April 24, 1934. L. HAMMOND 1,956,350

ELECTRICAL MUSICAL INSTRUMENT

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Fig. 1.

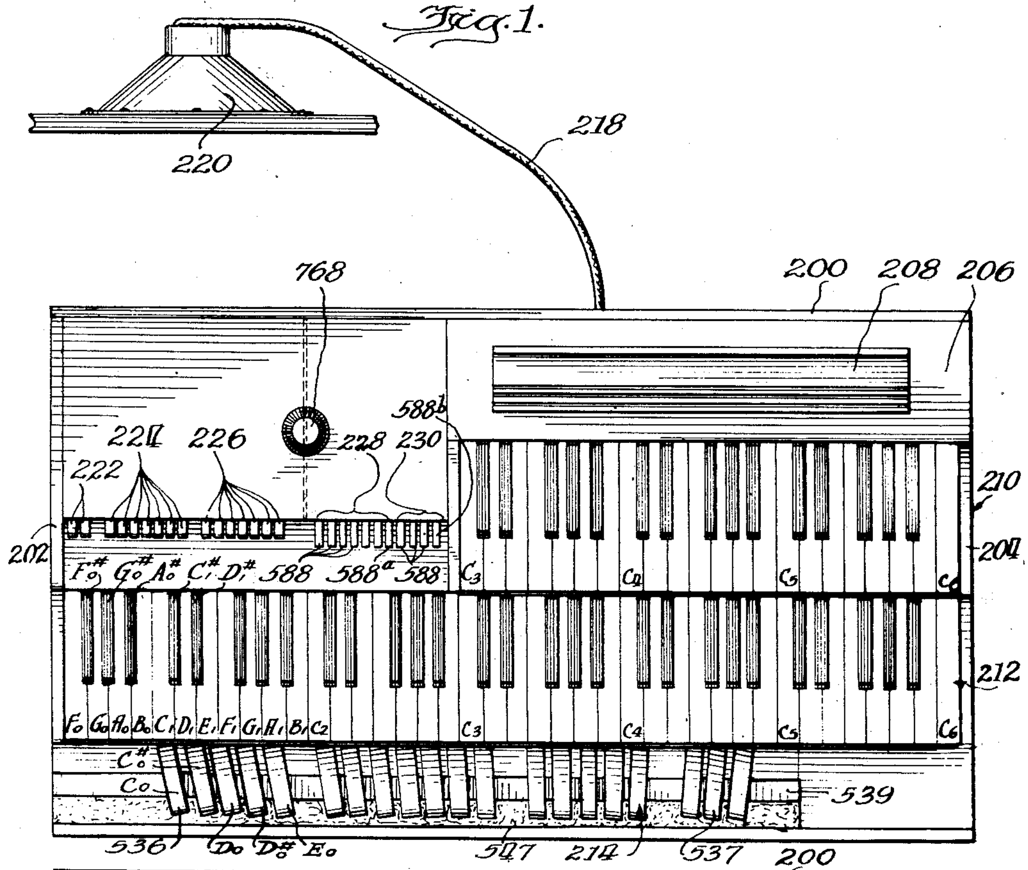
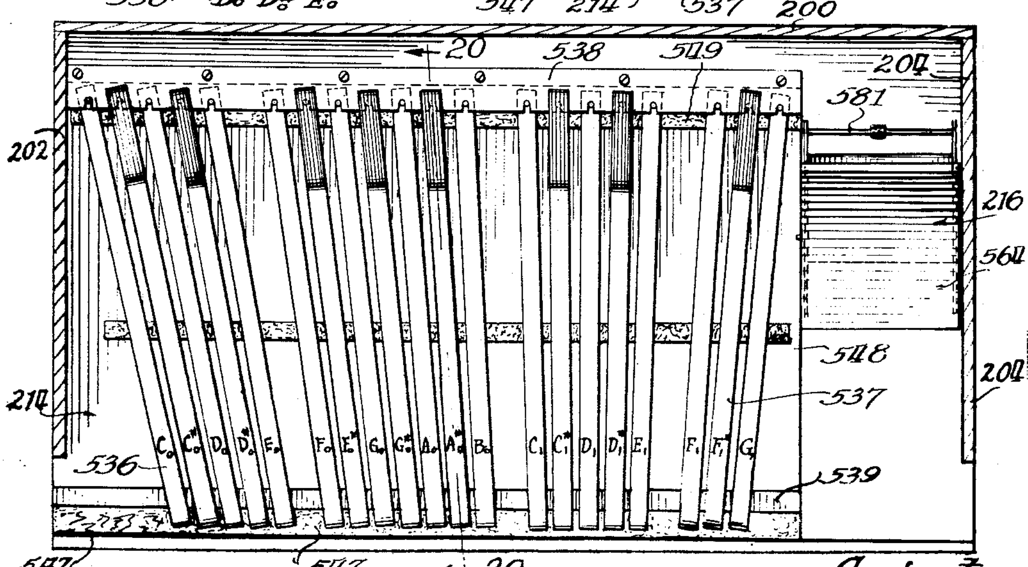


Fig. 2.



Inventor:
Laurens Hammond
Williams, Bradbury, McCaleb & Hinkle
Attys.

April 24, 1934. L. HAMMOND 1,956,350

ELECTRICAL MUSICAL INSTRUMENT

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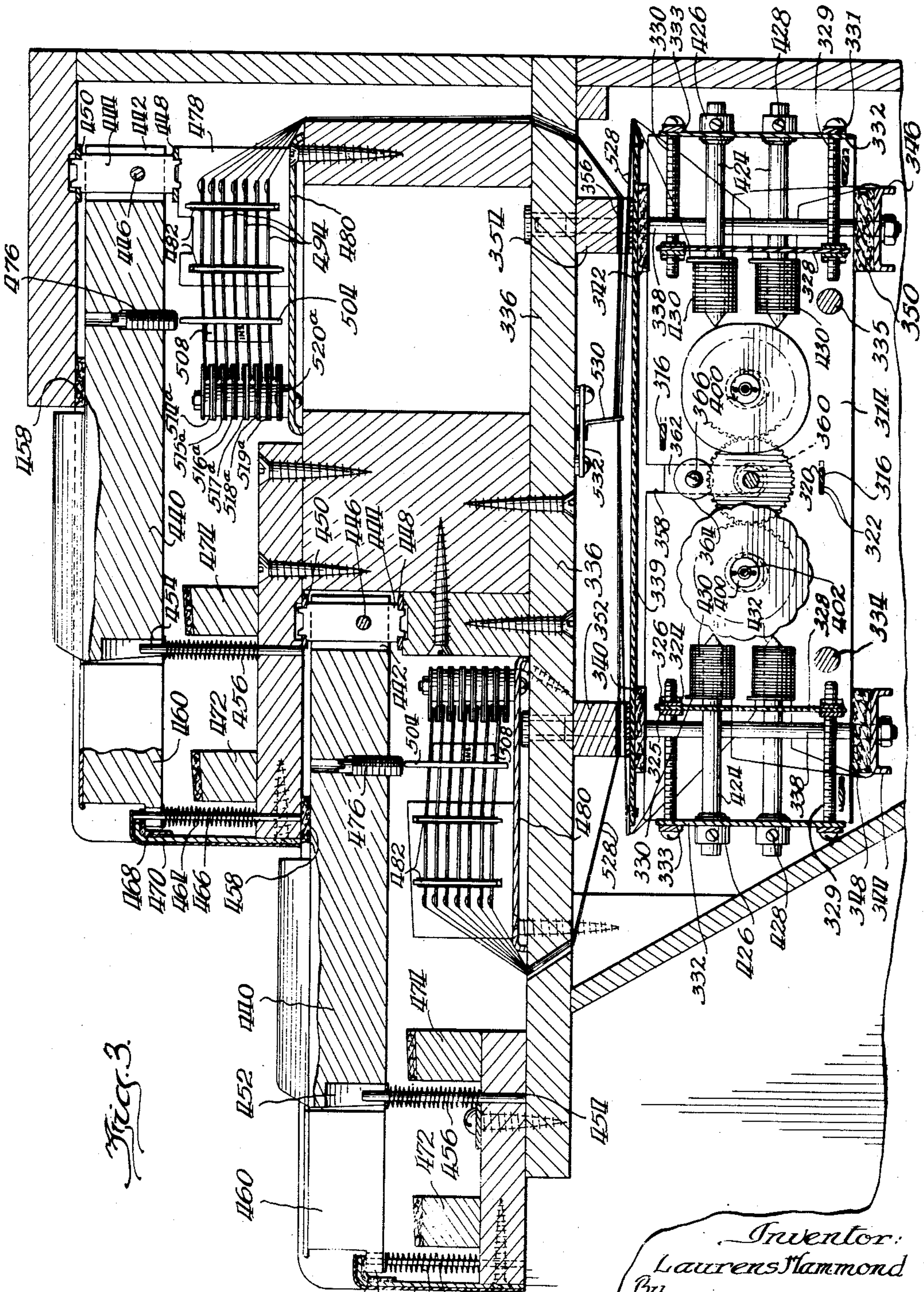

Fig. 3.

Inventor:
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle Attys.

ELECTRICAL MUSICAL INSTRUMENT

Filed Jan. 19, 1934 18 Sheets-Sheet 3

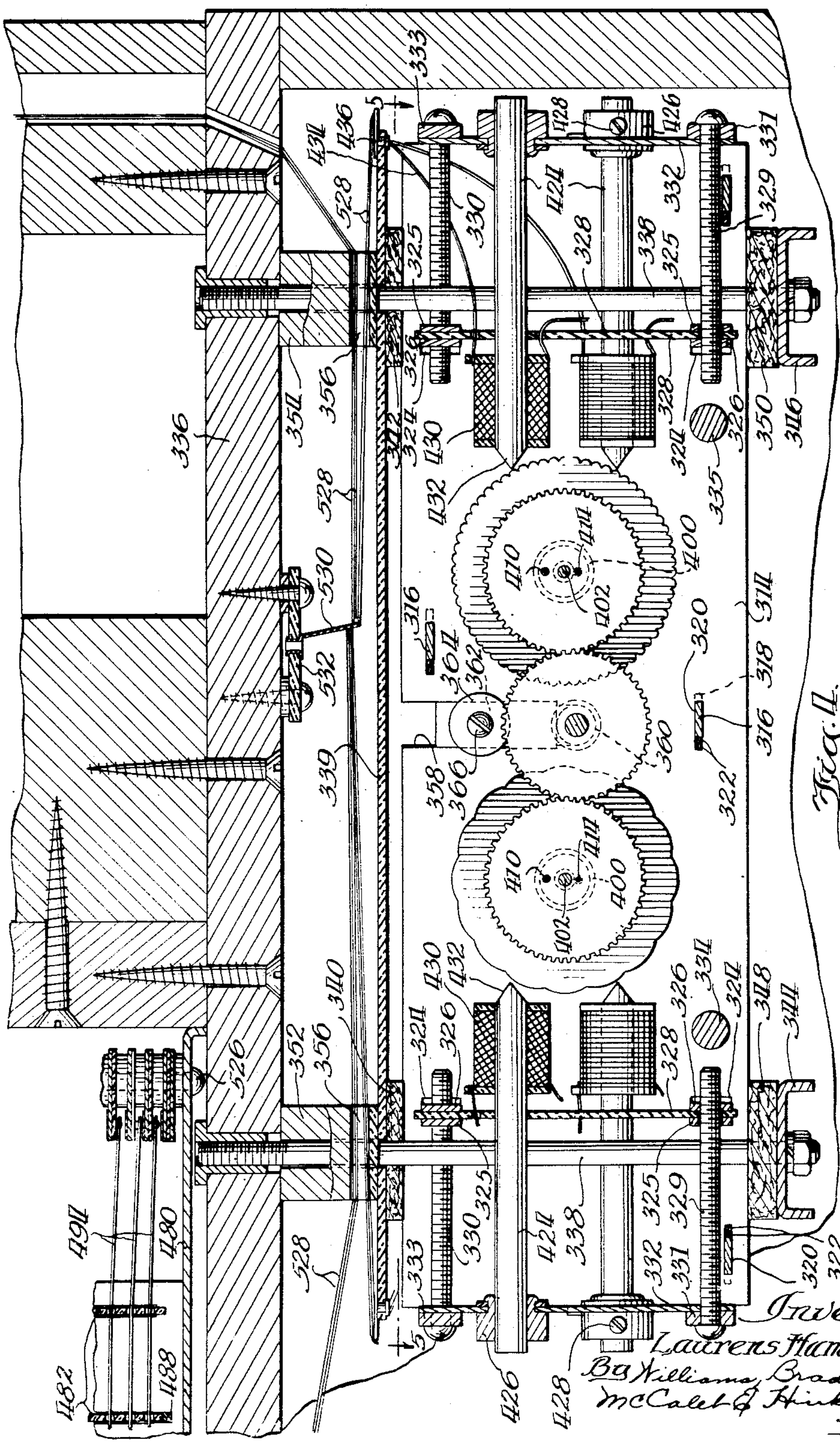

Fig. 4.

Inventor:
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle
Attys.

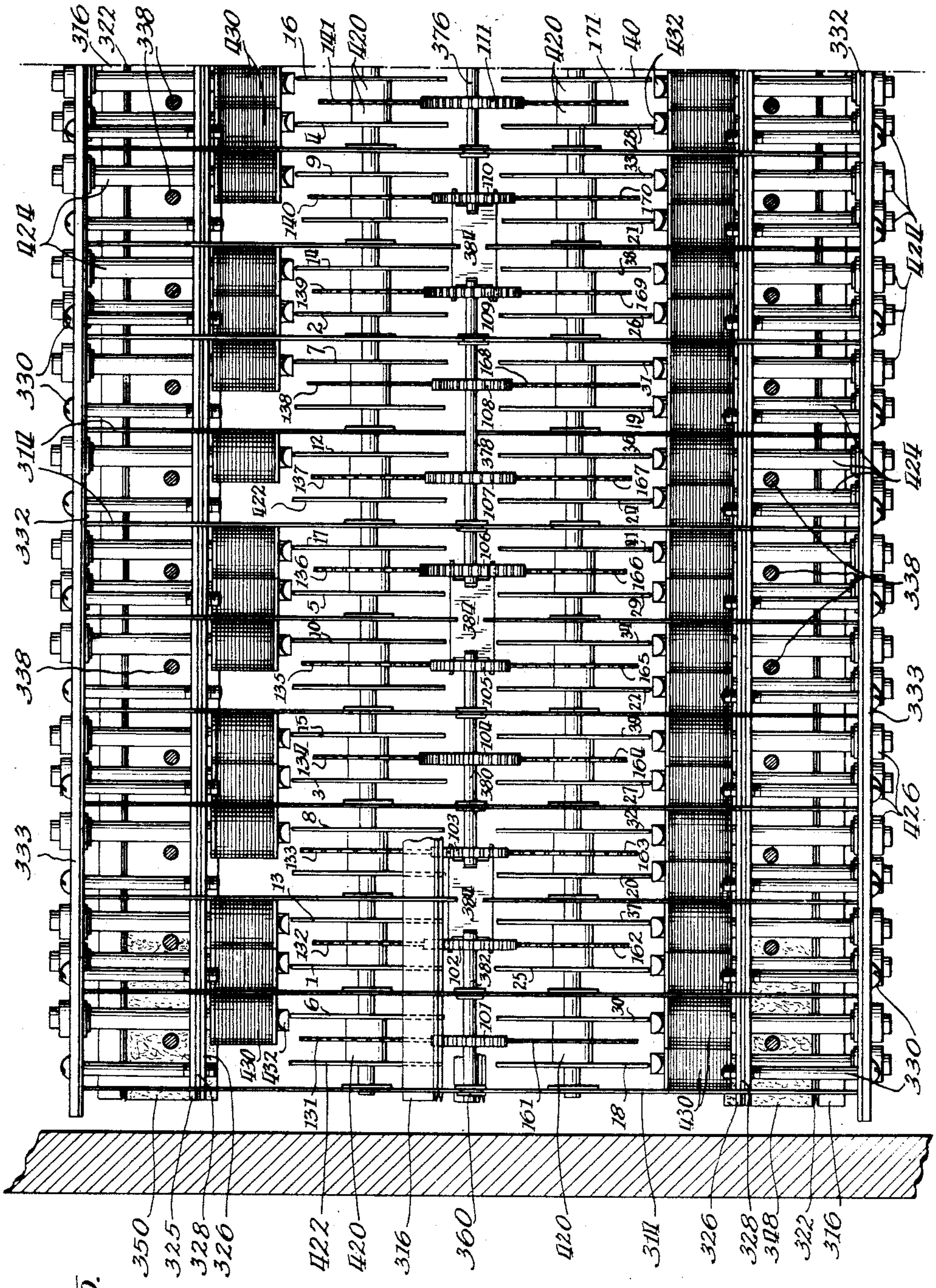

Fig. 5.

Inventor:
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle
Attys.

April 24, 1934. L. HAMMOND 1,956,350

ELECTRICAL MUSICAL INSTRUMENT

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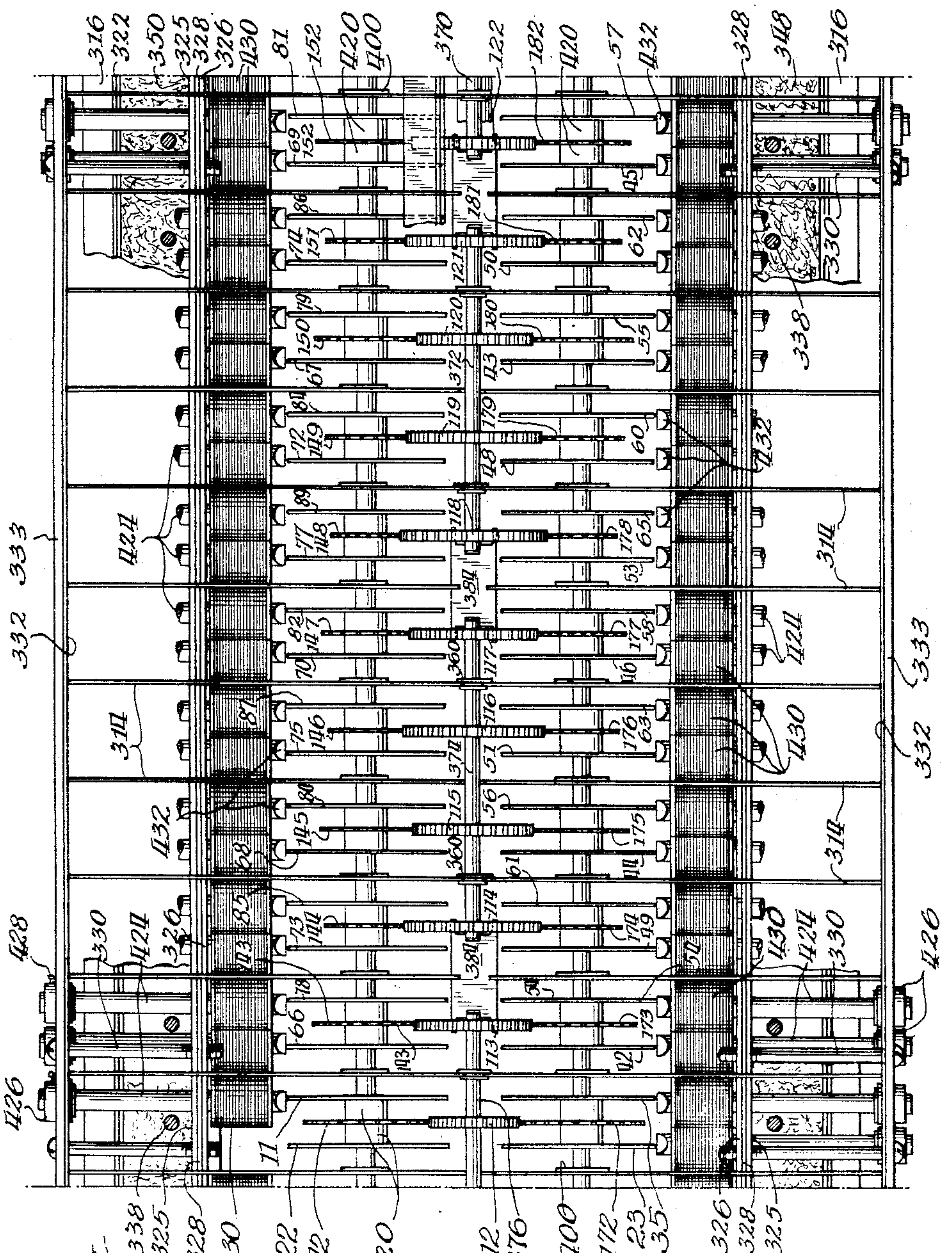

Fig. 5a

Inventor:
Laurens Hammond
By
Williams, Bradbury, McCaleb & Hinkle
Attys.

April 24, 1934.

