Oct. 21, 1941. E. E. REID 2,259,858

MUSICAL INSTRUMENT

Filed Nov. 25, 1938 4 Sheets-Sheet 1

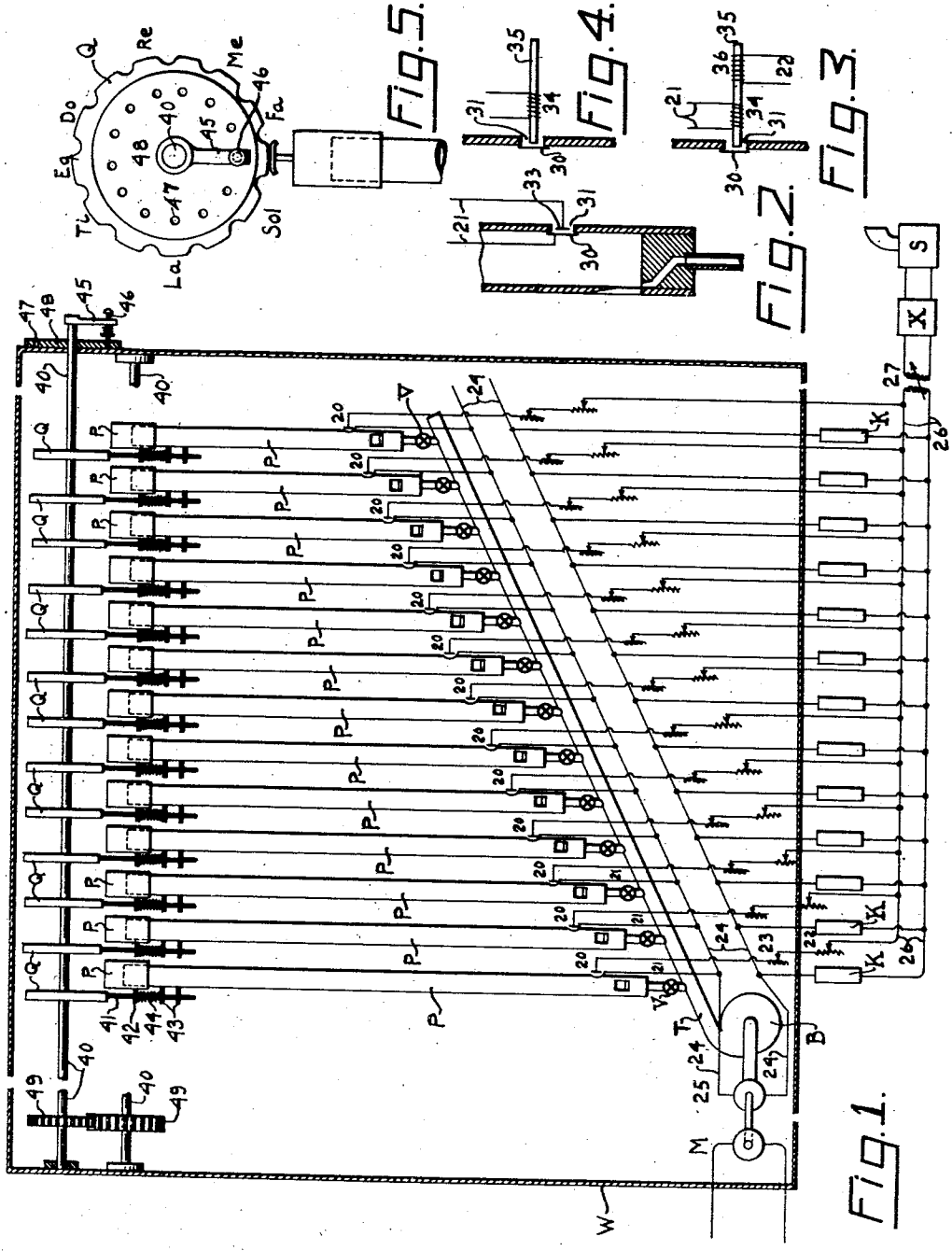


Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

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MUSICAL INSTRUMENT

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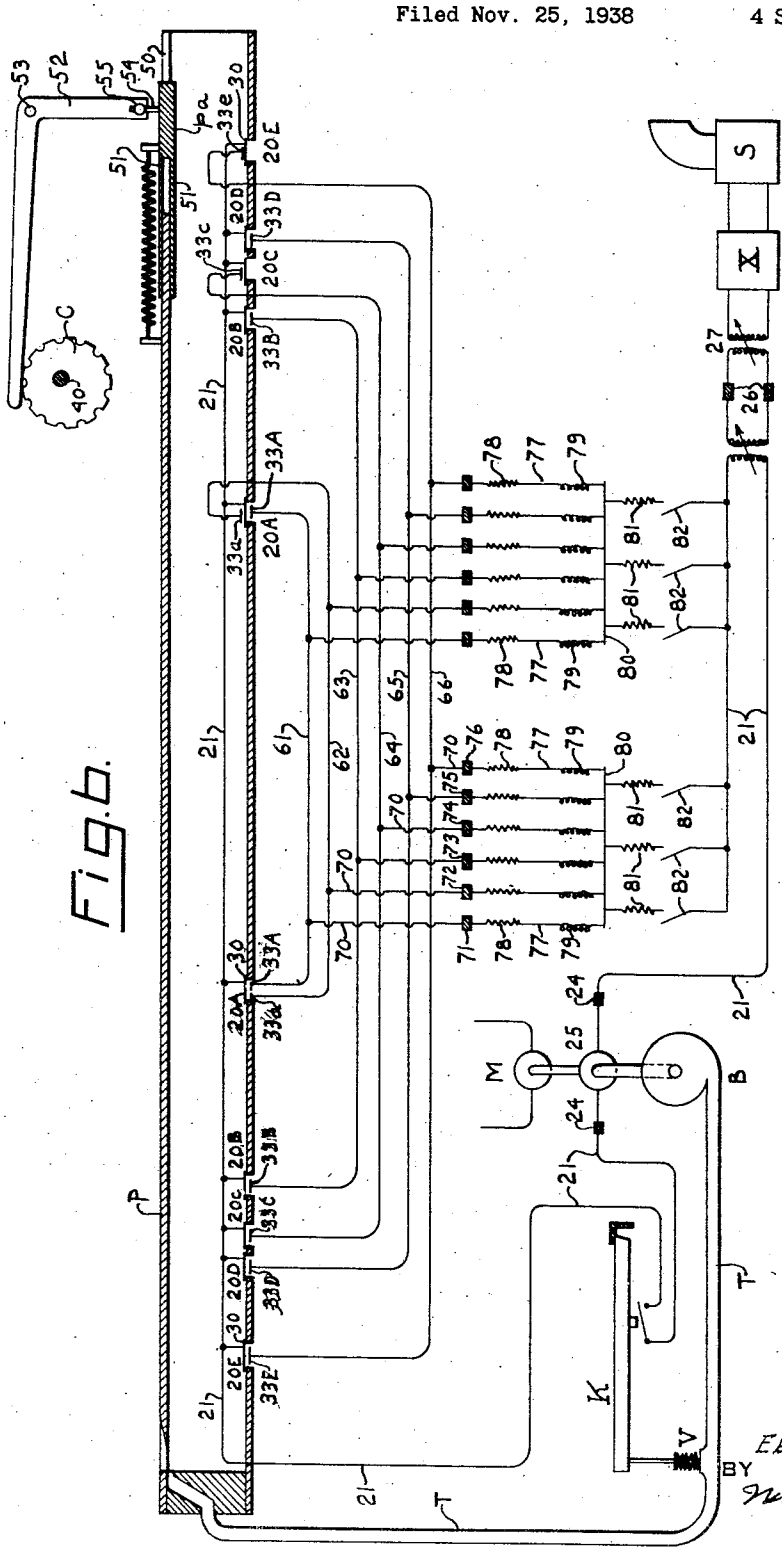


Fig. 6.

