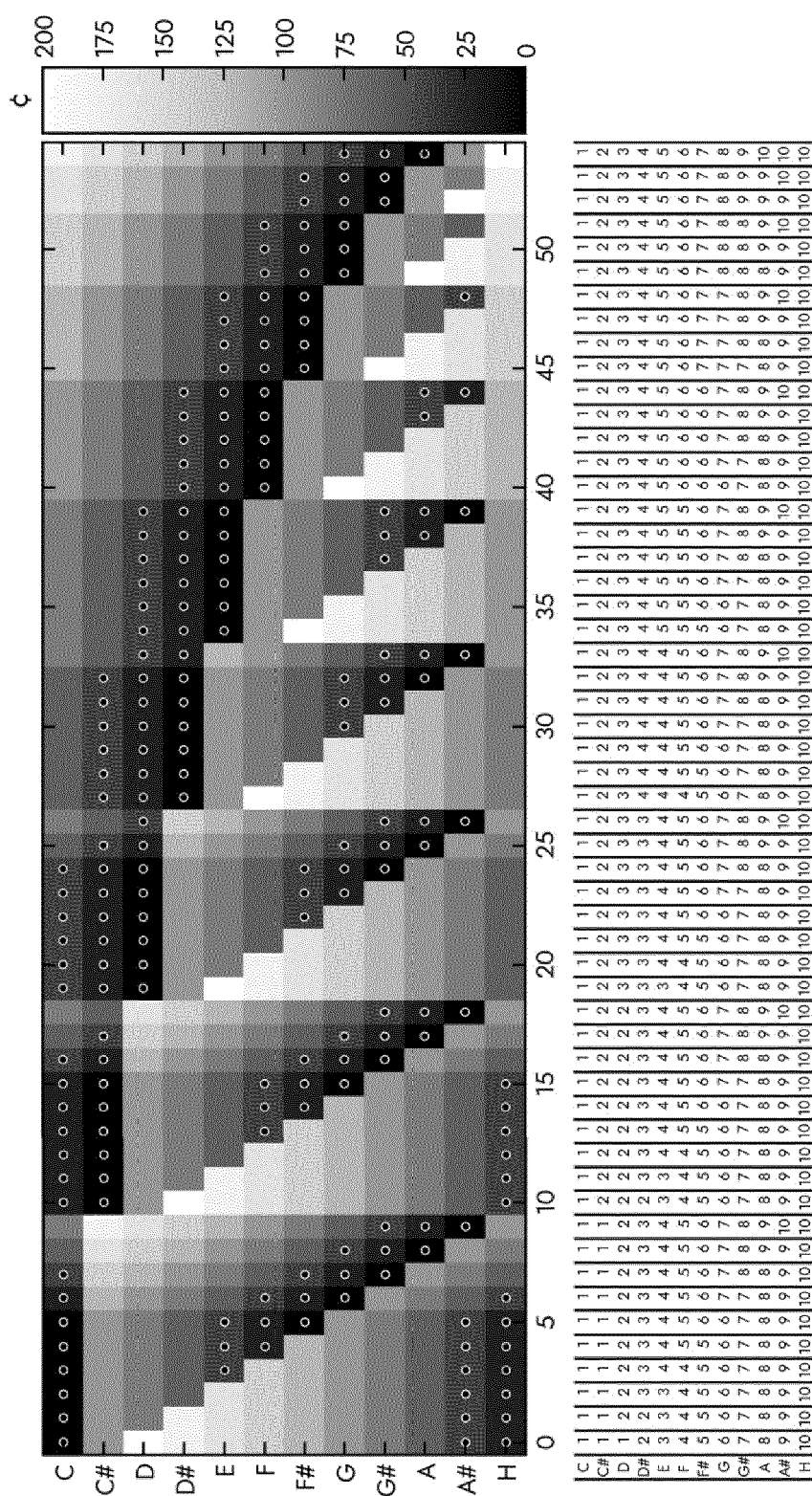
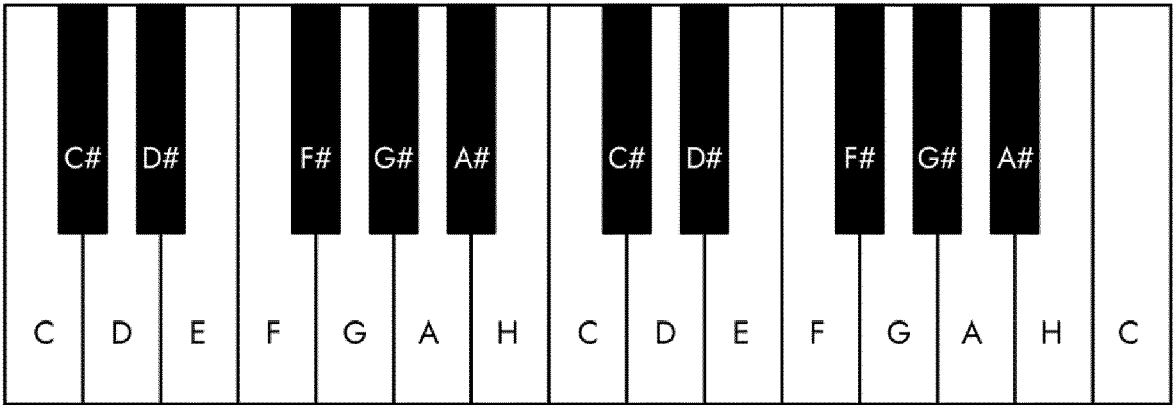


Fig. 5

Original scale 12 TET



Alternative scale 10 TET

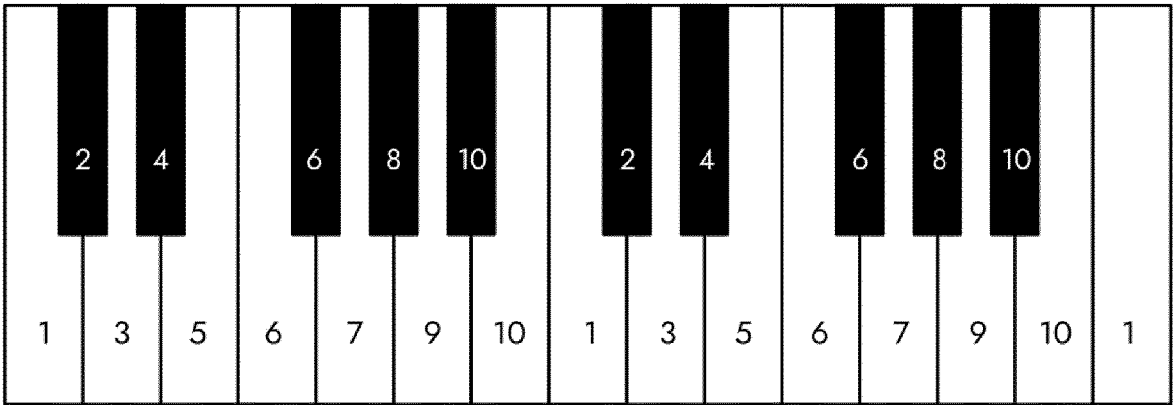


Fig. 6



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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			



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