L. HAMMOND

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18 Sheets-Sheet 6

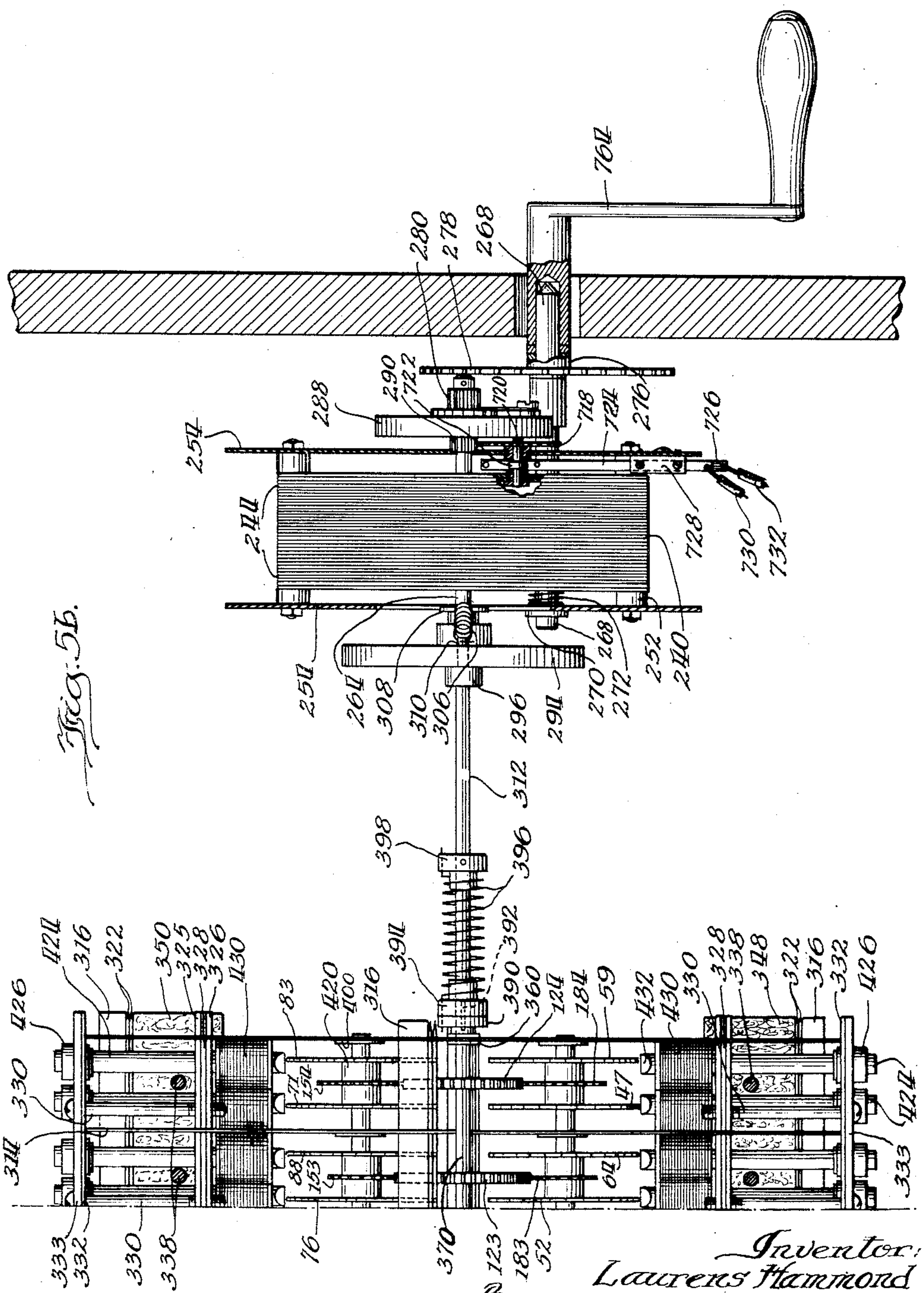

Fig. 56.

Inventor:
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle
Attys.

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ELECTRICAL MUSICAL INSTRUMENT

Filed Jan. 19, 1934 18 Sheets-Sheet 7

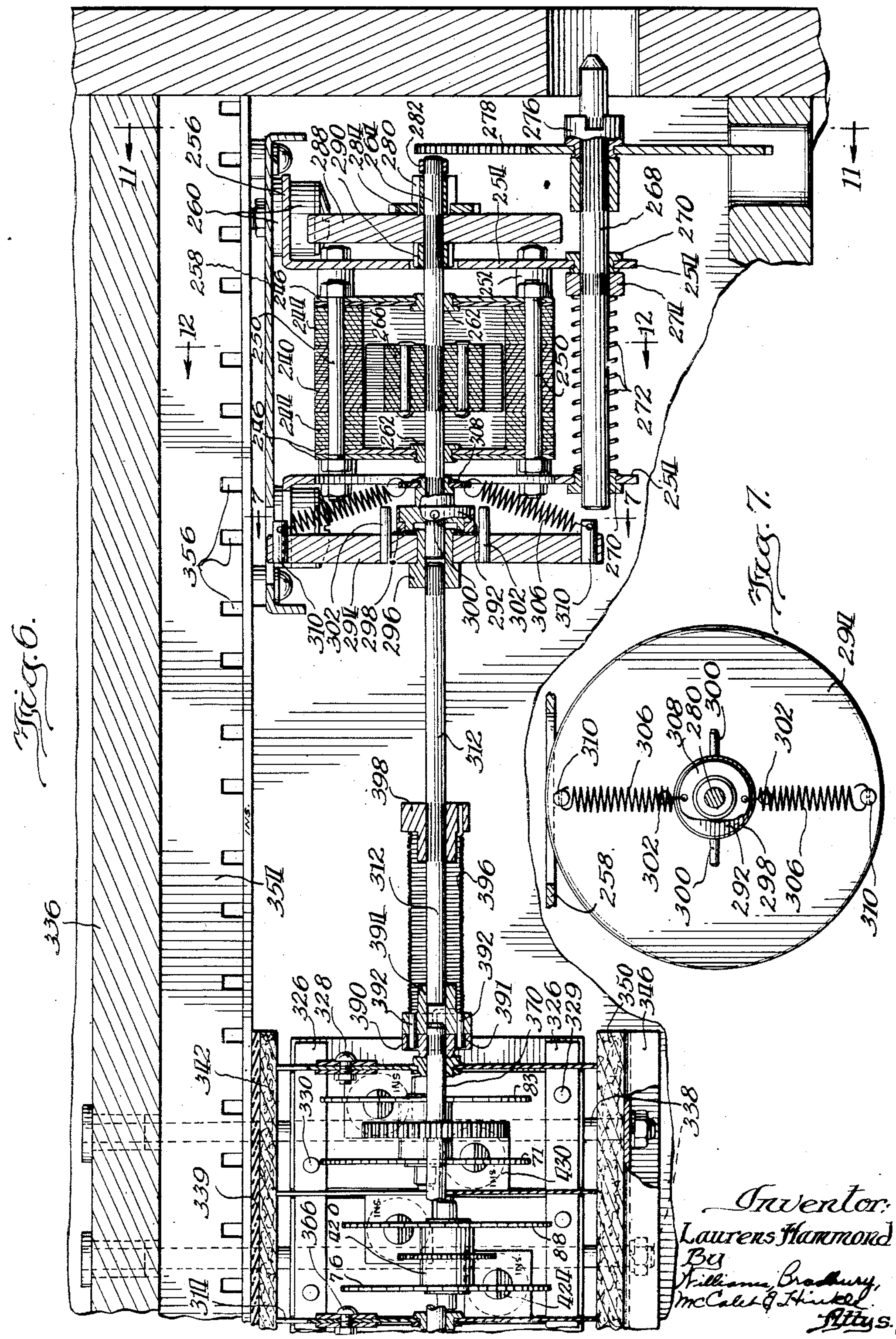
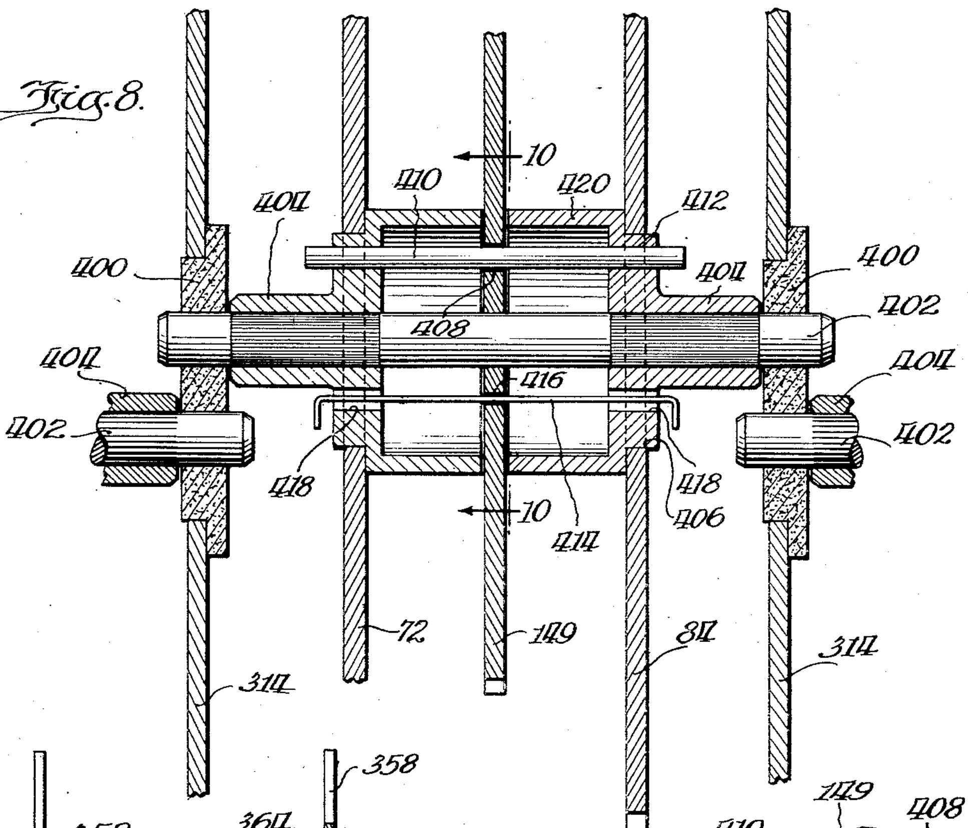


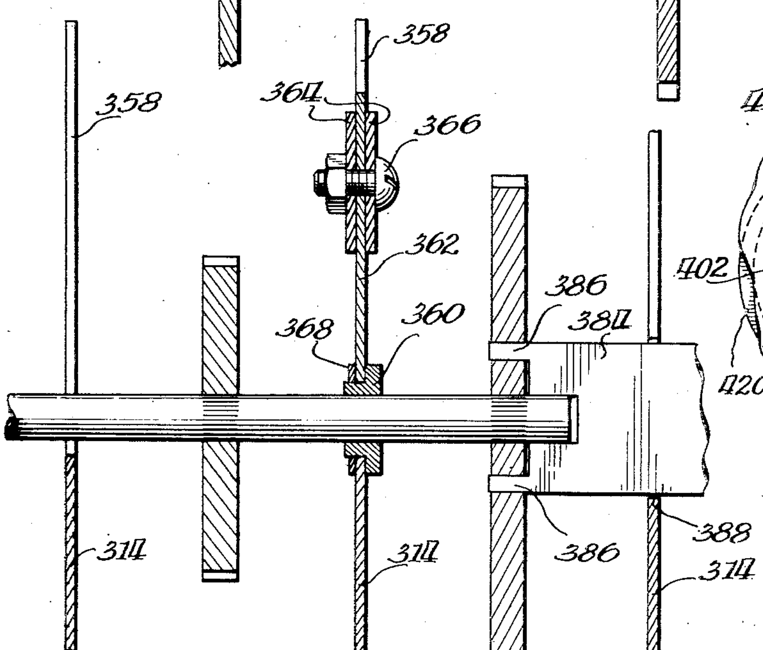
Fig. 6.

Fig. 7.

Inventor:
Laurens Hammond
By
Williams, Bradbury,
McCaleb & Hinkle
Attys.

Fig. 8.





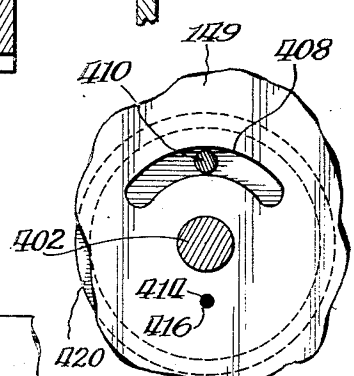


Fig. 10.

Fig. 9.

Inventor:
Laurens Hammond
By
Williams, Bradbury, McCaleb & Hinkle
Attys.

April 24, 1934. L. HAMMOND 1,956,350

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Fig. 11

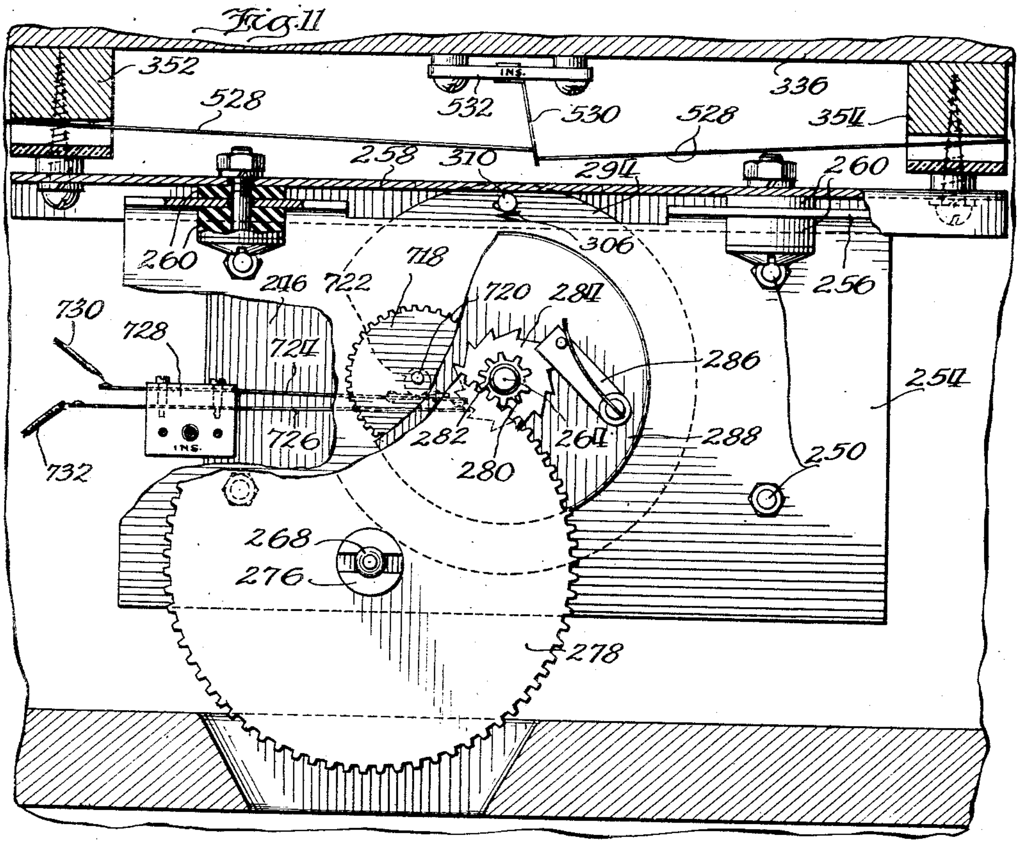
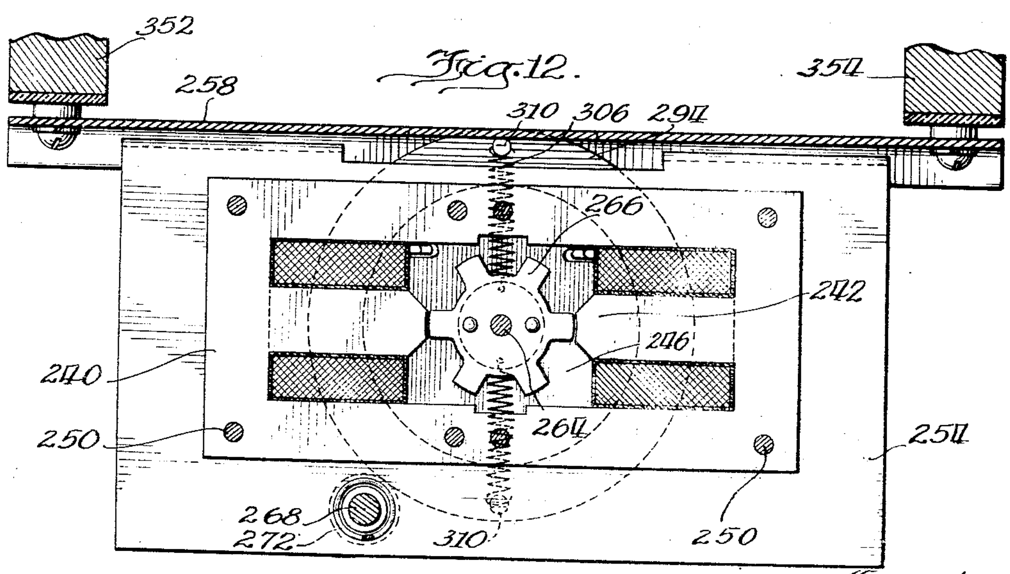


Fig. 12.



Inventor:
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle
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ELECTRICAL MUSICAL INSTRUMENT

Filed Jan. 19, 1934 18 Sheets-Sheet 10

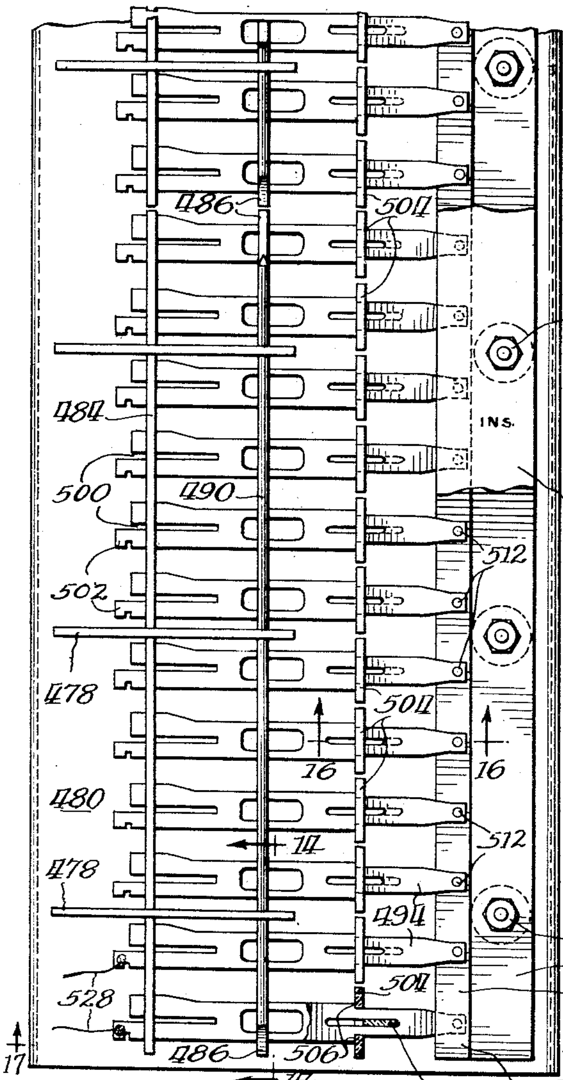
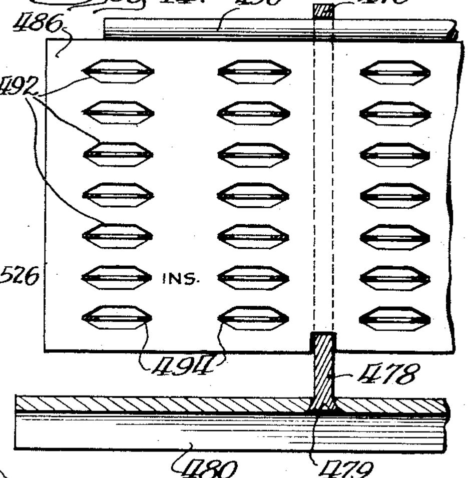


Fig. 13

Fig. 14.



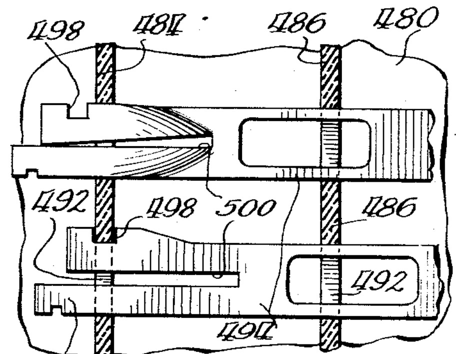
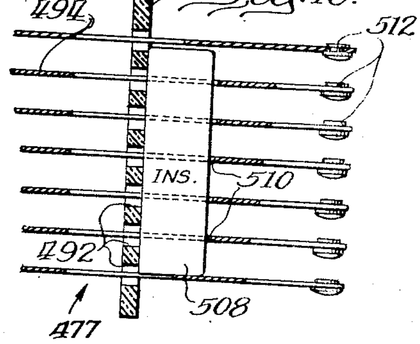


Fig. 15.

Fig. 16.