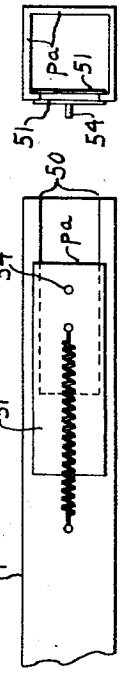


Fig. 8.

Fig. 7.

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MUSICAL INSTRUMENT

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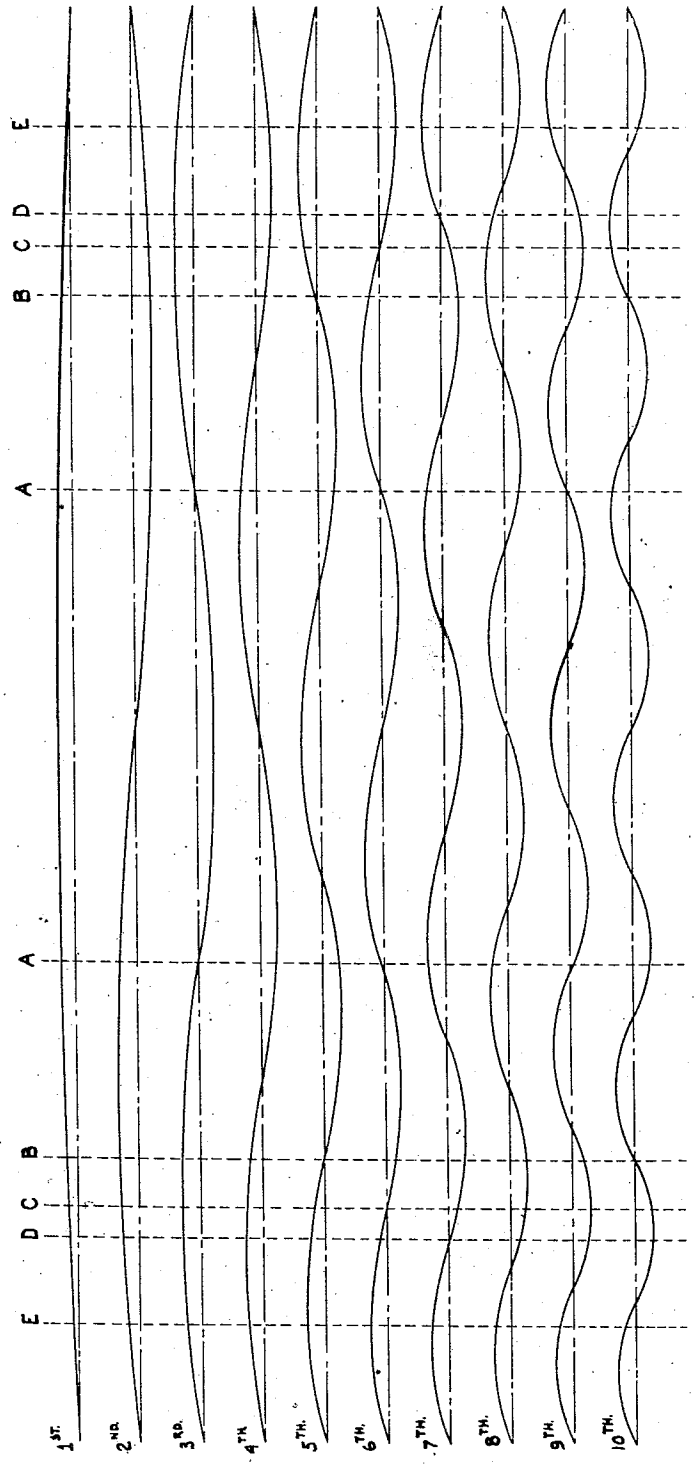


Fig. 9.

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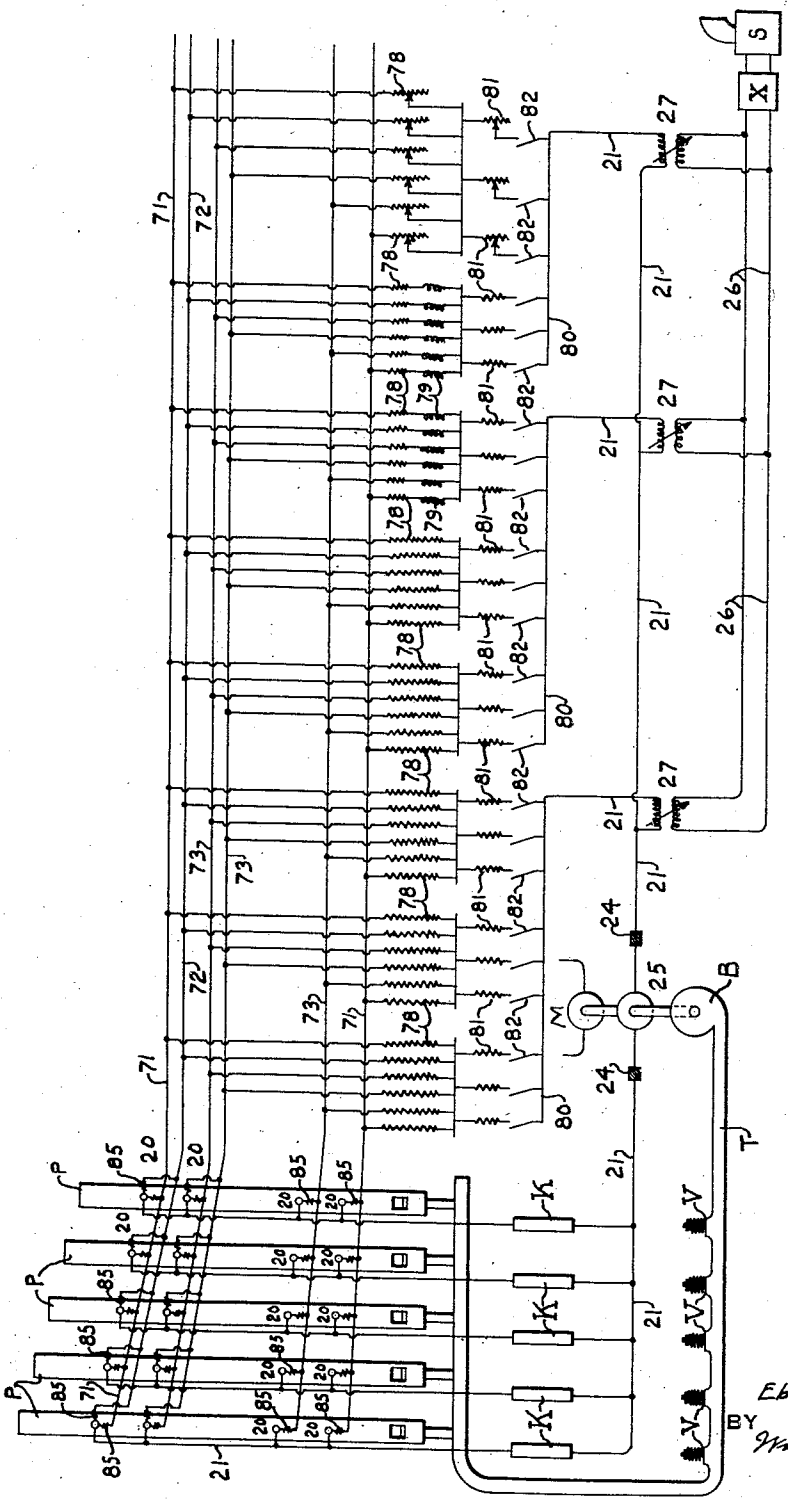


Fig. 10.