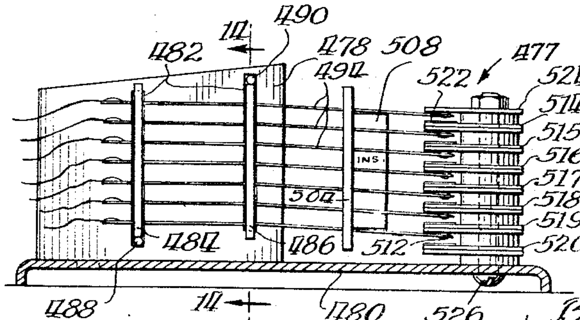


Fig. 17.

Inventor:
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle
Attys.

April 24, 1934. L. HAMMOND 1,956,350

ELECTRICAL MUSICAL INSTRUMENT

Filed Jan. 19, 1934 18 Sheets-Sheet 11

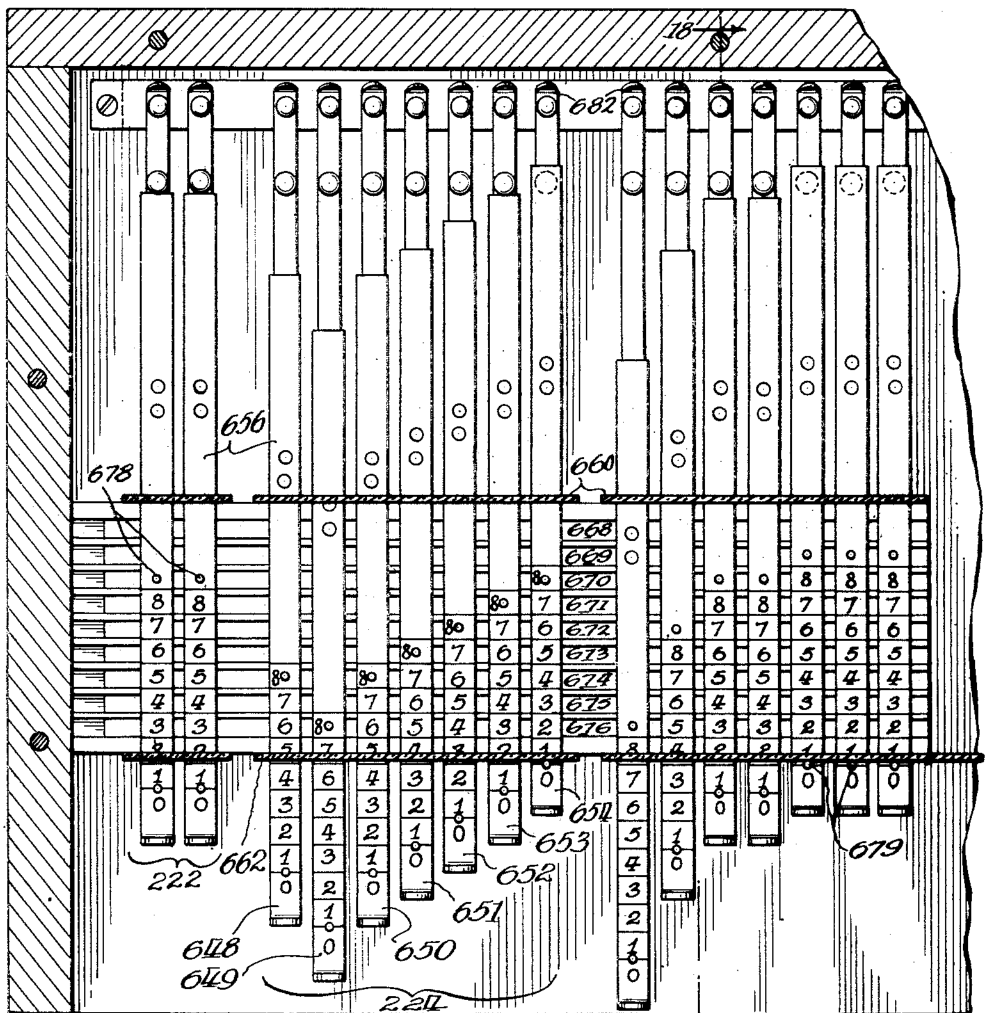


Fig. 19.

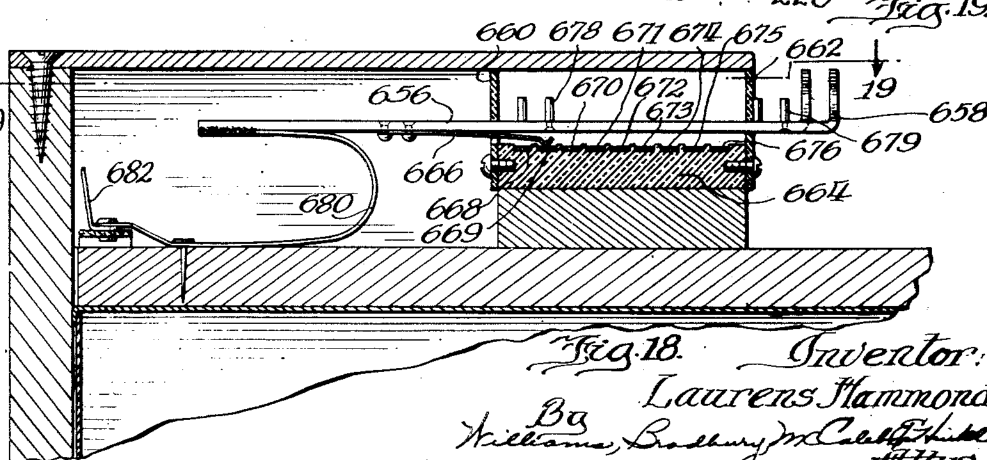
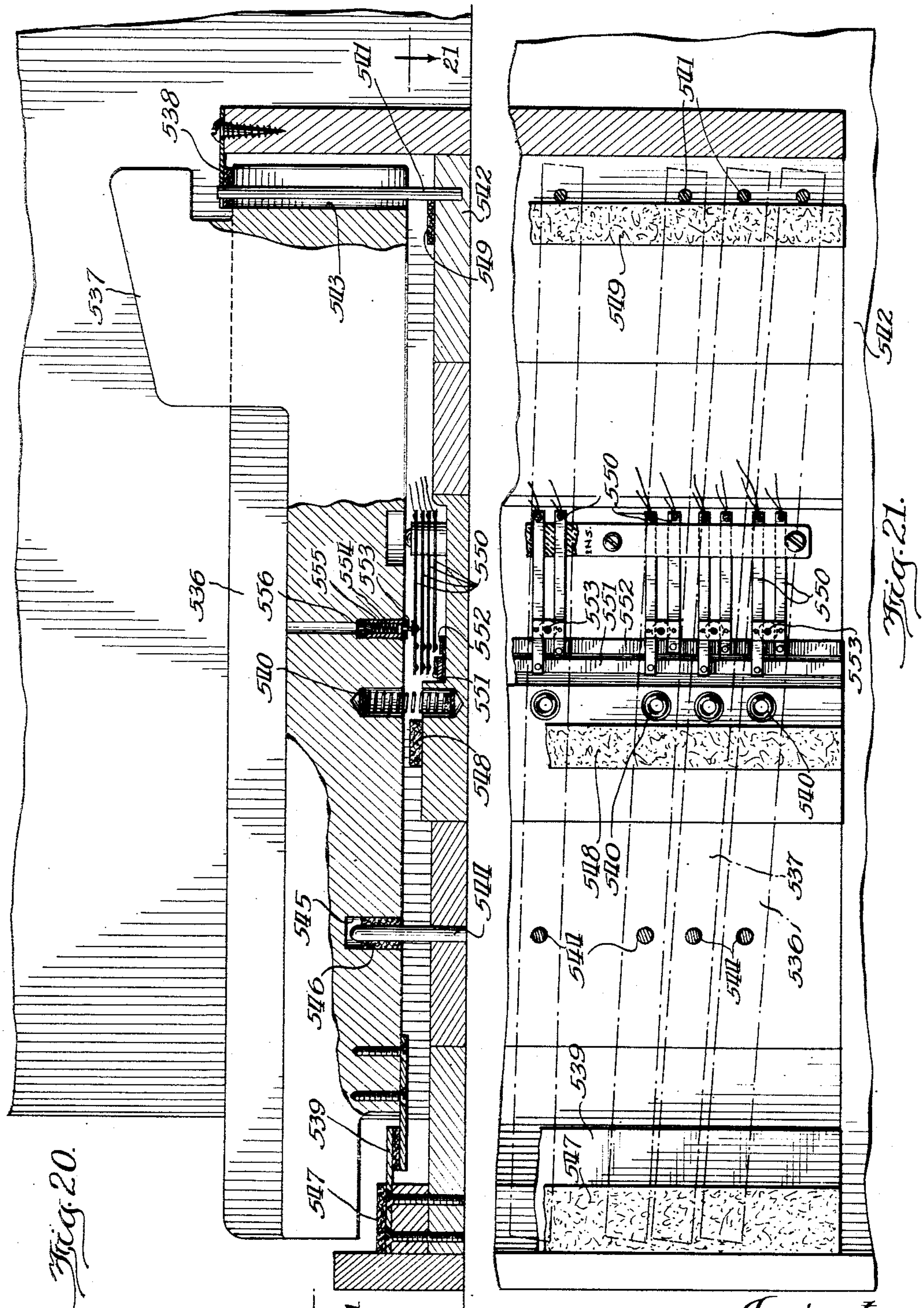


Fig. 18.

Inventor:
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle
Attys.

ELECTRICAL MUSICAL INSTRUMENT

Filed Jan. 19, 1934 18 Sheets-Sheet 12



Inventor:
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle. Attys.

April 24, 1934. L. HAMMOND 1,956,350

ELECTRICAL MUSICAL INSTRUMENT

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Fig. 22.

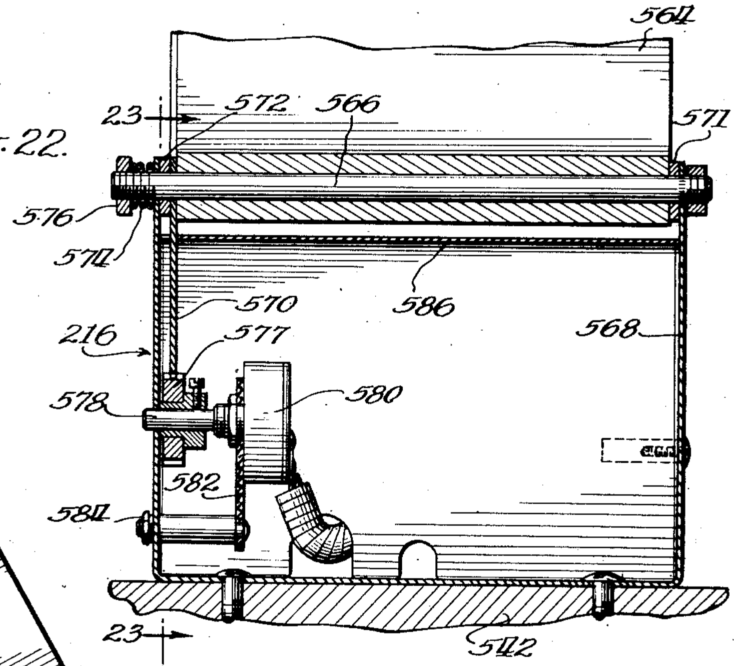
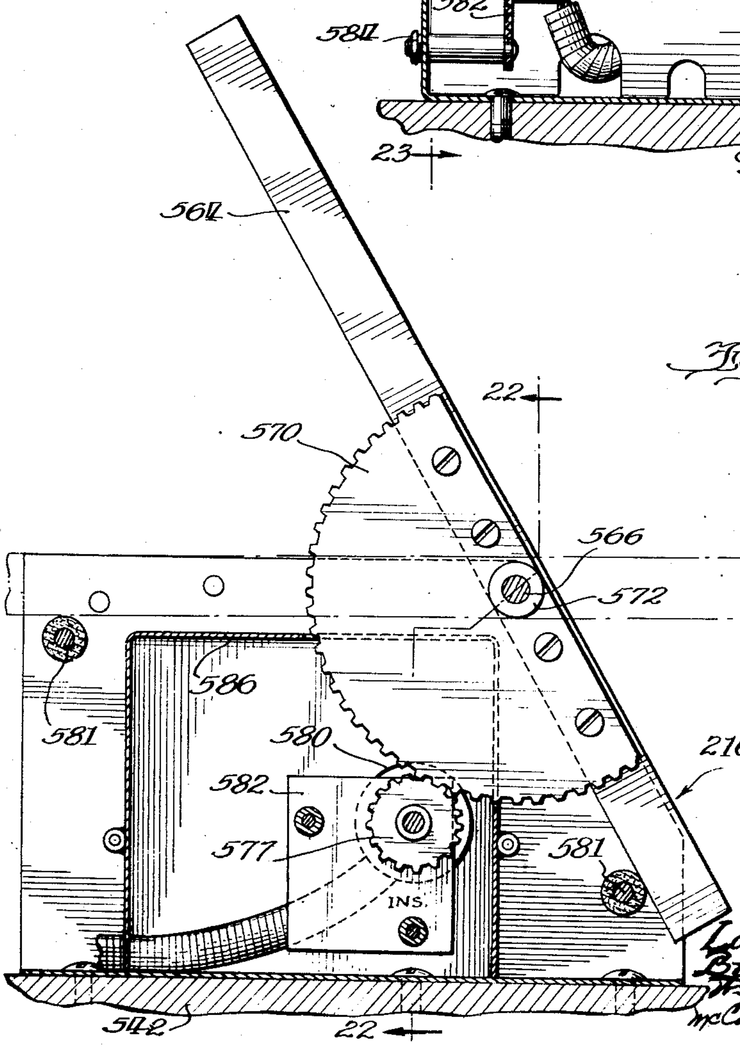


Fig. 23.



Inventor:
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle Attys.

ELECTRICAL MUSICAL INSTRUMENT

Filed Jan. 19, 1934

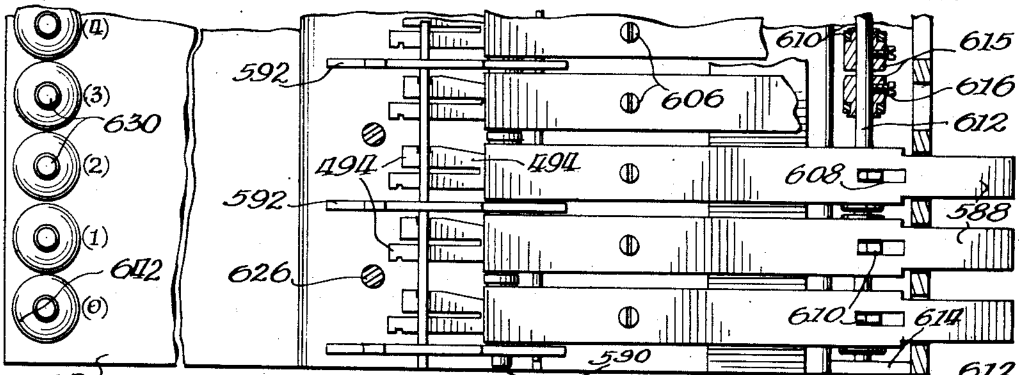


Fig. 25.

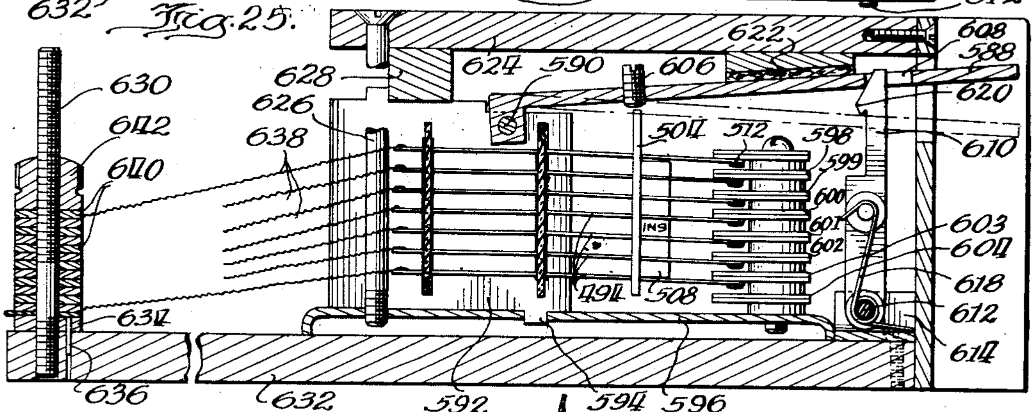


Fig. 24.

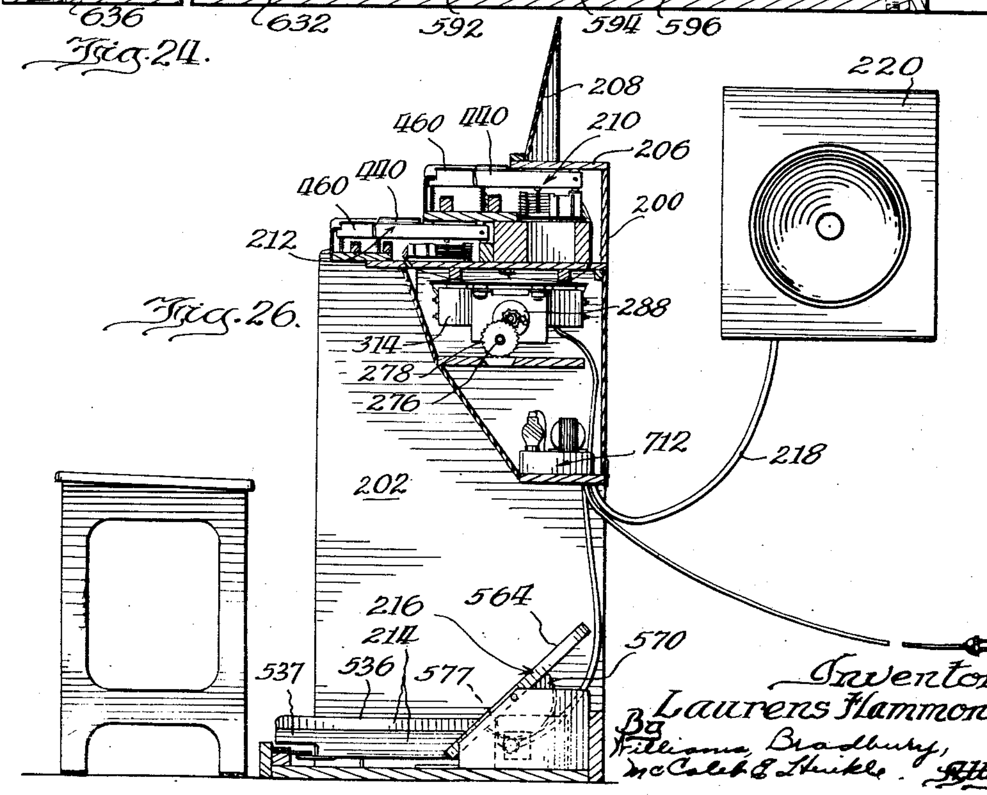


Fig. 26.

Inventor:
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle. Attys

April 24, 1934. L. HAMMOND 1,956,350

ELECTRICAL MUSICAL INSTRUMENT

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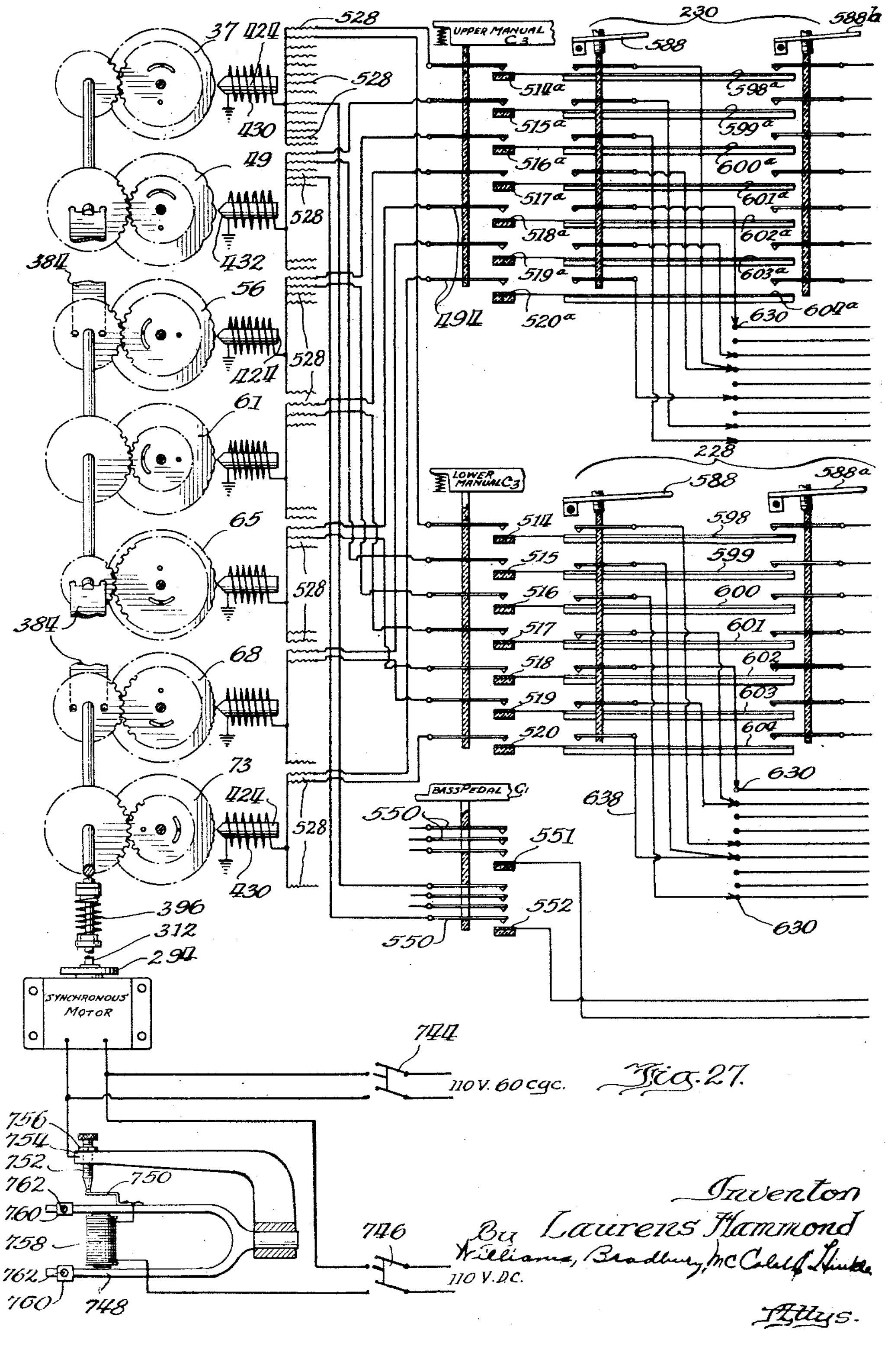

Fig. 27.