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Patented Oct. 21, 1941

2,259,858

UNITED STATES PATENT OFFICE

2,259,858

MUSICAL INSTRUMENT

Ebenezer Emmet Reid, Baltimore, Md.

Application November 25, 1938, Serial No. 242,206

10 Claims. (Cl. 84—1.04)

My invention relates to musical instruments, and especially to instruments in which range of tone pitch and variety of tonal qualities are desirable, though the tonal qualities given by their individual sound devices or the like are relatively unalterable. My invention is eminently adaptable to the organ, whose pipes or reeds are not practically adjustable for variety of tonal quality, though their pitch depends on length. While I have hereinafter explained my invention with reference to its applications in a wind instrument, particularly an organ, it will be understood that the invention is also applicable to musical instruments of other types.

The organ is almost unique amongst musical instruments for the enormous variety of tone qualities that it can give—altogether aside from differences of pitch. Besides diapason tones, organ pipes can produce tones resembling the oboe, the flute, the violin, etc. Moreover, a fine organ will have a variety of tonal characteristics in each of these types: e. g., several varieties of diapason and oboe tones; a dozen or so varieties of flute tones; and an almost endless variety of string tones—indeed, a very fine organ might have as many as a hundred string tones. The instrument must also have a considerable range of volume or loudness in its various tones; for a small organ, greatly limited in variety and power, is little regarded by persons of any musical taste.

But while organ pipes can be designed for manifold varieties of tone quality and loudness, the individual pipe is limited in both respects; i. e., it gives its intended tone only when blown with a certain definite wind-pressure; and if the pressure is sufficiently increased to give much greater loudness, or vice versa, the quality of the tone changes materially, so that it no longer fills its intended place in the tonal scheme of the instrument, and is generally less pleasing besides. Hence a fine organ may have several pipes for each desired tone character of every note in the usual pipe range of six octaves. The number of pipes is often still further augmented, because some organ pipes giving satisfactory fundamentals (especially in the case of diapasons) must be of such large cross-section that they do not produce sufficiently loud overtones, and additional pipes of suitable pitch are therefore provided to supply the deficient overtones.

With a pipe organ of six octaves, a set or "row" of 73 pipes is required for each character of tone in each division or keyboard of the organ, and additional sets may be needed to give the desired flexibility of loudness control, as explained above. A moderately large organ (costing about $20,000) may have four divisions or keyboards, with 10 stops on the first manual or "great", requiring 730 pipes; 20 stops on the second manual or "swell", requiring 1460 pipes; 10 stops on the third manual or "choir", requiring 730 pipes; and five stops on the pedal, requiring 160 pipes; a total of 45 stops and 3080 pipes as the minimum, leaving out of account the possibility of a fourth manual, the "solo." Large organs have from two to five times this number of stops and pipes, or even more.

To operate all the pipes—each with its own valve and wind supply—an elaborate action is required; and hence any organ large enough to give satisfactory variety and power is bulky, complicated, and costly, with infinite possibilities of slight derangement, often very troublesome and expensive to repair.

One important feature of my invention relates to obviating such drawbacks of organs and other instruments, enabling them to give full variety of tone and loudness with a greatly reduced number of sound devices or the like, and a less elaborate action. As few as 73 pipes may suffice for a good organ covering the full range of six octaves, including pedal, when constructed according to my invention. Thus the instruments can be built much simpler and more compact than heretofore, and at much lower cost, all without necessity for any sacrifice of quality or capabilities.

Another important feature of the invention relates to adapting one and the same instrument, at will, for playing in various different musical scale intonations, such as the equitempered scale, the natural harmonic scale, or the old Greek scale, etc. Indeed, an instrument suitably embodying this feature of the invention can be adapted or changed over whenever desired for music written in any major key of any scale, and also in minor keys.

Either or both of the above-stated features of the invention can be included in a given instrument, as desired; however, the simplification of the instrument in accordance with the first-mentioned feature of my invention greatly facilitates adapting it for changing over to play in

different scales, or with different keys as fundamentals.

In carrying out my invention, I preferably translate the action of the pipes or other such devices of the instrument into electrical impulses of suitable musical frequencies, which may be modified, combined, amplified or reduced, and finally (re) converted into sound. In this way, the actual sounds from the organ pipes or the like become so entirely superfluous that they may even be suppressed more or less completely, not merely by dispensing with all usual sound-magnifying means, but even by enclosing the pipes or devices in a sound-proof casing, or using devices which play their role in generating electrical impulses without emitting any sounds. Various types of pick-up may be used to translate the action of the pipes or other devices into electrical impulses,—several of which are described hereinafter. Such electrical translation facilitates the control and variation of loudness and tonal characteristics, either or both, and is thus a means of reducing the number of sound-devices or the like required, and of simplifying the instrument. Accordingly, the organ need not have more than a single set of 73 pipes, or perhaps one or two sets for each division of a large organ, if it is preferred to add a second "reed" set to each division. Allowing for 5 octaves in the manuals, with a pedal ranging one octave lower, and notes ranging two octaves higher to be played by coupling of manuals, only 97 pipes would be needed. And the pipes, beside being so greatly reduced in number, can be made smaller in diameter than in ordinary organs, and can be coiled for greater compactness, because the electrical features permit of magnifying the fundamental and other partials as desired. Small pipes are richer in overtones than large pipes, so that their use enriches the tones of the instrument.

To enable the instrument to be adapted or changed over at will for playing in any scale or intonation and with any desired key as fundamental, I provide for correspondingly "tuning" or changing the pitches of the various sound devices or the like, which is easily done by suitably changing their effective lengths. This might, indeed, be done in an organ of the ordinary type, without any of the electrical features above referred to, though with the usual large number of pipes, such "vari-tuning" (as I term it) would involve greatly increased mechanical complication of an already over-complicated mechanism, and a much higher cost for the instrument. But with only a single set of 73 pipes, or with only some one or two such sets to each division or manual of an instrument, the vari-tuning arrangements can be so simple as to be easily practicable. Indeed, such a vari-tunable instrument may be far simpler than an ordinary organ having the same variety of tones and power.

Of course my invention may be only partially applied in an instrument: e. g., an organ may have more pipes than suggested above, if more are preferred for any reason; and electrical translation, etc., may be used in only one or more of its divisions or keyboards, or only in certain stops, while the rest of its pipes may be directly heard, just as in ordinary organs. Such an organ may omit the vari-tuning feature altogether, or may have it only for certain divisions, or may have it throughout, for both its pipes with electrical translation and its directly heard pipes. In some cases, moreover, pipes equipped for electrical translation may also be heard directly, either at the same time, or alternatively, or sometimes one way and sometimes the other. Electric translation is very useful for supplying or supplementing deficient overtones of large pipes, as well as for magnifying the tones from small pipes.

Various other features and advantages of the invention, besides those already referred to, will appear from the following description of species and forms of embodiment, and from the drawings. Indeed, all the features shown or described are of my invention, so far as novel.

In the drawings, Fig. 1 is a general diagram of certain portions of one type of instrument conveniently embodying my invention.

Fig. 2 is a fragmentary longitudinal sectional view of one organ pipe such as shown in Fig. 1, with various accessory features diagrammatically illustrated, including an electrical pick-up.

Fig. 3 is a fragmentary sectional view illustrating another type of electrical pick-up; and Fig. 4 is a view similar to Fig. 3 showing yet another form of electrical pick-up.

Fig. 5 is a fragmentary diagrammatic view at right angles to Fig. 4, illustrating an arrangement for adjusting or vari-tuning a sound device, for playing in different scales or in different keys.

Fig. 6 is a diagrammatic sectional view of an organ pipe with different arrangements for vari-tuning, and with somewhat different electric circuit arrangements from those illustrated in Fig. 1; Fig. 7 is a fragmentary side view of the pipe shown in Fig. 6, taken at right angles to that figure, and omitting certain parts; and Fig. 8 is an end view of the pipe.

Fig. 9 is a diagram or chart illustrating an analysis of the air-pressure fluctuations in an open-ended organ pipe when blown.

Fig. 10 is a comprehensive general diagram of the circuits and electrical features of a complete instrument with a plurality of key-board divisions, manual or pedal, or both.

Fig. 1 illustrates in a highly diagrammatic way a representative portion of an organ conveniently embodying my invention, only the pipework P for one octave being shown. The wind-supply is indicated by a "blower" B driven by an (electric) motor M (which may be a 110 volt A. C. motor of constant speed type), and a wind-trunk T supplied by blower B and connected to pipes P through wind-chests with admission valves V. The action is represented by keys K corresponding to the pipes P, without any illustration of their operating connections to the valves V. These parts may be of any suitable design and construction; and of course all necessary or desirable parts and accessories not here shown may be provided. As here shown, the pipes P may be enclosed in a sound-proof casing W, so that no sound from them can be directly heard.

As shown in Figs. 1 and 2, each pipe P is provided with a "pick-up" **20** which is responsive to fluctuations of air pressure in the pipe, and is connected in an electric circuit **21** controlled by a key K, and hereinafter conveniently referred to as a "tone-circuit" or "playing circuit." Each circuit **21** is shown as including variable resistance **22** and inductance **23**, which may serve either for calibration or voicing purposes, or for varying the tonal quality from the corresponding pipe P: i. e., increasing the resistance **22** reduces the relative strength of the lower partials, while increasing the inductance **23** reduces the relative

strength of the higher partials. Each circut 21 may be connected to a suitable (D. C.) source of voltage (and current), here represented by a constant potential circuit 24 across which the circuits 21 are connected in parallel. A suitable constant-voltage source for the circuit 24 is represented by a D. C. generator 25 (of low voltage, such as 6 to 8 volts, for example) driven at constant speed by any suitable means, such as the electric motor M already mentioned. As shown in Fig. 1, the circuits 21 are suitably connected (preferably in parallel) to an output circuit 26. In or across this circuit 26 is connected a sound device S, such as a loud-speaker or a telephone receiver, with an amplifier X (such as used in radio) interposed between it and the rest of the circuit 26. A variable transformer coupling 27 is also preferably interposed in the circuit 26, between the circuits 21 and the amplifier X.

As shown in Figs. 1 and 2, each pick-up 20 is preferably located close to one end of its pipe P, where it is exposed and responsive to fluctuations of air pressure in the pipe corresponding to all the desired partials of the pipe tone. For this it generally suffices to place the pick-up within about 5% of the pipe length from the end of the pipe; although it may be closer if desired. The particular pick-up 20 represented in Fig. 2 comprises a highly flexible vibratile diaphragm 30 mounted in or over an opening 31 in the wall of the pipe P, substantially flush with its inner surface. Like a telephone or loud-speaker diaphragm, this diaphragm 30 is preferably equally responsive to pressure fluctuations of all frequencies within the musical range, without any selectivity or resonance: it may be of iron or steel, or of paper faced with gold-leaf on its outer side, or of any other material or construction affording flexibility and conductivity. With the diaphragm 30 may be associated any suitable electric pick-up device. As shown in Fig. 2 the pick-up 20 operates on the condenser principle, and the pick-up device in question comprises a metal plate 33 parallel with the plate 30 and as close thereto as is consistent with their never coming in contact. The diaphragm 30 is connected to one side of the circuit 21, and the plate 33 to its other side. When the diaphragm 30 vibrates in and out in the opening 31 with fluctuations of air pressure in the pipe P, the capacity of the condenser formed by the members 30, 33 varies correspondingly, and electrical impulses of like frequency and pitch are produced in the circuit 21, and are transmitted, with suitable amplification, to the sound device S, which converts them into musical sounds of like pitch and corresponding loudness.

Figs. 3 and 4 illustrate magnetic pick-up devices which may be used with the diaphragm 30 when the latter is of ferromagnetic material.

The pick-up device shown in Fig. 3 comprises a coil or winding 34 associated with a soft (iron) ferromagnetic core bar 35 whose end is close to the ferromagnetic diaphragm 30, like the plate 33 in Fig. 2. The coil 34 is connected directly in the circuit 21. The device is electrically excited, by means of a primary coil 36 associated with the coil 34 and wound on its core 35. This exciting coil 36 may be connected in the circuit 24 and supplied with current from the source 25, Fig. 1. When the diaphragm 30 vibrates under pressure fluctuations in the pipe P, its movement alters the permeability of the field affecting the coil 34, producing electric current impulses therein and in the circuit 21, etc., as in the arrangement of Figs. 1 and 2. The ferromagnetic diaphragm 30 is not connected in circuit at all.

The pick-up device shown in Fig. 4 is self-excited, having a permanent magnet as the core 35 for its winding 34. The circuit 24 and generator 25 may therefore be omitted when this form of magnetic pick-up is used. Otherwise, its operation is just like that of the arrangement shown in Fig. 3.

As shown in Fig. 1, provision is made for varituning the organ pipes P, for scale-changing purposes, by adjusting the effective lengths and pitches of the pipes. One convenient way of doing this (especially in the case of metal pipes) is to provide each pipe P with an extension section in the form of a sleeve *p* telescoped around the main portion of the pipe with an easy sliding fit. By sliding such an associated sleeve *p* lengthwise of its pipe P, on or off the main portion thereof, the effective length of the pipe can be varied to any extent practically required. Any suitable means may be provided for selectively adjusting the pipe sleeves *p* in various correlations such that the notes from the pipes correspond to various desired musical scales or keys: as shown in Fig. 1, the adjustments are made by cams Q fixed on a common shaft 40 mounted to turn in suitable bearings on the organ framework or casing W. To obviate any interference with the air streams issuing from open-ended pipes, P, each cam Q may be offset to one side of the corresponding pipe-sleeve *p*, and may actuate the sleeve through an actuating and guide-rod 41, connected to the sleeve by a bracket-lug 42 and longitudinally slideable in suitably supported guide brackets 43, 43, here represented (for convenience of illustration) as attached to the pipe P. As here shown, the cams Q are edge-cams which act to push the sleeves *p* further on to the pipes P and thus shorten the latter, in opposition to helical compression springs 44 interposed between brackets 42 and 43 and tending to push the sleeves *p* beyond the ends of the pipes and lengthen the pipes. As shown in Fig. 1, the scale-changing shaft 40 has a crank-arm 45 fixed thereon and carrying a spring-actuated longitudinally sliding locking pin 46 whose conical end coacts with corresponding socket-holes 47 in a suitable fixed locking part 48 carried by the organ-frame. Such a shaft 40 may extend along each row of pipes P in an organ, and the several shafts 40 (assuming that more than one is required) may preferably be inter-geared for concurrent operation by one crank 45, as indicated by the gears 49, 49 in Fig. 1, which shows a second shaft 45 for a row of pipes behind the row there visible.