Inventor
By Laurens Hammond
Williams, Bradbury, McCaleb & Hinkle
Attys.

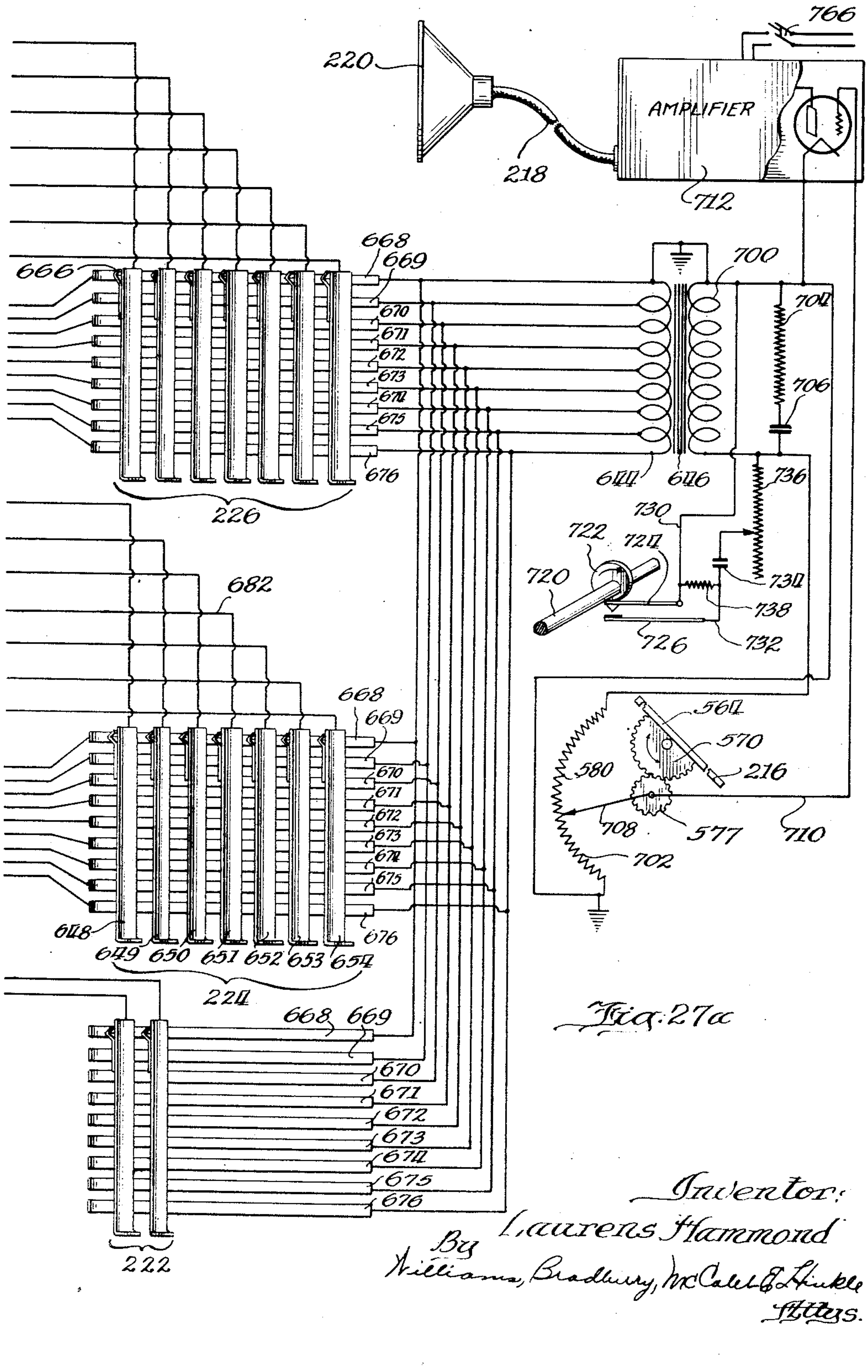

Fig. 27a

Inventor:
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle
Attys.

April 24, 1934. L. HAMMOND 1,956,350

ELECTRICAL MUSICAL INSTRUMENT

Filed Jan. 19, 1934 18 Sheets-Sheet 17

Ref. Char. of Key	n ROTOR						Frequency of Current Generated	Theoretical Frequency of Note in Equally Tempered Musical Scale A=440	Ref. Char. of 2n Rotor	" " " 3n	" " " 4n	" " " 5n	" " " 6n	" " " 8n
	Ref. Char.	No. of High Points	Driving Gear of n Rotor: Ref. Char.	Driving Gear of n Rotor: No. Teeth	Driven Gear for n Rotor: Ref. Char.	Driven Gear for n Rotor: No. Teeth								
C_0	1	2	102	85	132	104	32.692	32.703	13	20	25	29	32	37
$C^{\#}_0$	2	2	109	71	139	82	34.634	34.647	14	21	26	30	33	38
D_0	3	2	104	67	134	73	36.712	36.708	15	22	27	31	34	39
$D^{\#}_0$	4	2	111	70	141	72	38.888	38.890	16	23	28	32	35	40
E_0	5	2	106	69	136	67	41.194	41.203	17	24	29	33	36	41
F_0	6	4	101	54	131	99	43.636	43.653	18	25	30	34	37	42
$F^{\#}_0$	7	4	108	37	138	64	46.250	46.249	19	26	31	35	38	43
G_0	8	4	103	49	133	80	49.000	48.999	20	27	32	36	39	44
$G^{\#}_0$	9	4	110	48	140	74	51.891	51.913	21	28	33	37	40	45
A_0	10	4	105	66	135	96	55.000	55.000	22	29	34	38	41	46
$A^{\#}_0$	11	4	112	67	142	92	58.260	58.270	23	30	35	39	42	47
B_0	12	4	107	54	137	70	61.714	61.735	24	31	36	40	43	48
C_1	13	4	102	85	132	104	65.384	65.406	25	32	37	41	44	49
$C^{\#}_1$	14	4	109	71	139	82	69.268	69.295	26	33	38	42	45	50
D_1	15	4	104	67	134	73	73424	73.416	27	34	39	43	46	51
$D^{\#}_1$	16	4	111	70	141	72	77.777	77.781	28	35	40	44	47	52
E_1	17	4	106	69	136	67	82.388	82.406	29	36	41	45	48	53
F_1	18	8	101	54	161	99	87.272	87.307	30	37	42	46	49	54
$F^{\#}_1$	19	8	108	37	168	64	92.500	92.498	31	38	43	47	50	55
G_1	20	8	103	49	163	80	98.000	97.998	32	39	44	48	51	56
$G^{\#}_1$	21	8	110	48	170	74	103.783	103.826	33	40	45	49	52	57
A_1	22	8	105	66	165	96	110.000	110.000	34	41	46	50	53	58
$A^{\#}_1$	23	8	112	67	172	92	116.521	116.540	35	42	47	51	54	59
B_1	24	8	107	54	167	70	123.428	123.470	36	43	48	52	55	60
C_2	25	8	102	85	162	104	130.769	130.812	37	44	49	53	56	61
$C^{\#}_2$	26	8	109	71	169	82	138.536	138.591	38	45	50	54	57	62
D_2	27	8	104	67	164	73	146.849	146.832	39	46	51	55	58	63
$D^{\#}_2$	28	8	111	70	171	72	155.555	155.563	40	47	52	56	59	64
E_2	29	8	106	69	166	67	164.776	164.813	41	48	53	57	60	65
F_2	30	16	101	54	161	99	174.545	174.614	42	49	54	58	61	66
$F^{\#}_2$	31	16	108	37	168	64	185.000	184.997	43	50	55	59	62	67
G_2	32	16	103	49	163	80	196.000	195.997	44	51	56	60	63	68
$G^{\#}_2$	33	16	110	48	170	74	207.567	207.652	45	52	57	61	64	69
A_2	34	16	105	66	165	96	220.000	220.000	46	53	58	62	65	70
$A^{\#}_2$	35	16	112	67	172	92	233.043	233.081	47	54	59	63	66	71
B_2	36	16	107	54	167	70	246.857	246.941	48	55	60	64	67	72
C_3	37	16	102	85	162	104	261.538	261.625	49	56	61	65	68	73
$C^{\#}_3$	38	16	109	71	169	82	277.079	277.182	50	57	62	66	69	74
D_3	39	16	104	67	164	73	293.698	293.664	51	58	63	67	70	75
$D^{\#}_3$	40	16	111	70	171	72	311.111	311.126	52	59	64	68	71	76
E_3	41	16	106	69	166	67	329.552	329.627	53	60	65	69	72	77
F_3	42	16	113	84	173	77	349.090	349.228	54	61	66	70	73	78
$F^{\#}_3$	43	16	120	74	180	64	370.000	369.994	55	62	67	71	74	79
G_3	44	16	115	98	175	80	392.000	391.995	56	63	68	72	75	80
$G^{\#}_3$	45	16	122	96	182	74	415.135	415.304	57	64	69	73	76	81
A_3	46	16	117	88	177	64	440.000	440.000	58	65	70	74	77	82
$A^{\#}_3$	47	16	124	67	184	46	466.086	466.163	59	66	71	75	78	83
B_3	48	16	119	108	179	70	493.714	493.883	60	67	72	76	79	84
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)

Fig. 28.

Inventor:
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle
Attys.

ELECTRICAL MUSICAL INSTRUMENT

Filed Jan. 19, 1934 18 Sheets-Sheet 18

Ref. Char. of Key	n ROTOR: Ref. Char.	n ROTOR: No. of High Points	Driving Gear for n Rotor: Ref. Char.	Driving Gear for n Rotor: No. Teeth	Driven Gear for n Rotor: Ref. Char.	Driven Gear for n Rotor: No. Teeth	Frequency of Current Generated	Theoretical Frequency of Note in Equally Tempered Musical Scale A=440	Ref. Char. of 2n Rotor	" " 3n "	" " 4n "	" " 5n "	" " 6n "	" " 8n "
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
C_4	49	16	114	85	174	52	523.076	523.251	61	68	73	77	80	85
$C^{\#}_4$	50	16	121	71	181	41	554.146	554.365	62	69	74	78	81	86
D_4	51	16	116	134	176	73	587.397	587.329	63	70	75	79	82	87
$D^{\#}_4$	52	16	123	105	183	54	622.222	622.253	64	71	76	80	83	88
E_4	53	16	118	103	178	50	659.200	659.255	65	72	77	81	84	89
F_4	54	32	113	84	173	77	698.181	698.456	66	73	78	82	85	—
$F^{\#}_4$	55	32	120	74	180	64	740.000	739.988	67	74	79	83	86	—
G_4	56	32	115	98	175	80	784.000	783.991	68	75	80	84	87	—
$G^{\#}_4$	57	32	122	96	182	74	830.270	830.609	69	76	81	85	88	—
A_4	58	32	117	88	177	64	880.000	880.000	70	77	82	86	89	—
$A^{\#}_4$	59	32	124	67	184	46	932.173	932.327	71	78	83	87	—	—
B_4	60	32	119	108	179	70	987.428	987.766	72	79	84	88	—	—
C_5	61	32	114	85	174	52	1046.153	1046.502	73	80	85	89	—	—
$C^{\#}_5$	62	32	121	71	181	41	1108.292	1108.730	74	81	86	—	—	—
D_5	63	32	116	134	176	73	1174.794	1174.659	75	82	87	—	—	—
$D^{\#}_5$	64	32	123	105	183	54	1244.444	1244.507	76	83	88	—	—	—
E_5	65	32	118	103	178	50	1318.400	1318.510	77	84	89	—	—	—
F_5	66	64	113	84	143	77	1396.363	1396.912	78	85	—	—	—	—
$F^{\#}_5$	67	64	120	74	150	64	1480.000	1479.976	79	86	—	—	—	—
G_5	68	64	115	98	145	80	1568.000	1567.982	80	87	—	—	—	—
$G^{\#}_5$	69	64	122	96	152	74	1660.540	1661.218	81	88	—	—	—	—
A_5	70	64	117	88	147	64	1760.000	1760.000	82	89	—	—	—	—
$A^{\#}_5$	71	64	124	67	154	46	1864.346	1864.654	83	—	—	—	—	—
B_5	72	64	119	108	149	70	1974.856	1975.532	84	—	—	—	—	—
C_6	73	64	114	85	144	52	2092.306	2093.004	85	—	—	—	—	—
—	74	64	121	71	151	41	2216.584	2217.460	—	—	—	—	—	—
—	75	64	116	134	146	73	2349.588	2349.318	—	—	—	—	—	—
—	76	64	123	105	153	54	2488.888	2489.014	—	—	—	—	—	—
—	77	64	118	103	148	50	2636.800	2637.020	—	—	—	—	—	—
—	78	128	113	84	143	77	2792.727	2793.824	—	—	—	—	—	—
—	79	128	120	74	150	64	2960.000	2959.952	—	—	—	—	—	—
—	80	128	115	98	145	80	3136.000	3135.964	—	—	—	—	—	—
—	81	128	122	96	152	74	3321.080	3322.436	—	—	—	—	—	—
—	82	128	117	88	147	64	3520.000	3520.000	—	—	—	—	—	—
—	83	128	124	67	154	46	3728.693	3729.308	—	—	—	—	—	—
—	84	128	119	108	149	70	3949.713	3951.064	—	—	—	—	—	—
—	85	128	114	85	144	52	4184.613	4186.008	—	—	—	—	—	—
—	86	128	121	71	151	41	4433.169	4434.920	—	—	—	—	—	—
—	87	128	116	134	146	73	4699.177	4698.636	—	—	—	—	—	—
—	88	128	123	105	153	54	4977.777	4978.028	—	—	—	—	—	—
—	89	128	118	103	148	50	5273.600	5274.040	—	—	—	—	—	—

Fig. 28a

Inventor:
Laurens Hammond

By Williams, Bradbury, McCaleb & Hinkle
Attys.

Patented Apr. 24, 1934

1,956,350

UNITED STATES PATENT OFFICE

1,956,350

ELECTRICAL MUSICAL INSTRUMENT

Laurens Hammond, Chicago, Ill.

Application January 19, 1934, Serial No. 707,280

74 Claims. (Cl. 84—1)

My invention relates generally to electrical musical instruments, and more particularly to instruments of this type in which the tone is produced by synthesis of the fundamental tone with various proportions of its harmonics.

I am aware that various attempts have been made in the past to produce an instrument of this character, but as far as I have knowledge, none of these attempts accomplish the desired result because of the failure to incorporate in the instruments certain fundamental principles of construction which I have found to be essential to the operability of devices of this character, as will hereinafter be more fully discussed.

It is a well known fact that any sustained musical sound can be analyzed into sine wave components, and for a given pitch the tone may be analyzed into a fundamental tone of certain amplitude and various amplitudes of different harmonics of the fundamental. It has been found that in most musical tones the predominant harmonics are those of the lower frequencies, and that harmonics above the eighth have very little effect in characterizing the tone, especially in the middle and upper registers where harmonics of a higher order would lie above the range of audibility.

Thus most musical tones may be produced by definite combinations of the fundamental tone with various proportions of the first eight harmonics.

The instrument of my invention employs the tempered musical scale not only in the production of the fundamentals but in the production of the various harmonics. As a result any desired chords may be played without causing audible beats.

It is thus the primary object of my invention to provide an electrical instrument for the production of musical tones upon which any desired musical composition may be played. Incident to this broad object of my invention are numerous other objects, the attainment of which contributes materially to the achievement of the primary object. These objects appear more fully in the accompanying specification, and include the following:

(1) To provide an improved means for generating a plurality of currents of different frequencies capable of being translated into musical sounds.

(2) To provide improved means for driving such generators at a constant speed.

(3) To provide improved circuits by which currents from various generators may be combined or synthesized.

(4) To provide improved means for eliminating the noise produced upon completing and breaking the various circuits, sometimes referred to as the "key thump" or "key click" noise.

(5) To provide an improved electrical circuit wherein a plurality of currents from different sources may be combined additively without appreciable cancellation or subtraction.

(6) To provide an electrical circuit in which selected proportions of electrical energy derived from sources of different frequencies may be combined.

(7) To provide selective means for changing the quality of the tones produced by the instrument.

(8) To provide selective means for changing the relative proportions of the electrical energy drawn from the generators of the fundamental and the various harmonics thereof.

(9) To provide selective means for simultaneously determining the quality of all of the tones produced upon depression of the keys of a manual.

(10) To provide means for rapidly conditioning the instrument to produce tones of any one of a plurality of preselected qualities.

(11) To provide means for easily changing said preselected qualities of tone.

(12) To provide means for adjusting the currents produced by the generators to compensate for unavoidable defects in the means ultilized to translate the currents into sound.

(13) To provide an arrangement of a plurality of generators of different frequencies which reduces inductive coupling between the generators.

(14) To provide an improved means for driving the generators at the different speeds required for the generation of the currents of different frequency.

(15) To provide improved means for producing tremolo effects.

(16) To provide improved methods of wiring the instrument wherein a number of the conductors serve as a means for introducing high resistances into the circuit.

(17) To provide an instrument of the type which is relatively light in weight and is portable.

(18) To provide an instrument having a number of key manuals with improved means for changing the quality of the tones produced by playing upon the different manuals.

(19) To produce similar generators for a plurality of different frequencies in which compensation may readily be made to cause the currents

produced by the generators when translated into sound to be of equal volume.

(20) To provide a plurality of generators of currents of different frequencies in which a single countershaft comprising a plurality of articulated sections is utilized for driving all of the generators.

(21) To provide a bank of generators for currents of different frequencies in a plurality of flexibly connected units, each unit including a plurality of generators of frequencies which are exact multiples of one another and each unit being shielded from the remaining units.

(22) To provide a plurality of generators for producing currents of different frequencies, made up of a plurality of similar units in which the rotor shafts of successive units are staggered relative to one another so that the rotor shafts of adjacent units may have a bearing in common.

(23) To provide an improved resilient driving connection between the synchronous motor and the generators.

(24) To provide an improved gearing arrangement for driving the rotors of the generators at the required speed.

(25) To provide an instrument in which chords may be played and in which all of the electrical current of the same frequency whether utilized in the various tones as fundamentals or as harmonics is derived from a common source.

(26) To provide an instrument in which diminution of the output derived from a given generator is obtained by a method which decreases the impedance of the output circuit.

(27) To provide an instrument having a plurality of keyboards in which there is a duplication of tone range and in which tones of different quality may be controlled by the different keyboards, in such manner that the depression of corresponding keys on two or more keyboards will result in a true combination of the individual tones produced thereby, without substantial energy loss.

(28) To provide an instrument having a plurality of alternating current generators of different frequency capable of generating relatively strong currents and by suitable resistances decreasing the actual currents utilized to a relatively small percentage of the possible output of the generators, combining the currents produced by various selected generators in predetermined relative proportions, and amplifying the composite current and translating it into sound.

(29) To provide means for compensating for the differences in the energy of the currents produced by the generators of different frequencies.

Other objects are the provision of an electrical musical instrument which may be economically produced in large quantities, in which there is a relatively small number of parts, in which the various elements may be readily assembled, and which will be durable.