Such operating means, including the individual length-selective actuating means or cams Q that are associated with the respective length-adjusting means *p* of the several sound-producing devices P and are definitely correlated with one another, as by the shaft(s) 40, coact with said length-adjusting means *p* to correlate the relative lengths and pitches of the sound-devices P to various concurrent-pitch correlations, severally corresponding to different musical scale intonations, as is more fully explained hereinafter.

Fig. 5 affords an end view of the shaft 40, with its crank-arm 45, locking pin 46, and fixed locking part 48, and also one of the pipe-length adjusting cams Q. The cam outline illustrated is adapted to tune the corresponding pipe P to

the equitempered scale and also (alternatively) to the natural harmonic scale in any of 12 keynotes as fundamentals: accordingly, it has 13 projections (which are designated in Fig. 5 by appropriate movable scale symbols) for engaging a bevel-edged actuating head on the rod 41, Fig. 5. By making the cam Q of adequate size, it can obviously be provided with any required number of additional projections, for also tuning the pipes P to the natural minor scale on any one of 12 keynotes, or to any desired keynotes on any other scale(s). Thus the operating means comprising the cams Q coact with the length-adjusting means *p* to adjust and correlate the sound-devices P to effective lengths which produce notes of the equitempered scale intonation, and also, alternatively, to effective lengths which produce notes of natural harmonic scales of various different intonations.

Considering a cam projection *Eq* which adjusts the corresponding pipe P to any desired pitch on the equitempered scale, the other 12 cam projections shown in Fig. 5 that will produce the correct pitches for the natural scale in the designated keys as fundamentals may readily be determined, upon the principle that the vibration-frequency or pitch produced by a pipe is inversely proportional to its length, and taking into consideration that with the cam arrangement in Fig. 1, an increase in cam-projection radius means a decrease in pipe-length, and vice versa.

In the following table are given the vibration numbers of the equitempered scale of the octave beginning with middle C and having A=440 vibrations per second. In another column are the vibration frequencies of the natural harmonic scale based on C=261.625 as do, the keynote. The designations of these as do, re, me, etc., are intended to represent a movable scale in which the frequencies are related according to the true ratios of the natural scale, and of which the keynote may have the pitch of any note of the equitempered scale. The last column gives the natural scale frequencies as percentages of those of the equitempered scale when both scales have the same keynote. These ratios hold regardless of what note of the equitempered scale is taken as the keynote of the natural scale. Thus if D=293.664 be taken as the keynote do of a natural scale, the re of such scale will make 0.99774 times as many vibrations as the equitempered E, and a pipe P to produce it must be longer by 0.226% than for the equitempered E. For the arrangement shown in Figs. 1 and 5, the ratios in the table show how much the pipe P must be lengthened or shortened, and hence the differences in the projections of the cam. For other pipes, the differences in cam projections will be proportional to the lengths of the pipes to which they belong.

Note	Equi-tempered	Note	Natural	Ratio
C	261.625	Do	261.625	100.00
C sharp	277.182	Do sharp	275.933	100.452
D	293.664	Re	294.328	99.774
D sharp	311.126	Me flat	310.074	100.339
E	329.627	Me	327.031	100.791
F	349.228	Fa	348.833	100.113
F sharp	369.994	Fa sharp	367.910	100.566
G	391.995	Sol	392.437	99.887
G sharp	415.304	La flat	413.432	100.453
A	440.000	La	436.042	100.907
A sharp	466.163	Ti flat	465.111	100.226
B	493.883	Ti	490.547	100.680

Figs. 6, 7, and 8 illustrate a somewhat different way of adjusting the effective length and pitch of an organ pipe by means of an associated movable section *pa*. It is here shown as applied to a square wooden pipe P*a*, though it is also applicable to circular metal pipes, or to pipes of any shape or material. As here shown, the movable section *pa* involves only one side of the pipe. Accordingly, the pipe has a longitudinal slot 50 of considerable width in one side, and the movable section *pa* is mounted to slide lengthwise in this opening, as a "filler," and includes sheet metal plates 51, 51 with their edges overlapping the edges of the pipe wall at both the sides and the inner end of the slot. Thus the plates 51, 51 not only form guide grooves that embrace the pipe wall at the sides of the slot 50, but also cover and close the opening that would otherwise exist between the inner end of the filler and the adjacent end of the slot 50 when the section *pa* is moved outward toward the end of the pipe, to increase its effective length.

For actuating the movable pipe wall section *pa*, there is shown in Fig. 6 a (rocker) lever 52 fulcrumed on a fixed pivot 53 and having one arm coacting with a pin 54 projecting outward from the pipe wall section *pa*. As here shown, the pin 54 is slidingly engaged in a transverse bore in a member 55 that is pivoted in the end of the lever 52, so as to rock relative to the lever about an axis parallel to the fulcrum 53. The lever 52 may be actuated by a cam Q on the shaft 40, which cam may be essentially like that shown in Fig. 5. The interposition of the lever 52 between the cam Q and the movable pipe section *pa* not only allows of magnifying or reducing the movement transmitted from the cam to the section *pa*, but allows pipes of different lengths to be properly adjusted with cams Q of identical size, by suitably varying the ratios of the lever arms. This may be done either by a different position of the fulcrum 53 in the lever, or by a different position of the cam shaft 40 relative to the fulcrum, or both. Obviously, with a suitably designed cam Q, the lever 52 may be of any class (1st, 2nd, or 3rd) most convenient and suitable for transmitting the cam action as desired, and may be used with a movable pipe section of the type shown in Figs. 1 and 5, as well as with that in Figs. 6, 7, and 8.

The pick-up arrangement shown in Fig. 6 differs from that of Fig. 1 in that it provides for fractionating the air pressure fluctuations in the pipe P for translation into electrical impulses, instead of simply translating such fluctuations en masse and undifferentiated: i. e., there are a plurality of pick-ups (here shown as resembling those in Figs. 1 and 2), each of which furnishes electrical impulses corresponding (predominantly or solely) to air-pressure fluctuations representing a certain part only of the pipe tone. In other words, the electrical pick-ups shown in Fig. 6 act to decompose the complex vibrations of the sound-devices P and to translate various relatively simple components thereof into electrical impulses of corresponding frequencies. Such selective action of the pick-ups can be secured in various ways, which may preferably be employed together and coordinated to give a narrower selectivity of effective electrical impulses, as illustrated in Fig. 6. If desired, the selection may be carried so far as to obtain electrical impulses corresponding substantially to a single pure partial of the pipe tone from each of the pick-up circuits in Fig. 6.

The explanation of various measures of selectivity illustrated in Fig. 6 will be rendered clearer by a preliminary exposition of the phenomena in an organ pipe P while it is being blown, as analytically illustrated in the diagram which is Fig. 9, whose length represents the length of the pipe. When such a pipe is blown, longitudinal air movements are set up in it, resulting in fluctuations or changes of pressure both above and below the surrounding atmospheric pressure level. Apparently irregular, the actual pressure changes may be resolved into a number of concurrent simple changes corresponding to the so-called "partials" of the pipe tone. There is little change of pressure at the "mouth" of the pipe when it is blown, or at its other (open) end, as at both of these places the air in the pipe can move freely in and out. Such points of maximum longitudinal air movement are termed "loops," while the points of zero or minimum longitudinal air movement are termed "nodes." Where there is maximum air movement (at the loops), the pressure changes are the least, and where there is minimum air movement (at the nodes), the pressure changes are the greatest. For various points along the length of a pipe, the relative magnitudes of the pressure changes corresponding to the fundamental, or first partial, of the pipe tone are as indicated by the displacement of the "1st" heavy line in Fig. 9 from the associated straight dot-and-dash base line, with a maximum at its middle. For the 2nd partial (or 1st overtone) of the pipe tone, the air pressure changes are as indicated by the "2nd" heavy line, with loops or points of no pressure variation where the heavy line crosses the dot-and-dash line, as well as at its ends, and with nodes or points of maximum pressure variation (which are always opposite in phase) at distances of ¼ of the pipe length from each of its ends. The pressure changes for the higher partials, up to the 10th, are indicated by similar heavy lines appropriately marked "3rd," "4th," "5th," etc. For a purpose that will appear hereinafter, dotted cross lines marked A, B, C, D, E, are drawn across the set of heavy lines at points corresponding to ⅓, ⅕, ⅙, ⅐, and 1/12 the pipe length from each end of the pipe as represented in the diagram, Fig. 9. Actually, the air movements and pressure fluctuations represented by all the heavy lines go on simultaneously in the pipe, all "superposed" on one another; but to represent these concurrent fluctuations in superposition, by a single line, would only be confusing. Usually, there are additional partials above the 10th, though the higher ones are of relatively less importance to the quality of the tone.

The following table shows the strength of each partial (up to and including the 10th) affecting a pick-up located at various points along a pipe such as shown in Fig. 6. In this table, the locations of the pick-ups are given in percentages of the pipe length measuring from one end, and the strengths of each partial are stated in percentages of its strength where it is the strongest. It will be understood that measuring from the other end of the pipe, the values of the odd-numbered partials would be the same as given in the table, and those of the even-numbered partials would be reversed as compared with those given. The table is useful in determining the best locations of pick-ups for any desired design of instrument.

Points of pipe	Strengths of partials at points indicated									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
1	3	6	9	12	16	19	22	25	28	31
2	6	12	19	25	31	37	42	48	54	59
3	9	19	28	37	45	54	61	68	75	81
4	12	25	37	48	59	68	77	84	90	95
5	16	31	45	59	71	81	89	95	99	100
5⅚	17	34	50	64	77	87	94	98	100	98
6	19	37	54	68	81	90	97	100	99	95
6¼	20	38	56	71	83	92	98	100	98	92
7	22	43	61	77	89	97	100	98	92	81
7½	22	43	62	78	90	97	100	97	90	78
8	25	48	68	84	95	100	98	90	77	59
8⅓	26	50	71	87	97	100	97	87	71	50
9	28	54	75	90	99	99	92	77	56	31
10	31	59	81	95	100	95	81	59	31	0
11	34	64	86	98	99	88	66	37	3	−31
11⅛	34	64	87	98	98	87	64	34	0	−34
12	37	68	90	100	95	77	43	12	−25	−59
12½	38	71	92	100	92	71	38	0	−38	−71
13	40	73	94	100	89	64	28	−12	−51	−81
14	43	77	97	98	81	48	6	−37	−73	−95
14⅜	43	78	97	97	78	43	0	−43	−78	−97
15	45	81	99	95	71	31	−16	−59	−89	−100
16	48	84	100	90	59	12	−37	−77	−98	−95
16⅔	50	87	100	87	50	0	−50	−87	−100	−87
17	51	88	100	84	45	−6	−56	−90	−99	−81
18	54	90	99	77	31	−25	−73	−98	−93	−59
18¾	56	92	98	71	19	−38	−83	−100	−83	−38
19	56	93	98	68	16	−43	−86	−100	−79	−31
20	59	95	95	59	0	−59	−95	−95	−59	0
21	61	97	92	48	−16	−73	−100	−84	−34	31
21¾	63	97	90	43	−22	−78	−100	−78	−22	43
22	64	98	88	37	−31	−84	−99	−68	−6	59
22⅔	64	98	86	34	−34	−87	−98	−64	0	64
23	66	99	83	25	−45	−93	−94	−48	22	81
24	68	100	77	12	−59	−98	−84	−25	48	95
25	71	100	71	0	−71	−100	−82	0	71	100
26	73	100	64	−12	−81	−98	−53	25	88	95
27	75	99	56	−25	−89	−93	−34	48	98	81
27⅞	77	98	50	−34	−94	−87	−17	64	100	64
28	77	98	48	−37	−95	−84	−12	68	100	59
28¼	78	97	43	−43	−97	−78	0	78	97	43
29	79	97	40	−48	−99	−73	9	84	94	31
30	81	95	31	−59	−100	−59	31	95	81	0
31	83	93	22	−68	−99	−43	51	99	61	−31
32	84	90	12	−77	−95	−25	68	98	37	−59
33	86	88	3	−84	−89	−6	83	90	9	−81
33⅓	87	87	0	−87	−87	0	87	87	0	−87
34	88	84	−6	−90	−81	12	93	77	−19	−95
35	89	81	−16	−95	−70	31	99	59	−45	−100
35⅝	90	78	−23	−97	−62	43	100	43	−62	−97
36	91	77	−25	−98	−59	47	100	37	−68	−95
37	92	73	−34	−100	−45	67	96	12	−86	−81
38	93	68	−43	−100	−31	77	88	−12	−97	−59
38⅜	94	64	−50	−98	−17	87	77	−34	−100	−33
39	94	64	−51	−98	−16	88	75	−37	−100	−31
40	95	59	−58	−95	90	95	59	−59	−95	0
41	96	54	−66	−90	16	99	40	−77	−83	31
42	97	48	−73	−84	31	100	19	−90	−64	59
42⅝	97	42	−78	−78	43	97	0	−97	−43	78
43	98	43	−79	−77	45	97	−3	−98	−40	81
44	98	37	−84	−68	59	90	−25	−100	−12	95
45	99	31	−89	−59	71	81	−45	−95	16	100
46	99.2	25	−93	−48	81	68	−64	−84	43	95
47	99.6	18	−96	−37	89	54	−79	−68	66	81
48	99.8	12	−98	−25	95	37	−90	−48	84	59
49	99.9	6	−99	−12	99	19	−98	−25	96	31
50	100	0	−100	0	100	0	−100	0	100	0

Recurring now to Fig. 6, it will be seen that pick-ups of the general type shown in Figs. 1 and 2 are located at points of the pipe P corresponding to the cross-lines A, B, C, D, E, in Fig. 9: i. e., at distances of ⅓, ⅕, ⅙, ⅐, and 1/12 the pipe length from each end of the pipe. These pick-ups are accordingly distinguished as **20A**, **20A**, etc. The corresponding pick-ups in opposite ends of the pipe P cooperate, and for this purpose have their condenser plates interconnected. The conjugate pick-ups **20A**, **20A** have condenser plates **33A**, **33A** at the same (outer) side thereof inter-connected or coupled together by a conductor **61**, and also have additional plates **33*a***, **33*a*** at their opposite sides, interconnected or coupled by a conductor **62**. The conjugate pick-ups **20B**, **20B** have plates **33B**, **33B** at the same side thereof interconnected or coupled by a conductor **63**; the pick-ups **20C**, **20C** have plates **33C**, **33C** at their opposite sides, coupled by a conductor **64**; the pick-ups **20D**, **20D** have plates **33D**, **33D** at the same side thereof, coupled by a conductor **65**; and the pick-ups **20E**, **20E** have plates **33E**, **33*e*** at their opposite sides, coupled

by a conductor 66. For brevity, a coupling conductor like 61, etc. is characterized as a direct coupler, and one like 62, etc. as a reversed coupler. All of the diaphragms 30 in Fig. 6 are shown connected to a conductor 21 that corresponds to one side of the tone-circuit 21 in Fig. 1.