Further objects will appear from the following description, reference being had to the accompanying drawings, in which:

Fig. 1 is a plan view of the instrument;

Fig. 2 is a horizontal sectional view showing the pedal keyboard and swell pedal;

Fig. 3 is a vertical cross-sectional view of the upper and lower manuals and the generator assembly;

Fig. 4 is an enlarged vertical sectional view of the assembly of the generators;

Figs. 5, 5*a* and 5*b* together constitute a plan view of the assembly of generators and the synchronous motor for driving the same, various parts thereof being shown in fragmentary section better to illustrate details;

Fig. 6 is an enlarged vertical cross-sectional view of the synchronous motor and its driving connections;

Fig. 7 is a vertical sectional view taken on the line 7—7 of Fig. 6;

Fig. 8 is a greatly enlarged vertical sectional view showing the mounting of the generator rotors;

Fig. 9 is a central vertical sectional view showing the bearing construction for the countershaft sections and the flexible coupling connecting the countershaft sections;

Fig. 10 is a fragmentary sectional view taken on the line 10—10 of Fig. 8;

Fig. 11 is a right side elevation of the synchronous motor, various parts associated therewith being broken away to show detail, the view being taken substantially on the plane of line 11—11 of Fig. 6;

Fig. 12 is a vertical sectional view of the synchronous motor taken on the line 12—12 of Fig. 6;

Fig. 13 is a fragmentary plan view of a section of multiple contact switches, parts thereof being shown in fragmentary section;

Fig. 14 is a fragmentary vertical sectional view taken on the line 14—14 of Fig. 13;

Fig. 15 is a fragmentary sectional view illustrating the method by which the switch contact members are mounted;

Fig. 16 is a fragmentary sectional view taken on the line 16—16 of Fig. 13, illustrating the means by which the switch actuator is connected to the switch contact members;

Fig. 17 is a transverse sectional view taken on the line 17—17 of Fig. 13;

Fig. 18 is a vertical sectional view of the timbre selector mechanism;

Fig. 19 is a sectional view taken on the line 19—19 of Fig. 18;

Fig. 20 is a vertical sectional view of the pedal keyboard taken on the line 20—20 of Fig. 2;

Fig. 21 is a plan view of a portion of the pedal keyboard with the pedals removed;

Fig. 22 is a vertical sectional view of the swell pedal and associated mechanism taken on the line 22—22 of Fig. 23;

Fig. 23 is a vertical sectional view of the swell pedal mechanism taken on the line 23—23 of Fig. 22;

Fig. 24 is a vertical sectional view of the stop key operated pre-set combination selector;

Fig. 25 is a fragmentary plan view of the mechanism shown in Fig. 24, various parts being broken away to show the details of construction;

Fig. 26 is a vertical sectional view of the instrument taken just inside the right-hand side wall and showing the general arrangement of the mechanism;

Figs. 27 and 27*a* together constitute a schematic wiring diagram of the instrument; and

Figs. 28 and 28*a* constitute a chart usable in conjunction with the wiring diagram to indicate the connections not shown in the diagram and setting forth the numbers of teeth, etc., in the various gearing utilized to drive the generators.

General description

The detailed description of the instrument of my invention will, I believe, be more readily understood if it is read with a previous general knowledge of the function and operation of the instrument as a whole. The following brief description is intended to furnish such general understanding of the invention.

The exemplary embodiment of my invention which is herein illustrated and described, comprises a console having two manuals, one having keys extending throughout the usual range of the musical scale, and the other having keys for the notes of the upper half of the scale. In addition to the manuals there is a pedal keyboard covering a limited range of bass notes. The instrument operates upon the principle of synthetically producing electrical waves of the desired frequency, and including various proportions of harmonics necessary to produce a tone of the desired quality or tone color. The currents generated in the instrument are of low voltage and amperage and are fed through a transformer to an amplifier and translated into sound by means of a suitable loud speaker.

The means for generating the electric currents of different frequencies comprises a plurality of alternators, one for each frequency necessary to produce the fundamental of the tempered musical scale, the voltages of currents generated by the different alternators being adjusted so that the tones produced upon the depression of individual keys are of equal intensity or loudness. Each alternator comprises a permanent magnet wound with a coil, the coils of the generators of the lower frequencies having a larger number of turns than those of the alternators for the higher frequencies, thus making it easier to adjust the alternators for generating currents which will be translated into sounds of equal intensity.

The rotors of the alternators are driven from a constant speed motor, preferably a synchronous motor, which may be supplied with alternating current from a source of regulated frequency, or may be supplied with an interrupted direct current produced by a tuning fork interrupter. If the interrupted current is used, adjustment of the frequency of vibration of the tuning fork may be made, thus in effect "tuning" the instrument. This may be desirable when the instrument is to be used in an orchestra or is to be accompanied by another musical instrument which cannot be readily tuned.

The alternators are driven from a countershaft which is connected to the synchronous motor by a highly elastic flexible coupling. The countershaft is made in sections which are coupled together by a simple type of universal joint, each section of the countershaft having a number of driving gears attached thereto. Each of the driving gears meshes with two driven gears, which are mounted for rotation on rotor shafts, and are flexibly connected to rotate the latter through a very light spring.

In the embodiment shown and described herein, there are 89 alternators, there being seven different shapes of rotors employed, the rotors having respectively 2, 4, 8, 16, 32, 64 and 128 high points. Generally speaking, there are two rotors upon each rotor shaft, although in some instances there is only one rotor on the rotor shaft. Each key controls a plurality of switches, in the present embodiment seven in number. The seven contacts closed by the depression of a key close seven separate circuits to seven different alternators, the alternators developing currents having the fundamental n frequency and other frequencies which are either exactly or very closely $2n$, $3n$, $4n$, $5n$, $6n$, and $8n$. The closing of these switches by the keys connects these generators respectively to bus-bars, there being one bus-bar to receive currents of frequencies corresponding to the fundamentals of tones to be produced, and separate bus-bars to receive currents of frequencies corresponding (either exactly or approximately) to each of the enumerated harmonics. These bus-bars are adapted to be connected to the primary of an output transformer, a selector device being provided whereby the bus-bars may be connected to a selected number of turns of said transformer primary. Since, generally speaking, the apparent increase in intensity of a musical tone does not vary directly with the increase in energy utilized in propagating the tone, the primary of the transformer is tapped at intervals of increasing numbers of turns so that the apparent loudness of a musical tone may be increased in apparently regular steps by passing the current through a geometrically increasing number of turns of the primary of the transformer. Each of the bus-bars may, through the selector device, be connected to any desired tap of the primary.

A selector device as above generally described is provided for the main or lower manual, as well as for the upper manual and, with slight differences, for the pedal keys. In addition, a pre-set combination selector is provided for each of the selectors by means of which the bus-bars may be substantially simultaneously connected to preselected taps on the primary of the transformer merely by the depression of a single key closing a plurality of switch contacts.

With the apparatus above briefly outlined, a musical tone of any desired quality (within reasonable limits) may be produced merely by proper selection and proper proportioning of the energy corresponding to the fundamental frequency of the tone, and that corresponding to its harmonics. Both manuals and the pedal keyboard utilize current from the same alternators, and the circuit arrangement is such that if current from a single generator is necessary for the production of partials in a plurality of tones when a plurality of keys are simultaneously depressed, the generator will supply increased energy to the primary of the transformer, depending upon the number of times that current of that particular frequency is present either as a fundamental or as a harmonic. Since all of the current of a certain frequency is supplied from the same alternator, the currents are necessarily in absolute synchronism and in phase. As a result, chords may be played upon the instrument while retaining the true tone quality of the individual notes composing the chord.

General features of construction

The instrument of my invention may be mounted in any suitable console, herein illustrated as comprising a rear wall 200 (Figs. 1 and 2), side walls 202 and 204, and an upper manual cover 206 upon which a music rack 208 may be mounted. The instrument comprises an upper manual 210 consisting of keys C_3 to C_6 inclusive, a lower manual 212 consisting of keys F_0 to C_6 inclusive, and pedals 214, C_0 to G_1 inclusive and a volume control or swell pedal 216. The instrument is connected by a cable 218 to a loud speaker unit 220 which may, if desired, be located some distance from the console, or may be mounted in the console. The quality of the tone of the bass pedals is controlled by selectors 222, the quality of the tones produced by the lower manual is controlled by selectors 224, and the quality of tone produced by the upper manual is controlled by selectors 226. Pre-set combination selector keys 228 are provided for changing the tone quality of the lower manual to any one of six pre-set combinations of fundamentals and harmonics, these keys corresponding to some of the stops on a conventional pipe organ. Keys 230 are control means similar to the keys 228 for changing the tone quality for the upper manual to any one of a plurality of pre-set combinations.

The synchronous motor

The power for operating the instrument is derived from a synchronous motor illustrated in Figs. 6, 7, and 12, which comprises a plurality of laminations 240 which are of the shape of a hollow rectangle having inwardly extending pole projections 242. Additional laminations 244 in which the pole projections 242 are not present, are secured at each side of the laminations 240, and two pairs of imperforate laminations 246 form closures for the opening formed by the other laminations, the laminations 240, 244 and 246 being clamped together by bolts 250. The bolts 250 adjacent the ends of the laminations are provided with spacers 252 and project through a pair of supporting plates 254, the upper ends of which have flanges 256 which are bolted to a bed plate 258, washers 260, of rubber or other suitable material, being located on each side of the flanges 256 to form a cushion mounting for the motor.

A pair of bearing bushings 262 are secured in the two pairs of laminations 246 respectively, a rotor shaft 264 being journalled in these bearings. A six-pole laminated rotor 266 is suitably secured to the rotor shaft 264 in alignment with the pole projections 242 of the laminations 240. A starting shaft 268 is mounted in bearings 270 secured in the supporting plates 254, the shaft being normally pressed to the right (Fig. 6) by a compression coil spring 272, one end of which bears against the left-hand bearing bushing 270 and the other end bearing against a collar 274 which is secured to the shaft. A jaw clutch member 276 is secured to the starting shaft 268 and forms a hub for a gear 278 which is adapted to mesh with a pinion 280 rotatably mounted upon the end of the rotary shaft 264 and held thereon by a collar 282 pressed on the shaft. A ratchet wheel 284 is secured to the pinion 280 and is adapted to be engaged by a spring pressed pawl 286 carried by a disc 288 which is non-rotatably secured to the shaft 264.

A pinion 290 is secured to the shaft 264 adjacent the disc 288 for driving the tremolo mechanism to be hereinafter described. The left-hand end of the rotor shaft is provided with a collar 292 which is tightly pressed thereon. An inertia element 294 mounted on a hub 296 is rotatable upon the end of the rotor shaft 264, a friction washer 298 being interposed between the inertia element 294 and the collar 292 to cause a certain amount of frictional resistance to relative movement of the inertia element 294 and the shaft 264. Relative movement of the inertia element and the shaft 264 is positively limited by a pin 300 passing through the collar 292 and shaft 264 and having its ends projecting from the collar, the ends of the pin 300 being adapted to engage stop pins 302 pressed into the inertia element 294. A pair of tension coil springs 306 have their inner ends secured to a disc 308 peened to the collar 292 and their outer ends secured to pins 310 secured in the inertia element 294. A countershaft section 312 is secured to the bushing 296 of the inertia element 294 so as to rotate therewith.

The alternating current generators and drive therefor

The tone wheel rotors for the alternators are mounted in a suitable unitary frame composed of a plurality of frame plates or sheets 314 shown in Figs. 4, 5, 5*a*, and 5*b*. The frame plates 314 which are of magnetic material, are held in properly spaced relation by a plurality of bars 316 which have notches 318 formed therein engaging the frame plates 314. The bars 316 project through slots 320 formed in the frame plates and are held in position with their notches 318 engaging the frame plates by a pair of wires 322, Fig. 4.

The frame plates 314 each have four apertures 324 punched therein (Fig. 4) through which pairs of bars 325, 326, extending the length of the generator assembly, project. A magnet supporting plate 328 is positioned between the bars 325, 326, and extends between adjacent frame plates 314, there being two magnet supporting plates 328 for each of the compartments formed by the frame plates 314. Each of the magnet supporting plates 328 is held in place by a pair of screws 329, 330. The screw 329 projects through a bar 331 extending longitudinally the full length of the assembly, through a suitable opening in a side plate 332, through an opening in the bar 325 and is threaded in a tapped hole formed in the bar 326. Similarly, the screw 330 extends through a cross bar 333 and opening in the side plate 332, an opening in the upper cross bar 325 and is threaded in a tapped hole in the upper cross bar 326. Rods 334, 335 project through suitable openings in the frame plates 314 and aid in keeping these plates in alignment.

The generator frame assembly is suitably supported from a board 336 by a plurality of pairs of bolts 338 which project through a top plate 339 of insulating material, through suitable strips 342 of felt or similar material, and through suitable channels 344, 346, the upper faces of which are provided with felt strips 348, 350. The frame plates 314 are thus clamped between the felt strips 340, 342, and 348, 350. The generator assembly is spaced from the board 336 by a pair of wooden strips 352, 354 which have slots 356 formed therein to receive the wiring, as will hereinafter appear.

Each of the frame plates 314 has a central vertical slot 358, these slots being provided to receive countershaft bearings 360 which are held in place at lower ends of the slots by filler strips 362, the latter being clamped in place by a pair of washers 364 and a bolt 366. Lateral movement of the bearing 360 is prevented by a washer 368 which, together with a flange on the bearing, forms an annular groove to receive the edge of the plate 314 and the end of the filler strip 362.

There are a plurality of countershaft sections 370, 372, 374, 376, 378, 380 and 382, (Figs. 5, 5*a* and 5*b*) each of which is mounted in a pair of bearings 360. Driving gears 101 and 102 are secured to the countershaft section 382; driving gears 103, 104 and 105 to the countershaft section 380; driving gears 106, 107, 108 and 109 to the countershaft section 378; driving gears 110, 111, 112 and 113 to the countershaft section 376; driving gears 114, 115, 116 and 117 to countershaft section 374; driving gears 118, 119, 120 and 121 to countershaft section 372; and driving gears 122, 123 and 124 to countershaft section 370. The countershafts are interconnected for limited relative universal movement by connectors 384 (Fig. 9) each of which has a pair of projections 386 at each end, these projections fitting rather loosely in suitable holes formed in the driving gears 101 to 124 which are located at the ends of the countershaft sections. Those of the plates 314 through which the connectors 384 project have suitable openings 388 formed therein so as to permit free rotation of the connectors.

The countershaft section 370 (Fig. 6) has a collar 390 secured thereto, the collar having a pair of holes 391 formed therein to receive pins 392 carried by a coupling sleeve 394. The latter fits over the end of the shaft 370 and forms a supporting bearing for the adjacent end of countershaft section 312. A torsion coil spring 396 of considerable length has one end anchored to the sleeve 394 and the other end secured to a collar 398, pinned to the shaft 312. The coil spring holds the sleeve 394 against the collar 391 with the pins 392 in the holes 391. Due to the great length of the spring 396 and the relatively small diameter of the wire used, the spring forms an exceedingly elastic driving connection between the countershaft sections 312 and 370. The bearing of the countershaft section 312 in the sleeve 394 forms a frictional means for dissipating a small amount of energy upon relative rotation of the countershaft sections 312 and 370 to aid in damping hunting. The friction developed in the spring 396 between adjacent turns which are tightly wound, also operates in the same manner.

Each of the frame plates 314 has a pair of rotor shaft bearings 400 pressed therein, as shown in Fig. 8. Rotor shafts 402 are journaled in these bearings 400 and have a pair of bushings 404 pressed thereon. The bushings 404 have shoulders 406 formed thereon, over which the rotors 1 to 89 are pressed. These rotors or tone wheels have either 2, 4, 8, 16, 32, 64, or 128 high points formed thereon, as indicated in the third column of the chart, Figs. 28 and 28*a*.

The rotors are formed of magnetic material and the shape thereof is accurately computed so that the current produced, as will hereinafter appear, is substantially of true sine wave form. A driven gear, (131 to 154 and 161 to 184 inclusive) is mounted upon each of the rotor shafts 402, the gear being provided with a crescent-shaped slot 408 through which a pin 410 projects, the pin 410 passing through suitable drilled holes 412 formed in the flanges of bushings 404 and forming a positive limiting stop for movement between the bushings and the gear. A length 414 of fine spring wire projects through a small hole 416 formed in the driven gear 149 (Fig. 8), the ends of the spring wire projecting through suitable holes 418 formed in the radial flanges of the bushings 404, and being bent over to prevent the wire from moving out of place. Due to the fact that the spring wire 414 makes it necessary for the rotor to rotate with the driven gear 149, (although there may be relative oscillation of these parts) the drive between the rotor and the gear may be termed a resilient non-slipping driving connection. The bushings 404 have hollow cylindrical portions 420 which limit lateral sliding movement of the gear on the shaft. The rotor shafts 402 are not in alignment but are alternately staggered making it possible to use a single bearing member 400 as a bearing for the ends of adjacent shafts. The bearing member 400 may be of any suitable anti-friction material.

In some instances the rotor shaft carries but one rotor, in which case a blank disc 422 (Fig. 5) of non-magnetic material is secured to the bushing 404 so as to balance the other rotor and to give the assembly the proper rotary moment of inertia.

A plurality of permanent magnets 424 (Fig. 4) are mounted in bushings 426 secured to the side plates 332, the magnets projecting through suitable openings formed in the magnet supporting plates 328. Each of the bushings 426 is provided with a set screw 428 so that the magnet may be locked in adjusted position. A coil 430 is mounted upon each of the magnets 424 adjacent the point 432 thereof, one terminal of the coil being grounded and the other terminal being connected by a conductor 434 to a soldering lug 436 riveted to the insulating top plate 339. In Fig. 5*a* portions of the generators are omitted.

The four rotors (in a few instances three) which are mounted between a pair of adjacent frame plates 314, are adapted to generate currents whose frequencies are multiples of one another. This relationship will be apparent from the third column of the chart, Figs. 28 and 28*a*. In this way inductive coupling between the generators in a single compartment is not very objectionable, since the presence of a slight harmonic cannot cause discord. It will be understood that each group of generators is shielded from its adjacent group by the frame plates 314 which are of a magnetic material such as lamination iron.

The current generated by each of the generators or alternators may be very accurately controlled by moving the permanent magnet 424 toward or away from the periphery of its associated tone wheel rotor. Having been moved to the desired position, it may be firmly locked in place by tightening the set screw 428.

It is of very great importance that the rotors be very accurately centered on their respective shafts, so that the minimum air gap between the point 432 of the magnet and the rotor will be constant as the rotor is turned. To accomplish this result, I prefer to form the tone wheel on a hobbing machine, press it on its bushing, 404, very accurately center the tone wheel by a collet which engages the periphery thereof, and then bore the bushing. In this way the hole in the bushing will be very accurately centered with respect to the periphery of the wheel. The bushing is then pressed on the shaft.

A second very important requirement is that the tone wheels be rotated at as constant a speed as is possible. In the construction above described this constant speed of rotation is obtained first by using a synchronous motor. As is well known, most power companies now regulate the speed of their alternators with a very high degree of accuracy so that the frequency variation in the current generated and supplied to the consumers does not vary from the standard frequency by more than a fraction of a percent, and furthermore, that such slight variations in frequency are not sudden but usually take place gradually during extended periods of time. Thus, the synchronous motor will run at a very nearly constant speed. The synchronous motor is, however, subject to slight hunting. This hunting is practically eliminated or is at least greatly reduced by the use of the inertia wheel 294. If the rotor tends to hunt, the inertia wheel 294 will move relative to the motor shaft and due to the interposition of the friction washer 298 will dissipate the greater portion of the energy which tends to cause the motor to hunt.

The shaft 312 will not, however, be driven at sufficiently constant speed to obtain good results from the instrument, and I have therefore interposed resilient or flexible and frictional coupling means in the form of the long torsion spring 396. This spring serves as a further means to absorb the energy which would otherwise be expended in accelerating and decelerating the countershaft.

The countershaft sections 370 etc. are therefore driven at a very nearly constant speed. It is, however, practically impossible to produce meshing gears and pinions which are capable of transmitting power from one shaft to another with the required high degree of accuracy. For example, suppose that if a gear having an outside diameter of one inch, for instance, should be made so that its true pitch circle should run eccentric by one thousandth of an inch, it would follow that the driven gear would be alternately accelerated and retarded during each revolution of the driving gear in an amount such that the low speed would compare to the high speed in the proportion of 499 to 501. Such a change of speed of the driven assembly would cause highly objectionable changes in speed of the driven rotors and would spoil the quality of the music produced.

It is because of this fact that slight differences in what might appear to be trifling features of construction will render the instrument inoperative satisfactorily to produce musical compositions, that it is necessary to describe the construction of the parts and the physical constants involved in greater detail than might ordinarily be required. It is believed that the failure of other experimenters in this field to appreciate these limiting factors is responsible in a great measure for the fact that none of them succeeded in producing an operative instrument of this type.

In early attempts to build a machine of this nature, I thought it would be possible to drive the generators with rigid commercial gearing. All such attempts failed, notwithstanding the most elaborate precautions in cutting accurate gears. It must be remembered that the rotor of the alternator in its close proximity to the field pole constitutes a magnetic type of microphone in which any change of motion of the wheel is translated into current which is amplified along with the current which it is desired to produce. Due to the imperfection of any gearing which it is possible to make by ordinary machine shop practice, the driven gear will of necessity rotate at a varying speed. It will not only do this because of the eccentricity of pitch circles, irregularity of teeth, and the like, but will be thrown forward and will be retarded by a slapping action in the clearance between teeth. Furthermore, it is not the amount of such relative motion which counts but it is the forces developed in such motion which are of importance.