Assuming that the diaphragms 30 of all the pick-ups in Fig. 6 are equally responsive to pressure fluctuations of all frequencies in the musical range, as suggested in connection with Figs. 1 and 2, the selectivity of the coupled pick-up arrangements just described will be clear from the locations of various loops or points of no pressure change in Fig. 9, and from observing that in the opposite ends of the pipe the even-numbered partials are in opposite phase and the odd-numbered partials are in like phase.

At the coupled pick-ups 20A, 20A, the 3rd, 6th, 9th, 12th, and 15th partials have loops or points of no pressure change, and so are of no effect in either of the couplers 61 or 62. As the even-numbered partials are in opposite phase at these pick-ups 20A, 20A, the resulting electrical impulses in the direct coupler 61 oppose and cancel one another, and only the impulses from the 1st, 5th, and 7th partials remain. At these same pick-ups 20A, 20A, furthermore, the impulses from the 1st, 5th, 7th, 11th, and 13th partials oppose one another and cancel out in the reversed coupler 62, leaving only the impulses from the 2nd, 4th, 8th, 10th, and 14th partials. At the coupled pick-ups 20B, 20B, the 5th and 10th partials have loops or points of no pressure change, and the impulses from the even-numbered partials oppose one another and cancel out in the direct coupler 63, leaving only those from the 1st, 3rd, 7th, 9th, and 11th partials. At the coupled pick-ups 20C, 20C, the 6th and 12th partials have loops or points of no pressure change, and impulses from the odd-numbered partials oppose one another and cancel out in the reversed coupler 64, leaving only those from the 2nd, 4th, 8th, and 10th partials. At the coupled pick-ups 20D, 20D, the 7th partial has loops or points of no pressure change, and the impulses from the even-numbered partials oppose one another and cancel out in the direct coupler 65, leaving only those from the 1st, 3rd, 5th, 9th, and 11th partials. At the coupled pick-ups 20E, 20E, the 12th partial has loops or points of no pressure change, and impulses from the odd-numbered partials oppose one another and cancel out in the reversed coupler 66, leaving only those from the 2nd, 4th, 6th, 8th, and 10th partials.

It will be seen, therefore, that each of the couplers 61, 62, 63, 64, 65, and 66 carries electrical impulses corresponding to but a minor and comparatively simple fraction of the whole pipe tone: viz., only three to five of its component partials, and but one or two of the lower partials, which are generally the most important. Thus these fractions are at once adapted for synthesis in various proportions to produce tones of different characters from that of the pipe itself as directly heard. If desired, however, these fractions can be further simplified or purified, even to a point where each coupler 61, 62, 63, 64, 65, 66 actually furnishes impulses to produce only a single partial. In doing this, it is generally very desirable to eliminate impulses corresponding to the inharmonious 7th partial, in so far as they have not already been eliminated, but it is generally unnecessary to eliminate impulses corresponding to partials which are octaves of the one particularly wanted, since these octaves serve to brighten all composite tones in which they are included.

One way of obtaining greater selectivity is to use vibratile members or diaphragms 30 that are selectively responsive or resonant to the desired frequencies of pressure fluctuation, instead of being equally responsive to all frequencies. This method is most effective in eliminating frequencies that are widely different from that desired, but are not octaves of it. Another method is to interpose in the electrical connections from the couplers 61, 62, 63, 64, 65, 66 suitable inductances and resistances that will let the desired impulses pass freely, but dampen or block out the others. Both of these methods (selective pressure response and electrical damping) may be combined in the same pick-up circuit 21, Fig. 6. As shown in Fig. 6, the vibratile pressure-responsive members 30, which are selectively responsive to different component parts of the pipe tone, are located at various different points in the length of the pipe P where they are severally exposed to fluctuations of air pressure in the pipe corresponding to different parts of the tone, including the part to which each member 30 is resonant, as well as other components. As already mentioned, there is substantially a loop of minimum pressure change at each member 30 for part of the pipe tone, while the selective resonance of each member 30 includes only a portion of the pressure fluctuations corresponding to the rest of the pipe tone. And thus the pipe tone is decomposed and translated, by the members 30 and the coacting parts 33, into electrical impulses of frequencies corresponding to various component parts of this tone. By these methods, the substantially pure 1st, 2nd, 3rd, 4th, 5th, and 6th partials may be taken from the couplers 61, 62, 63, 64, 65, and 66 respectively.

Fig. 6 shows electric circuits and arrangements somewhat more elaborate than those in Fig. 1, but essentially similar, for combining or synthesizing the electrical impulses derived from the various components of the complex vibrations of the sound-producing devices P in a plurality of different combinations of frequencies, and in various relative strengths, and for converting them into complex playing tones of a plurality of correspondingly different tonal qualities for each fundamental pitch. To avoid repetitive description, various parts and features are marked with the same reference characters as in Fig. 1, with an added letter where such distinction appears necessary. As here shown, all the diaphragms 30A, 30B, etc. are connected in parallel to one side of the playing circuit 21 for the pipe P, as already mentioned, and all the couplers 61, 62, etc. are connected in parallel to the other side of this circuit 21, through lead-branches 70 thereof. The branches 70 for corresponding circuits 61 of all the pipes P in each division of the instrument may be connected to a corresponding trunk-wire or bus-bar 71 (that appears in section); those for corresponding circuits 62 to a corresponding wire or bar 72; and so on. As shown in Fig. 6, there are a plurality of groups of the leads 70 and bus-bars 71, 72, etc. The bus-bar 71 of each group are connected through leads 77 including serially connected adjustable resistances 78 and inductances 79 to a common trunk-wire 80, which is in turn connected to the circuit-wire 21 through a plurality of parallel leads, each including a volume-control resistance 81 and a stop-switch 82. The resistances and inductances 78, 79 pertaining to each group serve

for eliminating electrical impulses corresponding to undesired partials, and for proportioning the retained partials to give the desired composite tone-quality for the notes from all pipes in the corresponding division of the instrument. After the resistances 81 have been calibrated, the tone-quality and loudness of all notes from a given division of the instrument are determined by closing one or another stop-switch 82: e. g., closing one or another of the stop-switches 82 for one group may produce loud, medium, or low diapason tones; closing one or another of the stop-switches 82 for another group may produce loud, medium, or soft violin tones; and so on. In Fig. 6, the circuit 24 is shown as consisting of bus-bars or trunk-wires (shown in section) that extend throughout the instrument, for the connection of all the playing circuits 21 thereto. The circuit 26 is similarly shown as consisting of bus-bars or trunk wires (shown in section) that extend throughout the instrument, or such divisions or other portions thereof as are served by the (common) sound device S with its amplifier X and variable transformer coupling 27, for general loudness-control.

Fig. 10 is a more comprehensive diagram of an instrument embodying my invention, showing a row or series of pipes P equipped with pairs of conjugate pick-ups 20 such as shown in Fig. 6, located at points ⅓ and ⅕ its length from each end of each pipe, these particular locations being of course merely illustrative, though advantageous for certain purposes. The pick-ups 20 for the upper ends of the pipes P are intended to be double, like the pick-up 20A for the right-hand end of the pipe P in Fig. 6, while the pick-ups 20 for the lower ends of the pipes P are single, like the pick-ups 20B in Fig. 6. As here shown, each pick-up 20 is connected to a corresponding trunk-wire 71 (corresponding to that so marked in Fig. 6) through a calibrating resistance 85. By making the resistances 78 or the inductances 79 in the leads from the two opposite sides of the double pick-ups of widely different values (i. e., very low in the one case, and very high in the other), either the corresponding odd-numbered partials or even-numbered partials can be virtually suppressed, or made so weak as to be insignificant. In other respects, the various parts and features shown in Fig. 10 are like those in Fig. 6, and are marked with the same reference characters, to dispense with repetitive description. It will be observed, however, that three manuals are indicated, each connected to the output circuit 26 of the sound device S through independent resistances 27 adjustable for volume control; also, that for one of the manuals there is a set of resistances 78 and 81 that may be manually adjusted by the organist to give any tone qualities that he may desire.

From the foregoing description, and particularly from Figs. 1, 6, and 10, it will be apparent that an instrument suitably embodying my invention permits of playing in various intonations and tonal qualities with a much smaller number of sound-devices and length-adjustments thereof than of available pitches and tonal qualities.

I claim as my invention, and desire to secure Letters Patent of the United States:

1. A musical instrument comprising, in combination, a series of sound-producing devices whose pitches vary with their effective lengths; length-adjusting means associated with the several sound-producing devices for variously adjusting their individual effective lengths and pitches; and operating means for said length-adjusting means comprising definitely correlated individual length-selective actuating means associated with the respective length-adjusting means of the several sound-producing devices, and coacting with said length-adjusting means to correlate the relative lengths and pitches of the sound-producing devices to various concurrent-pitch correlations, severally corresponding to different musical scale intonations.

2. A musical instrument as set forth in claim 1 wherein said length-adjusting means adjust the various sound-producing devices to effective lengths which produce notes of the equitempered scale intonation, and also to effective lengths which produce notes of natural harmonic scales of various different intonations; and said operating means coact with said length adjusting means to correlate the relative lengths and pitches of said sound-producing devices in correspondence to the equitempered scale intonation, and also, alternatively, to various natural harmonic scale intonations.

3. A musical instrument comprising, in combination, a series of pipes; length-adjusting means associated with said pipes for variously adjusting their individual effective lengths and pitches; and operating means for said length-adjusting means comprising definitely correlated individual length-selective actuating means associated with the respective length-adjusting means of the several pipes, and coacting with said length-adjusting means to correlate the relative lengths and pitches of the pipes to various concurrent-pitch correlations, severally corresponding to different musical scale intonations.

4. A musical instrument as set forth in claim 3 wherein the operating and length-selective actuating means comprise cams associated with the respective length-adjusting means.

5. In a musical instrument having a series of sound-producing devices which produce complex vibrations and whose pitches vary with their effective lengths, and electric pick-ups for translating various components of the complex vibrations of said devices into electrical impulses of corresponding frequencies; the combination with said pick-ups and said sound-producing devices of length-adjusting means associated with the several sound-producing devices for variously adjusting their individual effective lengths and pitches; operating means for said length-adjusting means comprising definitely correlated length-selective actuating means associated with the respective length-adjusting means of the several sound-producing devices, and coacting with said length-adjusting means to correlate the relative lengths and pitches of the sound-producing devices to various concurrent-pitch correlations, severally corresponding to different musical scale intonations; and means for combining the electrical impulses derived as aforesaid from the various components of the complex vibrations of the sound-producing devices in a plurality of combinations of frequencies and relative strengths, convertible into complex playing tones of a plurality of tonal qualities for each fundamental pitch, so as to permit playing in various intonations and tonal qualities with a much smaller number of sound devices and length-adjustments thereof than of pitches and tonal qualities.

6. In an organ, the combination with a series of pipes of complex tones; length-adjusting means associated with said pipes for variously

adjusting their individual effective lengths and pitches; and operating means for said length-adjusting means comprising definitely correlated individual length-selective actuating means associated with the respective length-adjusting means of the several pipes, and coacting with said length-adjusting means to correlate the relative lengths and pitches of the pipes to various concurrent-pitch correlations, severally corresponding to different musical scale intonations; electric pick-ups associated with each pipe and severally responsive to fluctuations of air pressure in the pipe corresponding to different parts of the pipe tone, for decomposing and translating the pipe tone into electrical impulses of frequencies corresponding to the several parts thereof aforesaid; and means for combining these electrical impulses in a plurality of combinations of frequencies and relative strengths, convertible into complex playing tones of a plurality of tonal qualities for each fundamental pitch, so as to permit playing in various intonations and tonal qualities with a much smaller number of pipes and pipe-length adjustments than of pitches and tonal qualities.

7. In an organ, the combination with a series of pipes of complex tones; length-adjusting means associated with said pipes for variously adjusting their individual effective lengths and pitches; and operating means for said length-adjusting means comprising definitely correlated individual length-selective actuating means associated with the respective length-adjusting means of the several pipes, and coacting with said length-adjusting means to correlate the relative lengths and pitches of the pipes to various concurrent pitch correlations, severally corresponding to different musical scale intonations; vibratile members located at a plurality of points in the length of each pipe and severally responsive to fluctuations of air pressure in the pipe corresponding to different parts of the pipe tone; means coacting with said members to translate their vibrations in response to the different fluctuations of air pressure in the pipes into electrical impulses of corresponding frequencies; and means for combining these electric impulses in a plurality of combinations of frequencies and relative strengths, convertible into complex playing tones of a plurality of tonal qualities for each fundamental pitch, so as to permit playing in various intonations and tonal qualities with a much smaller number of pipes and pipe-length adjustments than of pitches and tonal qualities.

8. The combination with a system for synthesizing impulses of different frequencies in various relative strengths and converting the resultants into sounds, of a wind pipe of complex tone, and a plurality of pressure-actuated electric pickups with connections for feeding their outputs to said system, the several pickups comprising selectively resonant vibratile pressure-responsive means that are resonant, respectively, to different component parts of the pipe tone, and are located, lengthwise of the pipe, where each of them is exposed to fluctuations of the wind pressure that include the part of the pipe tone to which it is resonant and also other component parts of the pipe tone, whereby the complex pipe tone is decomposed and translated into electrical impulses of frequencies corresponding to various component parts of said tone, and said impulses are combined in various different relative strengths and reconverted into tones of correspondingly different qualities.

9. The combination with a system for synthesizing impulses of different frequencies in various relative strengths and converting the resultants into sounds, of a wind pipe of complex tone, and a plurality of pressure-actuated electric pickups with connections for feeding their outputs to said system, said pickups comprising selectively resonant vibratile pressure-responsive means located at different points in the length of the pipe where they are severally exposed to fluctuations of air pressure in said pipe corresponding to different parts of its tone, while their respective resonances each include only a portion of the pressure fluctuations to which they are thus respectively exposed, whereby the complex pipe tone is decomposed and translated into electrical impulses of frequencies corresponding to the several parts thereof, and said impulses are combined in various different relative strengths and reconverted into tones of correspondingly different qualities.

10. The combination with a wind pipe of complex tone, and electric pickup means associated with said pipe, of selectively resonant vibratile pressure-responsive means coacting with said electric pickup means and exposed to the fluctuations of air pressure in said pipe at a point thereof where there is substantially a loop of minimum pressure change for the fluctuations corresponding to part of the pipe tone, while the selective resonance of said pressure-responsive means includes only a portion of the pressure fluctuations corresponding to the rest of said tone.

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