To illustrate this point I call attention to the fact that the voltage of a current generated in the coil is proportional to the rate of change of flux in the magnet. The rate of change of flux is in turn proportional to the rate of change of motion of the wheel. The rate of change of motion of the wheel is proportional to the forces acting upon the wheel, which is very different from motion which these forces produce. This effect is strikingly illustrated by tapping a tone wheel with a small hard object. The blow may be so small as to produce insignificant motion of the wheel, but will result in a loud crash of sound in the output of the apparatus. Thus the slapping action between teeth of rigidly connected gearing will produce extraneous noises in the output as well as changes in pace of the wheel which will mar the quality of the tones produced.

There is a certain small amount of friction between the driven gear 404 (Fig. 8) and the rotor shaft 402, and the rotors and bushings to which they are attached have a certain rotary moment of inertia. The resiliency of the spring is such that the period of hunting which can take place between the gear 149 and the rotors is relatively slow. Thus any hunting which may take place will be at a frequency below the audible range, and if the resultant variations of the current produced by the generators is sufficient to be audible in the sound produced, the effect will be that of a slight tremolo, which will not detract from the musical quality of the tone but rather enhance it.

It is obvious that once the spring is introduced between the driven gear and the rotor, the maximum value of force due to acceleration and deceleration which can be transmitted to the wheels is limited to the amount of force necessary to flex the spring through an angle sufficient to compensate for angular inaccuracies of the gear drive. If this force is thus limited it follows that the rate of change of flux and consequently the voltage of an extraneous frequency is limited to an exceedingly small value.

The importance of uniform speed of rotation of the wheels cannot be overemphasized. The arrangement of synchronous motor and drive just described constitutes the mechanical equivalent of an electrical filter circuit, in which the relatively rough speed of the armature of the synchronous motor is conveyed to the loose fly wheel 294 in such manner that the change of speed of the fly wheel is less pronounced than that of the armature. The more even speed of the fly wheel is then communicated through the resilient spring drive to the countershaft system in such manner that the changes in speed of the latter are less pronounced than that of the fly wheel. The resilient drive between the tone wheels themselves and the driven gear causes the tone wheels to turn even more smoothly.

In the manufacture of the rotor assemblies and the means for driving the rotors, a high degree of accuracy in the making and assembling of the parts is required, but in using the rotor construction and drive therefor which I have invented, the requirement for accuracy is not sufficiently stringent to prohibit manufacture of the instrument on a commercial production basis. Without the resilient drive for the tone wheels, it would not be feasible to endeavor to manufacture an instrument of this type on a commercial basis and it is questionable whether a device could be made on an experimental basis with sufficient accuracy to accomplish the desired result.

With the construction of my invention the frame which supports the generator is, as a whole, relatively flexible and no extremely high degree of accuracy is necessary in its mounting. In fact, the frame may be warped considerably without interfering with the satisfactory operation of the generators. This is due to the fact that each compartment between successive frame plates 314 is constructed as a unit, and each individual generator may be adjusted to deliver the desired current strength without affecting the adjustment of the other generators.

As above stated, I believe that the failures of prior experimenters with this type of instrument were due largely to the lack of the provision of means for driving the generators at a constant speed. For example, in a generator driven directly by gears, the irregularities in the speed of the generator due to the unavoidable irregularities in gear teeth even though machine cut with precision tools, would be so great as to cause the tones produced to vary in pitch to such an extent that the "music" would be intolerable. Similarly, in experimental devices in which the generators were driven by belts, the slight slippage of the belts or even slight variations in the tension and thickness of the belt caused by variations in temperature and humidity, would result in such excessive variations in the pitch of the tone produced as to render the instrument valueless, except possibly as a means for sounding one note at a time.

It will be noted that in the construction invented by me, the rotors are mounted adjacent the ends of the rotor shaft, and that only two rotors are mounted on a single rotor shaft. It is therefore possible to straighten the rotor shaft so that both rotors will turn concentrically.

Key action and key switches

Referring to Fig. 1, the lower key manual comprises keys F_0 to C_6 bearing reference characters corresponding to the notes of the musical scale. As shown in Fig. 3, each of the black keys of the keyboard, comprises a body 440 having a slot 442 at its rearward end to receive a support 444 to which it is pivoted by a rod 446 which may extend the full length of the keyboard. The supports 444 fit in suitable slots formed in straps 448 and 450 which are suitably secured to the framework of the keyboard. The forward ends of the bodies 440 of the keys are provided with recesses 452 which receive pins 454 which serve as guides for compression coil springs 456. Upward movement of the black keys is limited by a strip 458 of felt or other suitable material.

Each of the white keys comprises a body 460, the rearward end of which is pivotally supported in the same manner as the black keys, and which is provided at its forward end with a projecting flange 462. The key is normally held in its uppermost position by a compression coil spring 464 held in position by a pin 466, the upper end of which projects through an opening formed in the flange 462. Upward movement of the white keys is limited by a strip of felt 468 secured to the inwardly turned flange of a front finishing plate 470. The downward movement of the white keys is limited by a felt faced stop 472 extending longitudinally of the keyboard, whereas downward movement of the black keys is limited by a felt faced stop 474 likewise extending the length of the keyboard. Each of the black keys and each of the white keys is provided with an adjustable set screw 476 for the operation of the contact switches.

Referring to Figs. 3, and 13 to 17 inclusive, the contact switches 477 are supported by a plurality of vertical plates 478 which have lugs 479 peened to a horizontal supporting plate 480, the latter being suitably secured to the top board 336 (Fig. 3). The vertical supporting plates 478 are each provided with a pair of elongated vertical slots 482 to receive a number of strips 484, 486 of insulating material. These strips each have notches spaced along one edge thereof which are adapted to engage the plates 478, this engagement being maintained by a number of wires 488, 490, which hold the strips 484 and 486 at the upper and lower ends respectively of the slots 482.

As shown in Fig. 14, the strips 484, 486 are each provided with a plurality of rows of apertures 492, there being one vertical row for each key of the keyboard. Switch contact elements 494, as best shown in Figs. 13 and 15, are carried in the supporting strips 484, 486. The contact members 494 are conformed that they may be slipped through the apertures 492 from the left (Figs. 13 and 15), being held against retraction by the engagement of a notch 498 with the insulating strip 484. The end of the contact member 494 adjacent the notch 498 has a longitudinal slot 500 formed therein, so that the end of the member may be bent as indicated in Fig. 15 to allow the ends to spring outwardly and cause engagement of the notch 498 with the strip 484.

The member 494 is preferably made of spring bronze. The end of the member 494 has a notched extending portion 502 for facilitating the making of a soldered connection with a wire. Each of the vertical rows of contact members 494 is provided with an actuator 504 suitably slotted to embrace the contact members and held in position by a pair of shoulders 506 formed on each of the contact members and by a strip 508 of insulating material which rests upon the lowermost of the row of contact members. The insulating strip 508 projects through slots 510 formed in the intermediate contact members 494 and is held against removal by the uppermost of the contact members 494 since the slot in the latter is not as long as the slots 510 formed in the intermediate contact members.

A rivet 512, preferably made of silver but which may be made of other suitable material, is secured at the end of each of the contact members 494, forming a contact point for engagement with bus-bars 514, 515, 516, 517, 518, 519 and 520, each of which preferably has a strip 522 of silver secured thereto. The silver strip is preferably autogenously secured to the bus-bar which may be made of a baser metal. The bus-bars 514 to 520 each has associated therewith a strip 524 of insulating material, the bus-bars and insulating strips being secured to the horizontal supporting plate 480 by bolts 526 which are suitably insulated from the bus-bars.

From the above description of the contact switches it will be apparent that although a large number is required for a single instrument, they can be relatively economically manufactured and assembled. After having secured the strips 484, 486 in place, all except the upper contact member 494 need merely be pushed into place until their notches 498 engage the strip 484, and then after inserting the insulating strip 508 the uppermost contact member 494 may be pushed into place, thus locking the actuator 504 in position, since the insulating strip 508 is held against removal by the uppermost contact member. The bus-bars 514 to 520 need, of course, merely be assembled upon the bolts 526 and clamped in place by tightening the nuts on these bolts.

Each of the contact members 494 is connected by a high resistance wire 528 to one of the soldering lugs 436 (Fig. 4) which are riveted to the insulating top plate 339 and which form one of the terminals of each of the generators. The wires 528 are each of substantially the same length so as to offer the same amount of resistance and are led through slots 356 formed in the wooden strips 352, 354 (Fig. 4) to a longitudinally extending central comb 530 which is riveted to an insulating strip 532 secured to the board 336. By leading the wires 528 through the slots 356 and the slots in the comb 530, the slack in the wire may be taken up so that all of the wires will be taut and not tend to interfere with one another.

The upper key manual 210, which comprises keys C_3 to C_5 inclusive, is constructed in a manner substantially identical with that of the lower key manual and will therefore not be described in detail. The various parts of the upper key manual which correspond to those of the lower key manual have similar reference characters applied thereto, (except that the bus-bars are designated 514*a* to 520*a* instead of 514 to 520) and it is therefore believed that further description thereof is unnecessary.

The pedal keyboard (Figs. 1, 20, and 21) comprises twenty pedals, twelve of which are white pedals 536, and eight of which are sharp or flat note black pedals 537, the pedals being designated by the tones controlled thereby, namely, C_0 to G_1. As shown in Fig. 20, the pedals are held against a pair of felt covered stops 538, 539, by a relatively strong compression coil spring 540. Each of the pedals is held against lateral movement by a pin 541, the ends of which are anchored in the baseboard 542 and the stop 538, and which extends through a suitable slot 543 formed in the end of the key. The forward end of each key is guided by a pin 544 which projects into a drilled hole 545, and which is surrounded by a felt packing 546.

Suitable felt stops 547, 548 and 549 are provided to limit downward movement of the pedal. Seven contact switches 550 are provided for each of the pedals, these switches being arranged in groups of four and three, positioned in tandem. The contact switches of the group of three are adapted when the pedal is depressed to complete a circuit to a bus-bar 551, while the group of four completes a circuit to a bus-bar 552. It will be noted that one bus-bar thus provides the return circuit for three generators (the generator of the fundamental tone and its second and third partial) while the other bus-bar provides a return circuit for four generators (namely, the fourth, fifth, sixth and eighth partials). The contact switches may be of the general construction above described with reference to the lower key manual, and the bus-bars preferably have contact surfaces of silver, and the contact points at the ends of the contact members are preferably silver rivets, as described above.

The contact points of the contact members 550 of a group are pressed together and against the bus-bars 551, 552 respectively, by a plunger 553 which is pressed outwardly from its housing 554 by a compression coil spring 555. The degree of compression of the latter may be varied by means of an adjustable plug 556. The force necessary to close both groups of contacts for a single pedal is slightly less than that required to compress the spring 555. In normal operation when a pedal is pressed on either side of the spring 540, the plunger 553 will ordinarily not move in its housing 554. When, however, the foot is placed in the center of the pedal directly above the coil spring 540, the pedal as a whole may be translated downwardly and thus the central portion of the pedal will be moved a distance approximately twice as great as if the pedal were pressed upon either side of its center. Under these circumstances the plunger 553 will be forced inwardly into its housing 554 compressing the spring 555 and thus preventing damage to the contact members 550. When the forward end of the pedal is pressed it will be apparent that the rear stop 538 will act as a pivot whereas when the pedal is pressed at a point in the rear of the coil spring 540, the forward stop 539 will act as the pivot for the key.

The swell pedal mechanism (Figs. 22 and 23) comprises a pedal board 564 mounted for pivotal movement upon a shaft 566, the shaft being supported upon a metal housing 568 which is suitably secured to the baseboard of the instrument. A gear segment 570 is secured to the pedal 564. Pivotal movement of the pedal 564 is opposed by friction washers 571, 572 which surround the shaft 566 and are pressed against the end of the pedal 564 and the gear segment 570 respectively by a strong compression coil spring 574 which surrounds the shaft 566 and the tension of which may be adjusted by a nut 576 threaded on the end of the shaft 566. The casing 568 is sufficiently flexible that the spring 574 will exert sufficient pressure upon the pedal to hold it in any position to which it may be adjusted and frictionally to oppose movement of the pedal so that it may be conveniently operated by means of the foot. The gear segment 570 meshes with a pinion 577 secured to the rotating shaft 578 of a potentiometer 580. The potentiometer is mounted upon an insulating plate 582 secured to the housing 568 by a bolt 584. A shield 586 is provided to enclose the potentiometer 580. Oscillatory movement of the pedal 564 is limited by a pair of felt covered rods 581 mounted in the housing 568.

Explanation of the chart, Figs. 28 and 28a

It may be well at this time to refer to the chart, Figs. 28 and 28*a*, from which the connections to the various key switches and to the various generators may readily be determined. This chart also indicates the reference characters of the driving and driven gears for each rotor together with the numbers of teeth on these gears.

In the eighth column the frequency of the current generated by each of the rotors is indicated. This frequency may readily be compared with the theoretical frequency of the note in the equally tempered musical scale (A=440) which appears in the ninth column.

In the tenth column the reference character of the rotor which is utilized to generate the second partial ($2n$ or twice the frequency of the current generated by the fundamental n rotor), is given.

The eleventh, twelfth, thirteenth, fourteenth and fifteenth columns similarly given the reference characters of the rotors utilized in generating the third, fourth, fifth, sixth, and eighth partials or harmonics of the fundamental for each of the keys. The second, fourth, and eighth partials are exact harmonics of the fundamental, while the third, fifth and sixth are as close as the tempered musical scale permits.

As an illustration, this chart may be read as follows: The line commencing C_3 indicates that when this key is depressed a connection is made to the generator having rotor 37. The rotor 37 has sixteen high points and is driven by an 85-tooth gear 102 on the countershaft and a 104-

tooth gear 162 on the rotor shaft. The generator having rotor 37 generates a current having a frequency of 261.538 cycles per second, which is very close to the theoretical frequency 261.625 of the note C_3 in the equally tempered musical scale (A=440).

Depression of the key C_3 will also complete a circuit to the generators having rotors numbers 49, 56, 61, 65, 68, and 73, these generators supplying respectively substantially the second, third, fourth, fifth, sixth and eighth harmonics (the third, fifth and sixth harmonics will not be exactly true harmonics but will have frequencies corresponding with notes of the equally tempered musical scale).

Electrical circuits—generators to keys

Referring to Figs. 27 and 27*a*, the synchronous motor and the countershaft are diagrammatically illustrated as driving seven rotors. For the purposes of illustration the rotors selected are those which are usable in producing the tone of C_3, these rotors being numbers 37, 49, 56, 61, 65 68, and 73.

The generator windings 430 which surround the permanent magnets 424 of these generators, each has one of its terminals connected to a common conductor indicated as a ground. Each of these windings 430 will have substantially the same impedance at the frequency which it normally generates, in the present instrument approximately four ohms. The windings for the generators of the higher frequencies will therefore have a smaller number of turns than those of lower frequency. The other terminal of each of the generators has a plurality of the high resistance wires 528 connected thereto. The generator 37, it will be apparent by reference to the chart Figs. 28 and 28*a*, is connected to eight different key switches, namely, the switch for pedal C_0, the switches for keys F_0, $G_0\#$, C_1, F_1, C_2, and C_3 of the lower manual, and key C_3 of the upper manual.

In the diagram, (Figs. 27 and 27*a*) the key C_3 of the upper manual, key C_3 of the lower manual, and pedal C_1 have been selected as illustrative of the remaining keys. It will be noted that the generator having the rotor 37 is connected through a resistance 528 to a contact member of the switch for upper manual key C_3, through a similar resistance 528 to a contact member of the switch of the lower manual key C_3 and through a similar resistance wire 528 to the contact member of the base pedal C_1. The remaining contact members controlled by the upper manual key C_3 are respectively connected by means of resistance wires 528 to the generators 49, 56, 61, 65, 68 and 73 (the reference character of the rotor being for convenience utilized as the reference character for the generator as a whole). The remaining contact members of the lower manual key C_3 are likewise respectively connected by means of high resistance wires 528 to the last enumerated generators. The base pedal C_1 has one of its contact members connected to the generator 37 by means of a resistance wire 528 as previously pointed out and another contact member connected to the generator 49. The remaining connections to the contact members of the pedal C_1 are not illustrated in the wiring diagram since these members are connected to the generators 13, 25, 32, 41 and 44 respectively (see chart, Figs. 28 and 28*a*).

Selective synthesizer

As shown in detail in Figs. 24 and 25, a plurality of stop keys 588 are provided by means of which the relative proportions of electrical energy derived from the generators of the different partials may be controlled so as to produce a tone of the desired timbre or quality.

As shown in Fig. 1, it will be noted that there are four stop keys 588 in a group to control the tone quality for the upper key manual, and seven stop keys 588 to control the tone quality for the lower manual. The stop keys 588 are pivotally mounted upon a rod 590 supported upon vertical plates 592 (Fig. 24) which have lugs 594 peened to a horizontal supporting plate 596. The vertical plates 592 in turn support vertical rows of contact members 494 which are operated by an actuator 504. The switch construction is substantially identical with that previously described and it is therefore unnecessary to describe it in greater detail.

The contact rivets 512 of these switches for the lower manual are adapted to make contacts with bus-bars 598, 599, 600, 601, 602, 603 and 604 respectively. These bus-bars are connected by suitable conductors with the bus-bars 514 to 520 inclusive, respectively, as shown in the wiring diagram Figs. 27 and 27*a*.

Each of the stop keys has an adjustable set screw 606 threaded therein for engagement with the end of the actuator 504 and is provided with a slot 608 for engagement with a latch 610. There is a latch 610 for each stop key of each group, the latches of each group being fixedly secured to a shaft 612 mounted in angle brackets 614 by means of a collar 615 and set screws 616 as shown in Fig. 25.

One or more torsion springs 618 are provided normally to urge all of the latches 610 of a group counterclockwise (Fig. 24), so that when a stop key 588 is depressed the latch 610 will, after the stop key reaches its lowermost position, move counterclockwise and retain the stop key in depressed position. It will be noted that downward movement of a stop key will cause clockwise movement of all of the latches 610 of the group a distance beyond that required to release any other stop keys which may have been held depressed, due to the shape of the nose 620 of the latch. Upward movement of the stop keys is limited by a felt faced stop 622 secured beneath the cover panel 624 which in turn is secured to the horizontal plate 596 by screws 626, a spacer 628 being interposed between the cover panel 624 and the upper edges of the vertical supporting plates 592 thus aiding in holding the switch assemblies firmly in position.

Nine binding posts 630 are threaded in the base 632, locked therein by a nut 634 which is held from rotating by a pin 636. A plurality of flexible wires 638 each have one end connected to one of the contact members 494 (Fig. 24) and at their other end are secured to a relatively thick brass washer 640, a plurality of which may be placed over any one of the binding posts 630 and secured thereto by a thumb nut 642.

The binding posts 630 are connected as indicated in the wiring diagram, Figs. 27 and 27*a*, to various taps of the primary 644 of an output transformer having a core 646. By thus connecting the output of the generators of the fundamental and harmonics to cause the currents generated thereby to flow through different numbers of turns of the primary of the output transformer, the quality of the tone produced may be readily varied. The wires 638 permit the owner of the instrument to utilize the stop keys 588 rapidly to condition the instrument to produce tones of any desired quality and permit the owner to change the predetermined combinations at will, as will more fully appear hereinafter.

As shown in Figs. 27 and 27*a* one of the stop keys 588*a* shown at the right in Fig. 27 is adapted to connect the bus-bars 598 to 604 inclusive to slides 648 to 654 inclusive, respectively.

As shown in Figs. 18 and 19, the slides 648 to 654 each comprise a bar 656 having an upturned handle portion 658. The upper surfaces of these bars are marked with the numerals 0 to 8 inclusive. The bars are longitudinally slidable in a pair of guide plates 660, 662 which are suitably apertured to receive the bars and are secured to a block 664 of insulating material. Each of the slide bars 656 is provided with a resilient sliding contact 666 which is adapted to make contact with any one of a plurality of bar-shaped conductors 668 to 676 inclusive, which are in turn connected to the various taps on the primary 644 of the output transformer. The sliding movement of the slide bar 656 is limited by a pair of stop pins 678, 679, secured thereto.

Each of the slide bars 656 has a flexible conductor 680 secured at the inner end thereof, the conductor being sufficiently elastic to permit the slide to move freely back and forth so as to bring the sliding contact 666 into electrical contact with any one of the conductor bars 668 to 676. The latter bars are imbedded sufficiently deeply in the insulating block 664 that portions of the latter project above the upper surface of the bars and thus enable the sliding conductor 666 to act as a resilient detent for the slide bars, holding them in set position against accidental displacement due to inadvertent jarring of the instrument.

The conductors 680 are connected by wires 682 to the vertical row of the contact members of the stop key 588*a* shown at the right in Fig. 27*a*. When this latter key is depressed the bus-bars 514 to 520 of the lower key manual switches will be connected through the bar conductors 598 to 604 inclusive to the slide bars 648 to 654 inclusive respectively. The slide bars may then be selectively positioned to cause all of the currents generated by the various generators of partials of depressed keys of the lower manual to flow to any one of the desired taps on the primary 644 of the output transformer. The fundamental tone current produced by the generator 37 upon the depression of key C_3, for example, may be conducted through a greater or lesser number of turns of the primary of the transformer by shifting the slide bar 648. Similarly, the current from the generators 49, 56, 61, 65, 68 and 73 may be conducted through the desired number of turns of the transformer by suitable manipulation of the slide bars 649 to 654 inclusive, respectively. The relative proportions of the currents from the generator of the fundamental and the generators of the various harmonics may thus be readily adjusted to produce a musical tone of the desired quality.

Output circuit

The various bus-bars 668 to 676, inclusive, are connected to taps on the primary transformer. The bus-bar 668 is grounded. The number of turns of the primary transformer between the bus-bars 669 to 676, inclusive, and the bus-bar 668, respectively, are indicated in the following table in which the maximum impedance of the output circuit looking into the primary of the transformer is given for different numbers of turns:

	Turns	Impedance
		Ohms
668–669	6	.0075
668–670	8	.015
668–671	11	.031
668–672	16	.0625
668–673	22	.125
668–674	32	.25
668–675	45	.5
668–676	64	1.0

It will be noted that the impedance of the transformer, looking into the primary winding is relatively low as compared with the impedance of each of the coils 430 of the generators, the impedance of the latter being approximately 4.0 ohms. Thus, even though a generator is connected to the bus-bar 676, the impedance offered by the primary 644 of the transformer will be only one-fourth of that offered by the winding 430 of the generator. The reasons for and advantages of this relationship will be pointed out in greater detail hereinafter.

The output circuit comprises a resistance of 100,000 ohms as represented by the potentiometer 580, which, it will be noted from Fig. 27*a*, is connected directly to the terminals of the secondary winding 700. The secondary 700 of the output transformer 646 should have approximately 447 times as many turns as the primary 644 in order properly to reflect the output load into the primary to give the impedance values listed above.

Likewise connected in series to the terminals of secondary winding 700 is a resistance element 704 and a condenser 706. For the purpose of illustration the element 704 may have a resistance of 9,000 ohms, while the condenser 706 may have a capacitance of .01 mfd.

The variable contact member 70[illegible] of the potentiometer 580 operated by the swell pedal 564 is connected by a shielded conductor 710 to the grid of a vacuum tube constituting part of an amplifier 712, the filament of the first stage tube of the amplifier being connected to the ground. The amplifier may be of any suitable construction, its output being fed to a loud speaker 220 through a cable 218.

Tremolo mechanism and circuits

Referring to Figs. 5*b*, 6 and 11, the previously mentioned pinion 290 upon the rotor shaft 264 of the synchronous motor (Fig. 6) meshes with a gear 718 secured to a shaft 720 rotatable in bearings mounted in the side frame plate 254 of the motor and in the motor laminations 246. The shaft 720 has an eccentric 722 rigidly secured thereto, the eccentric being adapted to engage a resilient flexible contact member 724 which together with its counterpart 726 is mounted in an insulating block 728 secured to the side frame plate 254 of the synchronous motor. Thus, whenever the synchronous motor is in operation the contact point of the contact members 724 and 726 will be pressed together periodically by the eccentric 722, five times per second.

The contact members 724, 726 have conductors 730, 732 connected thereto, respectively, the wire 730 (Fig. 27*a*) being connected to the ground and the wire 732 leading to one side of a condenser 734 having a capacity of .002 mfd. The other side of the condenser 734 is connected to the variable contact member of a rheostat 736 having a maximum resistance of 10,000 ohms, the end of resistance wire of this rheostat being connected to the grounded terminal of the secondary 700 of the output transformer. A resistance element 738 in the order of 2,000,000 ohms is connected between the conductors 730 and 732, forming a shunt around the contacts of the interrupter contact members 724, 726.

Due to the circuit employed, the tremolo effect will be more pronounced in tones of high frequency than in the low frequency tones.

Operation of instrument by direct current

In places where alternating current of the proper frequency is not available, the synchronous motor may be run from storage batteries or other source of current by using the tuning fork interrupter diagrammatically illustrated in Fig. 27.

When current other than the proper alternating current is to be used, the line switch 744, through which alternating current to the synchronous motor is regularly supplied, is opened and a similar switch 746, the poles of which are connected to the source of direct current, is closed. A tuning fork 748 has a contact member 750 secured to one of its prongs, this member having a point adapted to contact with a contact point at the end of an adjusting screw 752 threaded in a suitable stationary support 754 and locked in adjusted position by a nut 756. An electro-magnet 758 is positioned between the prongs of the fork, having one of its terminals connected to a source of direct current and the other terminal connected to the contact member 750. The adjusting screw 752 is connected to one terminal of the synchronous motor while the other terminal of said motor is connected to the source of direct current.

The tuning fork is provided with a pair of adjustable weights 760, one upon each of the prongs, which weights may be moved longitudinally on the prongs and locked in adjusted position by means of set screws 762. By shifting the weights 760 the frequency of vibration of the tuning fork may be varied so as to produce a pulsating current of the proper frequency for driving the synchronous motor.

When the instrument of my invention is to be played with other instruments which are not tuned to the same pitch, it may be desirable to operate the synchronous motor from a suitable direct current source and adjust the weights on the tuning fork until the instrument is in tune with the other instruments.

Operation

To condition the instrument for operation, assuming a suitable source of alternating current, the switch 744 is closed and the motor started by spinning it at approximately its synchronous speed by means of the starting crank 764 shown in Fig. 5b. Due to the interposition of the ratchet wheel 284 and pawl 286 the motor can be rotated only in the proper direction by the starting crank. With a little experience the operator will readily be able to determine the proper speed at which to start the motor. The inertia element 294 together with its resilient and frictional connection with the rotor shaft of the motor will make it possible for the motor to start when launched at a speed above its synchronous speed. If desired, a suitable auxiliary starting motor may be substituted for the hand starting crank. After the motor has been started, the switch 766 may be closed to supply power to the amplifier. If desired a common switch may be provided to take the place of switches 744 and 766. The instrument will then be in condition for use.

The musician will then depress one of the stop keys 588 in each of the groups 228 and 230 so as to predetermine the tone quality of the instrument for each of the manuals. Slides 222 may then be positioned to predetermine the quality of the tones controlled by the bass pedals.

If a tremolo effect is desired the knob 768 is adjusted to the position which gives the desired degree of tremolo effect, the knob 768 being connected to the movable contact of the rheostat 736 (Fig. 27a). The instrument may then be played in the manner of an organ with, however, several slight differences in technique.

In view of the fact that the sound is instantaneously produced upon depression of a key, whereas in a pipe or reed organ there is a certain time interval between the depression of the key and the production of the sound, it is possible to play trills and runs which could not be executed upon an organ.

The various wires 638 (Fig. 24) which lead to the switches controlled by the stop keys 588, may be connected so that upon depression of one of the stop keys the manuals may be conditioned to produce different tone qualities such, for example, as those of the flute, oboe, French horn, cello, violin, calliope, or any other instrument producing a sustained tone as distinguished from percussion instruments. The tone quality may be predetermined to simulate any instrument wherein the tone is constant in quality and in which the tones are produced as separate notes as distinguished from notes produced by slurring, such as in the slide trombone.

If the musician playing the instrument desires a tone quality other than those predetermined by the pre-set combinations controlled by the stop keys 588, he may depress the stop keys 588*a* and 588*b* and then experiment by manipulation of the slide selectors 224, 226, until a tone of the desired quality is produced. If the new tone thus produced is particularly pleasing to the player, he may, by changing the connections of the wires 638 associated with one of the stop keys 588, to different binding posts 630, retain this combination permanently for instantaneous use whenever desired, merely by depressing that stop key to which the connections have been made.

More specifically, the musician having set the slides 224 of the lower manual to a position which causes the production of a pleasing tone, may read the number indicated by the slides. For example, assuming that he has found the setting for the lower manual shown in Fig. 19 to produce a very pleasing tone, he will note the number indicated by the slides, namely, 4,643,210. He may then disconnect the wires 638 which lead to one vertical row of contact switches from the binding posts 630, and connect the wire 638 for the uppermost contact member of the row to the binding post 630 having the indicia (4) (Fig. 25); the wire 638 from the second contact member to the binding post (6); the third contact member to binding post (4); the fourth to binding post (3); the fifth to binding post (2); the sixth to binding post (1); and the seventh to binding post (0).

It will be noted that means is always provided whereby any particular bus-bar of one manual may be connected to ground by connecting it to binding post (0), for instance. This must always be done whenever one set of partials is to be omitted, for failure to do so will interconnect various generators such as to put undesired frequencies into the output circuit. This results from the fact that if a number of keys on one manual are simultaneously depressed, a number of generators will be connected through their series resistances 528 into a common open-circuited bus-bar. Currents flowing in these circuits will then be reflected into other bus-bars which are not so open-circuited but are connected to the output, and the resulting chords will be unsatisfactory.

It will be apparent that by adjustment of the slide selectors 224, a selection of any one of several hundred thousand different qualities of tone may be obtained. The musician will thus be able by experimenting to condition the instrument to produce practically any desired tone quality.

It should be borne in mind that in the present instrument any desired musical composition may be played, since there is practically no limitation upon the chords which may be played or upon the rapidity with which trills and the like may be executed.

Theory of operation

From a reading of the foregoing description of the construction and operation of the instrument of my invention it will be apparent that many novel principles of construction and operation are employed. There are a number of theoretical considerations which might well be pointed out here in some detail, which are fundamental and which should be understood in order thoroughly to comprehend the nature of my invention.

It is well known that the quality of a musical tone is determined by the relative amplitudes of the fundamental tone and various harmonics thereof. In other words, any sound having a regularly repeating wave form may be analyzed into a fundamental tone of certain amplitude and a plurality of harmonics of the fundamental tone, the amplitudes of which may be zero or have any other value, and similarly any musical tone of repeating regular wave form may be reproduced by synthetically combining various proportions of the fundamental and of the various harmonics of that tone.

In combining the fundamental with its harmonics, the relative phase angles of these partials is immaterial insofar as the effect upon the ear is concerned. Apparently the ear itself analyzes sound waves into the fundamental and its harmonics and the perception of the quality of the tone is determined solely by the relative amounts of energy at the different frequencies. This may readily be demonstrated by the fact that varying only the relative phase angles of various partials of a musical tone will cause changes in the form of the composite wave, these changes being so pronounced that except to the experienced person they would appear to be entirely different sounds, yet it has been found that all of them will sound alike.

A further principle which must be taken into account in the practical construction of an instrument such as above described is what is known as Weber's law, which, as applied to sound, is to the effect that equal increments of intensity of sound as interpreted by the ear are increments which bear a definite relationship to the intensity of the sound before the increment. Thus equal steps in "loudness" are steps increasing in a geometric ratio as far as energy is concerned. Thus it is possible to produce a tone of the same quality but of greater intensity merely by setting the selectors in such manner that each digit is one greater than that of the previous setting. If the slide selector for one manual has a given setting and the slide selector for the other manual be set with each slide at a digit one greater than that of the corresponding slide of the other manual, the tones produced by the manuals will be of different degrees of loudness but of the same tone quality.

Taking into consideration Weber's law, the taps on the transformer as above pointed out are respectively at 6, 8, 11, 16, 22, 32, 45 and 64 turns. This series of numbers consists of the nearest whole numbers to a geometrical series commencing with 6 and having the square root of 2 as a ratio. Since the voltage is proportional to the number of turns, and since the energy is proportional to the square of the number of turns, and it is the energy which determines the intensity of the tone ultimately produced, it will be seen that connecting a generator to a tap on the transformer one step higher than that to which it was previously connected, will result in substantially doubling the intensity of the tone produced.

Elimination of "natural" harmonics and "key click"

Presumably the noise known as "key click" or "key thump" resultant upon closing and opening the circuits including the generators, unless means are provided to prevent it, is a noise of variable and varying frequency, but, generally speaking, will have powerful components of relatively high frequency. I have entirely eliminated this disturbance in the circuits previously described, particularly by the provision of the by-pass 704, 706, about the high resistance 702 in the output circuit. This by-pass is not, strictly speaking, a filter circuit, since a portion of currents generated at every frequency will flow through this by-pass. However, the by-pass will offer greater impedance to low frequency currents than to currents of higher frequency.

Although the wave forms of the peripheries of the rotors are very carefully computed and the rotors are cut with a very high degree of accuracy for the purpose of obtaining as nearly a sine wave current as possible, it is probable that, due to unavoidable inaccuracies in the forms of the rotors, and due possibly to inductive coupling or additional reasons, the currents generated are not absolutely perfect sine waves but contain harmonic components of higher frequencies. These components would be "natural harmonics", that is, mathematically exact harmonics, as distinguished from the harmonics of the tempered musical scale, which are utilized in the instrument. Since the frequencies of the "natural harmonics" in many instances would differ sufficiently from the frequencies of the "tempered harmonics" of the tone being sounded to cause an audible beat, it is very desirable to eliminate these parasitic natural harmonics, even though they be of relatively low amplitude.

The by-pass 704, 706 will permit much of the energy of the natural harmonics to by-pass the resistance 702, since for these harmonics the impedance of the by-pass is much less than it is for the fundamental. Obviously the by-pass 704, 706 will likewise form a low impedance path for the tempered harmonics, but although a very large proportion of the current generated by the higher frequency alternators is thus dissipated, adjustments may readily be made in these alternators, in the manner previously described, so that the current which passes through the resistance 702 of the potentiometer 580 will be of sufficient strength to produce a tone of the same apparent intensity as that produced by the generators of low frequencies.

Assuming that the stop key 588*a* (Fig. 27) has been depressed and is locked in depressed position, the slides 648 to 654 of the lower slide selector 228 will be connected to the bus-bars 514 to 520 inclusive respectively and, depending upon the positions of the slide bars 648 to 654, will be connected to certain selected taps of the transformer primary 644, the return circuit being completed through a common conductor shown in the wiring diagram as a ground.

The current induced in the secondary 700 of the output transformer will flow partially through the resistance 702 of the potentiometer 580 and partly through the by-pass circuit including the resistance 704 and condenser 706. The by-pass circuit offers less impedance to currents of high frequency than to currents of low frequency. As a result, if the current produced by a single generator has "natural harmonics" (whose frequencies are exact multiples of the frequency of the fundamental) a much greater percentage of the currents of the harmonics than of the current of the fundamental will flow through the by-pass circuit 704, 706. As a corollary the harmonic current will be reduced in the resistance 702 of the potentiometer 580.

Owing to the great loss in energy of the higher frequencies occasioned by the by-pass circuit 704, 706, the generators of higher frequencies are made much more powerful than the generators of low frequencies. Thus while a great amount of energy is dissipated in the by-pass circuit, sufficient energy is retained to make all of the notes sound with equal loudness.

When the machine is built and operated for the first time, it will be found that the different notes produced on one manual will be of different degrees of intensity. The loudness of each note depends on a large number of factors which includes among others the characteristics of the loud speaker, and its resonance to different frequencies, the errors of amplification of the amplifier taken as a whole, and the variations in voltages generated by the different alternators. Compensation may be made for all of these variations by moving the magnets of the different alternators so as to make the air gaps larger or smaller and thus raise or lower the generated voltage at each frequency in order that the desired over-all effect of equal intensity to the ear may be obtained. Thus the difficulties of frequency distortion which are present in all forms of music and speech transmission or recording such as are found in the telephone, phonograph, sound on film, and radio, are completely avoided. The quality of the music produced is dependent directly on the artistic judgment of a listener who may change the electrical input in such fashion as to obtain the desired effect as determined by his ear, as contrasted with other electrical musical devices in which an effort is made to so modify the apparatus and circuit as to reproduce accurately a tone which was acoustically generated.

It will be realized that in view of the fact that all the generators are made to the same general dimensions, alternators generating higher frequencies will out-put much more energy than low frequency generators. This is due to the fact that the energy of the generator arises from the change in flux and the number of times that this change takes place in a given time interval. As the magnets are all the same, the total flux tends to be about the same as does the change in flux. The energy output of the generator therefore tends to be proportional to frequency. In the output circuit less energy is wanted for high frequencies than for low frequencies and this effect is attained through the by-pass 704, 706, previously described.

Elimination of "robbing"

When a key, let us say the key C_3 of the lower manual, is depressed, seven circuits are substantially simultaneously completed by the seven contacts of the multiple switch associated with that key. Each of these circuits will include the winding 430 of a generator, and a high resistance 528. The resistance of the wire 528 is so high relative to the impedance of the remaining portion of the circuit that it will substantially determine the amount of current which will flow through the circuit. For example, the impedance of the generator winding 430 may be 4.0 ohms, and resistance of the wire 528, 15.0 ohms. The impedance of the remaining portion of the circuit is very low since even though the generator is connected across all of the turns of the primary 644 of the transformer the impedance will be but one ohm.

It will therefore be apparent that even though a plurality of circuits to a single generator are closed at the same time, the current flow through each of the different circuits will be substantially the same as if but one circuit had been completed to that generator. In other words, the completion of additional circuits to a single generator does not tend appreciably to diminish the current flow through the circuit originally completed. It may be said that the circuits do not "rob" one another. Although the circuits are connected in parallel to the generator, the individual resistances of each circuit are so high relative to the impedance of the generator, that only a small proportion of the electrical energy which might be generated is actually utilized by a single circuit. In fact, even if all of the circuits were simultaneously completed, the generator would still have a large reserve. Stated differently, the generators are very much more powerful than necessary to produce the desired signal, or, the circuits may be considered as extremely inefficient conductors of the required amount of energy.

Numerous changes, substitutions and modifications may be made in the instrument disclosed without departing from the more basic principles of my invention. The accompanying claims are therefore intended to include within their scope such obvious modifications, equivalents and substitutions as will be readily suggested to those skilled in the art.

For example, in the accompanying claims the terms "translating means" and "means for translating electrical pulsations into sound" are used in the general sense, since the instrument of my invention may be directly connected to a radio broadcasting apparatus and the translating means will then be the radio receiving apparatus. Similarly, where reference is made to "alternators" or "generators of alternating current", these terms are not intended to be considered in their restrictive sense but rather to include such substitutions as generators of pulsating direct current, oscillating vacuum tubes, vibrating reeds, or other means for producing a current having an alternating component.

Throughout the specification various constants have been set forth. These constants, such as the values of the impedances, the resistances, and capacitances, utilized in the circuits and in the sizes of the various parts and, as, for example, in the numbers of teeth in the gearing, may be varied, especially if compensatory changes are made in other parts of the instrument, and I therefore do not wish to be limited to the precise details set forth herein, but desire to include within the scope of the accompanying claims all such equivalent constructions as may be usable to accomplish the same results in substantially the same way.

I claim:

1. In an electrical musical instrument in which alternating current is used to produce musical tones, a manual including a number of different keys, a set of switches operated by each key, a plurality of sources of alternating current, and electrical connections from each of said sources to said switches, such that switches of different sets are connected to a single one of said sources.

2. In an electrical musical instrument in which alternating current is used to produce musical tones, a manual including a number of different keys, a set of switches operated by each key, a source of alternating current, electrical connections from said source to several switches, each of a different set, a plurality of additional sources of alternating current of different frequencies, and means for connecting said additional sources to other switches of said sets of switches.

3. In an electrical musical instrument in which alternating currents of different frequencies are used to produce musical tones, a manual including a number of keys, a set of switches operated by each key, a plurality of tone wheel generators of alternating current, and electrical connections from each of said generators to different switches of a plurality of said sets of switches.

4. In an electrical musical instrument, the combination of a plurality of sources of alternating current of different frequencies suitable for the production of musical tones, a plurality of manually operable keys, a plurality of switches controlled by each of said keys, selective means for translating current from said sources into sound, and a plurality of circuits from each source, each of said circuits including a high resistance, completed upon closure of said switches for conducting current from selected ones of said sources to said translating means.

5. In an electrical musical instrument, the combination of a plurality of generators of different frequencies, each of said generators having a pair of terminals, a common conductor connected to one terminal of each of said generators, and a plurality of separate branch circuits connected to the other terminal of each of said generators, a plurality of key operated multiple switches, one terminal of each of said multiple switches being connected in one of said branch circuits, and a high impedance connected in series in each of said branch circuits, said impedances each being of value greater than the internal impedance of the generator to which it is connected.

6. In an electrical musical instrument, the combination of a plurality of generators of different frequencies, each of said generators having a pair of terminals, a common conductor connected to one terminal of each of said generators, and a plurality of separate branch circuits connected to the other terminal of each of said generators, a plurality of manual keys, a plurality of multiple switches, one operated by each of said keys, one terminal of each of said multiple switches being connected in one of said branch circuits and permanently connected to one of said switches, and a current-limiting resistance element in each of said branch circuits.

7. In an electrical musical instrument, the combination of a plurality of generators of different frequencies, each of said generators having a pair of terminals, a common conductor connected to one terminal of each of said generators, and a plurality of separate branch circuits connected to the other terminal of each of said generators, a plurality of key operated multiple switches, one terminal of each of said multiple switches being connected in one of said branch circuits, and a high resistance in the form of a resistance wire physically connecting said generator and said key switches.

8. In an electrical musical instrument, the combination of a plurality of generators of different frequencies, each of said generators having a pair of terminals, a common conductor connected to one terminal of each of said generators, and a plurality of separate branch circuits connected to the other terminal of each of said generators, a plurality of key operated multiple switches, one terminal of each of said multiple switches being connected in one of said branch circuits, and a high resistance element in each of said branch circuits between the switch and the generator, the impedance of said element being greater than the internal impedance of the generator.

9. In an electrical musical instrument, the combination of a plurality of alternating current generators, a common conductor connected to one terminal of each of said generators, a plurality of resistance elements connected to the other terminal of each of said generators, said resistance elements being of high value relative to the impedance of the generators, a keyboard, switches operated by the keys thereof, said resistance elements which are connected at one end to a single generator being connected at the other end to switches associated with different keys of the keyboard, and translating means connected to said common conductor and the other terminals of said switches.

10. In an electrical musical instrument, the combination of a plurality of keys, sources of alternating current of different frequencies, means for translating electrical pulsations into sound; and a plurality of circuits, each including one of said generators, arranged to be closed upon the operation of one of said keys to said translating means, and a current limiting impedance in each of said circuits for greatly limiting the current flow through the circuit and making it possible simultaneously to operate a plurality of keys each of which controls a circuit from a common generator without causing a substantial reduction in the current flow through each circuit.

11. In an electrical musical instrument, the combination of a plurality of alternating current generators capable of generating currents of different frequencies, a high resistance connected in the output circuit of each of said generators, a tapped transformer, key controlled means for connecting selected ones of said generators to selected taps of the primary of said transformer, the whole of said primary having an impedance

low relative to the impedance offered by each of said resistances, and means connected to the secondary of said transformer for translating the currents produced therein into sound.

12. In an electrical musical instrument, the combination of a plurality of generators of alternating current of different frequencies, means for driving said generators at a constant speed, a conductor common to said generators, a key means controlled by said key to connect the output of selected ones of said generators to said common conductor, means connected to said conductor for translating electrical currents into sound, and means to change the relative proportions of the currents derived from the separate ones of the selected generators whereby the quality of the tone produced by said translating means may be progressively varied to produce musical tones of different qualities.

13. In an electrical musical instrument, the combination of a plurality of alternators each generating currents of a frequency differing from that of the others, the frequencies being those of the musical scale, a plurality of manually operable keys for connecting the output of selected ones of said alternators in parallel, means for selectively changing the relative proportions of energy drawn from the selected ones of said alternators, a second group of manually operable keys, means controlled by each of the keys thereof for connecting the same group of alternators in parallel as are connected by the corresponding key of the first group of keys, means for selectively changing the relative proportions of energy drawn from said alternators upon depression of the key of the second group, means for connecting the output of said alternators resultant upon depression of the key of the first group of keys with the output of the alternators resultant upon depression of the key of the second group of keys, and means for causing substantially an additive increase in output upon the simultaneous depression of said keys.

14. In an electrical musical instrument having a plurality of rotary generators of currents of the frequencies of a musical scale and having means for combining the currents produced by a plurality of generators, means for preventing an appreciable portion of the output of one generator from flowing through the other generators comprising a current-limiting impedance in the output circuit of each generator.

15. In an electrical musical instrument having a plurality of generators of currents of the frequencies of a musical scale and having means for combining the currents produced by a plurality of generators, means for preventing an appreciable portion of the output of one generator from flowing through the other generators comprising a current-limiting resistance in the output circuit of each generator.

16. In an electrical musical instrument in which musical tones are produced by electrical synthesis, separate conductors for the fundamental frequencies and for each of a plurality of the harmonics of the fundamental frequencies, said conductors being common for a plurality of different tones, an output transformer, and selective means for connecting each of said conductors to the primary of said transformer to cause the current in said conductors to flow through a selected number of turns thereof.

17. In an electrical musical instrument, the combination of a plurality of circuits, means for generating alternating currents of different frequencies having the relation of a fundamental and its harmonics in said circuits respectively, a transformer, and means for connecting a selected number of turns of the primary of said transformer in each of said circuits.

18. In an electrical musical instrument in which musical tones of different timbre are generated and synthesized by combining alternating currents of different frequencies from different sources into a common output circuit for impressing a signal upon an audio-frequency amplifier and loud speaker system, a transformer for connecting the generators to the amplifier comprising a core and a winding connected to the amplifier, a plurality of generator circuits, and independent switching means for causing the current in each of said circuits to flow selectively through a greater or lesser number of turns around the core of said transformer.

19. In an electrical musical instrument in which musical tones of different timbre are generated and synthesized by combining alternating currents of different frequencies from different sources into a common output circuit for translation into sound, a transformer having a secondary connected to the translating means, and a selectively operable switching means for causing currents from said sources to flow through a greater or lesser number of turns of the primary of said transformer.

20. In an electrical musical instrument, a keyboard including a plurality of keys, a multipole switch operated by each key, a plurality of generators of different frequencies, conductors connecting one terminal of each of said generators to poles of switches associated with different keys, a plurality of conductors each common to a plurality of said multi-pole switches, means for translating electrical pulsations into sound, one terminal of said translating means being connected to the other terminal of each of said generators, and switching means for connecting said conductors to one of a plurality of terminals of said translating means, the terminal of said translating means to which it is connected determining the loudness of the sound produced by the translating means.

21. An electrical musical instrument comprising a keyboard having a plurality of keys, a multipole switch operable by each key, a plurality of generators of currents of different frequency, each of the poles of said switch being connected to a different one of said generators, a plurality of common feeders, each feeder connected to receive current from one pole of each switch, a transformer having a core and primary and secondary windings, an audio-frequency amplifier connected to the secondary winding of said transformer, and independent switching means for connecting each of said feeders to said transformer in such manner that the current in each of said feeders may be caused to flow selectively through a greater or lesser number of turns of the primary of said transformer.

22. In an electrical musical instrument, the combination of a plurality of key manuals, sources of alternating current of different frequencies common to said manuals, translating means, and circuits controlled by said manuals for conducting current from said sources to said translating means, each of said circuits including resistance means of high value relative to the impedance of the circuit as a whole.

23. In an electrical musical instrument, the combination of a plurality of alternators for

generating currents of frequencies corresponding to the notes of the tempered musical scale, key controlled means for combining currents from said alternators to produce tones of the desired timbre, an output circuit, and means in the output circuit for suppressing exact harmonics produced by individual generators.

24. The method of synthetically producing musical tones of the desired timbre, which comprises generating currents of frequencies corresponding to the tones of the tempered musical scale and which may include unwanted exact harmonics, combining said currents in predetermined proportions to produce the desired tone quality by utilizing frequencies which are not exact multiples but are very nearly exact multiples of one another to provide the various partials, and suppressing the exact harmonics in the output circuit which may be generated and which would beat with the inexact harmonics.

25. In an electrical musical instrument for producing tones of complex timbre by combining pulsations of different frequencies by the depression of a single key, a series of generators for producing electrical pulsations at different frequencies corresponding to the notes of a musical scale, a keyboard comprising a plurality of keys, a plurality of switches for each key, and a plurality of circuits arranged to be completed by said switches, each of said circuits including in series one of said generators, a current-limiting resistance of a value which is high relative to the inductive impedance of the generator, and a load of an impedance which is small relative to the impedance of said current-limiting resistance, at least a portion of said load being common to a plurality of said circuits.

26. In an electrical musical instrument for producing tones of complex timbre by combining pulsations of different frequencies by the depression of a single key, a series of generators for producing electrical pulsations at different frequencies corresponding to the notes of a musical scale, a keyboard comprising a plurality of keys, a plurality of switches for each key, and a plurality of circuits arranged to be completed by said switches, each of said circuits including in series one of said generators, a current-limiting impedance of a value which is high relative to the internal impedance of the generator, and a load of an impedance which is small relative to the impedance of said current-limiting impedance, at least a portion of said load being common to a plurality of said circuits.

27. In an electrical musical instrument, in which chords may be played and in which the tones composing the chord are produced by combining currents of frequencies corresponding to the tones of the tempered musical scale and are produced by different generators each of which may generate exact harmonics in addition to the desired frequency, means for preventing beats and out of phase addition of the energy of the fundamental of one tone of said chord and a multiple of frequency of another tone of the same chord which comprises means for utilizing the energy from the same generator as a source of energy for both the fundamental of one tone and the harmonic of the other tone of a chord being played, even though the frequencies may not be exact multiples of one another, and means for suppressing natural and consequently exact harmonics which may be present in the individual currents which are combined.

28. In an electrical musical instrument, the combination of a plurality of sources of alternating current of different frequencies corresponding to the different notes of the ordinary tempered musical scale, a plurality of key operated means for substantially simultaneously combining currents from different ones of said sources to produce a tone of desired quality and to combine the individual tones into chords, and means for suppressing natural harmonics present in the currents from said sources which comprises filtering means external to the sources, said filtering means comprising a by-pass having progressively less impedance to currents of higher frequency.

29. In an electrical musical instrument having a load of relatively low impedance, a plurality of generators of different frequencies and of relatively low impedance, and a plurality of selectively closable circuits of relatively high impedance for connecting the generators to the load.

30. In an electrical musical instrument, means for eliminating key-click comprising a resistance and a capacitance connected in series across the output circuit of the instrument and forming a by-pass offering greater impedance to low frequency currents than to high frequency currents.

31. In an electrical musical instrument, means for preventing key clicks comprising a high resistance connected across the output of the instrument, and a condenser and second resistance connected in series, in parallel with said high resistance across the output of the instrument, said second resistance being of greatly lesser impedance than said high resistance, and with said condenser forming a by-pass offering less impedance to currents of higher frequency than to currents of lower frequency.

32. The method of eliminating or reducing audible key clicks in electrical musical instruments, which comprises generating electrical power far in excess of that required and at the frequencies of the tones of a musical scale, passing the output of key switch selected generators through a high impedance by-passed by a circuit offering less impedance to currents of high frequency than to currents of low frequency, and amplifying the current flow in said high impedance and translating it into sound.

33. In an electrical musical instrument, a bank of alternators for generating currents of different frequencies, each alternator comprising a permanent magnet, a winding about said magnet and a rotor having a plurality of high points; a plurality of shafts each forming a mounting for two of said rotors, the number of high points on one rotor being an exact multiple of the number of high points on the other rotor on the same shaft, and sheets of magnetic material having bearings therein for said shafts and forming shields adjacent the rotors.

34. In an electrical musical instrument, a bank of alternators for generating currents of different frequencies, comprising a countershaft formed in a plurality of separate articulated sections, a plurality of plates forming bearing supports for said countershaft sections, gears mounted on said countershaft sections, a pair of rotor shafts, one at each side of said countershaft, and a driven gear on each of said rotor shafts meshing with a gear on said countershaft.

35. In an electrical musical instrument, the combination of a plurality of alternators, a countershaft for driving said alternators, a resilient driving connection between said countershaft and said alternators, a synchronous motor, and

a spring driving connection between said synchronus motor and said countershaft.

36. In an electrical musical instrument, an alternator for generating a current of predetermined frequency, said alternator comprising a rotor shaft, a rotor mounted upon said shaft, a driven gear mounted on said shaft, resilient means connecting said driven gear and said rotor for driving said rotor and shaft from said gear, positive stop means between said driven gear and said rotor to limit relative rotational movement therebetween, a synchronous motor, and a resilient driving connection between said motor and said driven gear.

37. In an electrical musical instrument, an alternator for generating a current of predetermined frequency, said alternator comprising a rotor shaft, a rotor mounted upon said shaft, a driven gear mounted on said shaft, resilient means connecting said driven gear and said rotor for driving said rotor and shaft from said gear, and positive stop means between said driven gear and said rotor to limit relative rotational movement therebetween.

38. In an electrical musical instrument, the combination of a plurality of plates of magnetic material secured together in parallel spaced relation, and a plurality of rows of rotor shafts having bearings supported by said plates, each of said plates except the end plates having a bearing common to two rotor shafts, the alternate ones of said shafts being in alignment and spaced laterally from the adjacent shafts.

39. In an electrical musical instrument, the combination of a bank of alternators for generating currents of different frequencies, some of the alternators generating currents of frequencies which are harmonics of the frequencies generated by other alternators of the bank, and a plurality of sheets of magnetic material, one of said sheets being positioned between each alternator and all other alternators which generate currents of frequencies which are not exact multiples of the frequency of the current generated by that alternator.

40. In an electrical musical instrument, the combination of a generator for producing current of a predetermined frequency with a high degree of accuracy, a rotor forming part of said generator, a relatively constant speed motor, a resilient driving connection between said motor and said rotor, and means for positively limiting relative movement between said rotor and said driving connection.

41. In an electrical musical instrument, the combination of a plurality of tone wheels, shafts for supporting said tone wheels, a synchronous motor, gearing connected thereto for driving said tone wheels at different speeds, and means individual to each of said shafts for damping hunting movement of the shaft.

42. In an electrical musical instrument, the combination of a shaft, a tone wheel rotor carried by said shaft, a gear loosely mounted on said shaft, a highly elastic spring connecting said gear and said shaft, and a relatively constant speed motor for driving said gear.

43. In an electrical musical instrument, the combination of a tone wheel rotor, a gear for driving said rotor, said gear being coaxial with said rotor and capable of oscillation relative thereto, and resilient means forming a driving connection between said gear and said rotor.

44. In a musical instrument, a rotating member for accurately generating pulsations of a predetermined frequency, a rotating element for driving said member, motor means for driving said element at a relatively constant speed, and a highly elastic resilient means connecting said element and said member, the resiliency of said means being so proportioned relative to the rotary moment of inertia of said member that relative movement between said member and said element will be of such long periodicity relative to the frequency of the current generated that the variation in the frequency of the pulsations generated by said member will not appreciably affect the musical quality of the instrument.

45. In an electrical musical instrument, the combination of a tone wheel rotor, a gear for driving said rotor, said gear being coaxial with said rotor and capable of oscillation relative thereto, and resilient means connecting said gear and rotor, the relation between the resiliency of said means and the rotary moment of inertia of said rotor and parts rotating therewith being such that any hunting oscillations set up in said rotor will be of a frequency which will not substantially interfere with the musical quality of the tone resulting from translation of the energy generated by said rotor into sound.

46. In an electrical musical instrument, the combination of a plurality of rotors forming parts of electric current generators, a synchronous motor for driving said rotors, and a resilient and frictional coupling connection between said synchronous motor and said rotors whereby pronounced hunting of said synchronous motor will not be transmitted to said rotors.

47. In an electrical musical instrument in which musical tones are produced by electrical synthesis, means for combining currents of different frequencies in any selected proportions to obtain the desired quality in the tone produced, and manually operated means for substantially instantaneously rendering said selective means ineffective and causing said frequencies to be combined in any one of a plurality of different predetermined proportions.

48. In an electrical musical instrument, the combination of means for generating currents translatable into musical tones, a synchronous motor for driving said means, and manually controlled means driven by said motor periodically to by-pass a portion of the current produced by said means to introduce a tremolo effect into the music produced thereby.

49. In an electrical musical instrument in which a plurality of alternating current sources of different frequencies are used to build up a complex musical tone, a plurality of rotary alternators, a manual including a number of different keys, a plurality of switches in separate circuits operated by each key, a common output circuit, and electrical connections between said alternators, switches, and output circuit, such that the terminals of a single such alternating current source may simultaneously be connected to said output circuit through switches operated by different keys of said manual.

50. In an electrical musical instrument in which currents of different frequencies are combined to produce a musical tone, a keyboard having a plurality of keys, a plurality of rotary electric generators of different frequencies, means for translating the current produced by said generators into sound, a group of switches operable by each of said keys, and means to conduct current from said generators to said translating means, said conducting means comprising individual

conductors of high impedance connecting each generator with switches of a plurality of different groups.

51. In an electrical musical instrument, the combination of a tone wheel rotor, a gear for driving said rotor, and a resilient driving connection between said gear and rotor, the resiliency of said driving connection and the moment of inertia of the rotor being so related that the natural period of oscillation of the rotor relative to the gear is at a frequency below the range effectively translated into sound by the instrument.

52. In a musical instrument, the combination of twelve or more rotatable pulsation generators, a common source of power for driving said generators, and means individual to each of said generators for transmitting power from said source to said generators, each of said means including an element of such resiliency relative to the moment of inertia of the moving parts of the generator with which it is associated that the natural frequency of oscillation of the latter is below the frequency of the pulsations generated by any of said generators.

53. In a musical instrument in which rotating pulsation generators are used to generate a series of frequencies which are related to one another in a manner closely approximating the incommensurate ratios of frequency of the twelve semi-tones of the tempered musical scale, a plurality of rotating generator assemblies, at least twelve in number, a common source of driving power and driving connections between said source and said assemblies adapted to rotate said assemblies at predetermined exact speeds which may be expressed in simple fractions of the speed of said source, each of said connections including a highly resilient, non-slipping driving element.

54. In an electrical musical instrument in which keys are utilized to switch the output of generators of different frequencies into a common output circuit, the generators of higher frequency generating much more energy than those of lower frequency, means for minimizing clicking sounds in the output when generators are connected to the output by the key operated switches, said means comprising means in the output circuit for suppressing the energy of high frequencies in the output such that high tones will be no louder than low tones, notwithstanding the much greater energy output of the higher frequency generators.

55. In an electrical musical instrument, a bank of alternators for generating currents of different frequencies, some of the alternators generating frequencies which are harmonics of the frequencies generated by other alternators of the bank, and a plurality of sheets of magnetic material separating the bank of alternators into groups, the alternators in each group generating frequencies having the relation of a fundamental and its harmonics.

56. In an electrical musical instrument, means for introducing a tremolo effect in the output of the instrument comprising, a resistance element, a condenser, a periodically operated current interrupter, means for connecting all of said elements in series across the output circuit of the instrument, and a high resistance shunted around said interrupter.

57. In an electrical musical instrument, the combination of a plurality of generators, a common conductor connected to one of the terminals of each of said generators, a plurality of multi-pole key-actuated switches, and a plurality of current limiting impedances, each having one end connected to a pole of one of said switches and its other end connected to the free terminal of one of said generators.

58. In an electrical musical instrument, the combination of a plurality of tone wheels, shafts for supporting said tone wheels, a synchronous motor, gearing connected thereto for driving said tone wheels at different speeds, and resilient means individual to each of said shafts for minimizing rapid hunting movement of said wheels.

59. In an electrical musical instrument, the combination of a tone wheel forming the rotor of an electrical current generator, means for rotating said tone wheel, and a resilient driving connection between said means and said tone wheel, the resiliency of said connection bearing a predetermined relation to the rotary moment of inertia of said tone wheel and parts moving therewith, so that the frequency of any hunting of said tone wheel will not impair the musical characteristics of a tone derived from the current generated by the tone wheel.

60. In a musical instrument, a rotatable element for generating pulsations, a constant speed motor for driving said element and a plurality of resilient and frictional mechanisms connected one to the other and forming a driving connection between said motor and said element.

61. In an electrical musical instrument, the combination of a loud speaker, an amplifier to energize said speaker, a plurality of alternating current generators, key-operated switches for connecting said generators to said amplifier, apparatus for minimizing key clicks comprising a current carrying net-work conveying the energy of low frequency impulses more effectively than the energy of high frequency impulses, said net-work being interposed between said switches and said loud speaker.

62. In a musical instrument of the class described, a plurality of generators of different frequencies, a common conductor joining one terminal of a plurality of said generators, an output circuit, a plurality of keys, a set of switches operated by each key, a current limiting impedance permanently connected between each of said switches and a terminal of one of said generators, a plurality of bus-bars connected to receive current from a plurality of said switches and to convey said current to said output circuit, selective means for short-circuiting certain of said bus-bars to said common generator conductor when said bus-bar is not to be used, for the purpose of preventing undesired parasitic frequencies in the output circuit.

63. In a musical instrument of the class described, a plurality of generators of different frequencies, a common conductor joining one terminal of a plurality of said generators, an output circuit, a plurality of keys, a set of switches operated by each key, a current limiting impedance permanently connected between each of said switches and a terminal of one of said generators, and a plurality of bus-bars connected to receive current from a plurality of said switches and to convey said current to said output circuit.

64. In a machine of the class described, the combination of a set of generators, a keyboard including a number of keys, one multiple contact switch for each key, and current-limiting impedances, one of said impedances being connected to each of the contacts of each of said switches and one of said generators.

65. In a machine of the class described, the combination of a set of generators, a keyboard including a number of keys, one multiple contact switch for each key, current-limiting impedances, one of which is connected to each of said switch contacts and to one of said generators, an output circuit, a coupling device connected to carry energy in various degrees from said generators through said impedances and switches into said output circuit, and manually operable means for producing as many different musical tone qualities of a single note as it is possible to obtain by mixing fundamentals and harmonics of that note in various energy proportions as determined by the degrees of energy coupling obtainable in said coupling device.

66. In a machine of the class described, the combination of a set of generators, a keyboard including a number of keys, a multiple contact switch operable by each key, means for combining the currents produced by said generators in any one of a plurality of selected combinations to produce tones of different qualities, and a single current limiting impedance connected to each of said switch contacts, each of said impedances being connected to predetermine the energy output of its associated generator, irrespective of the tone quality to be produced.

67. In an instrument of the class described, the combination of a plurality of generators, a plurality of multiple contact switches, and a current limiting impedance of a value greater than the reactive impedance of the generator permanently connected to each of the contacts of said switches and to one of said generators.

68. In an instrument of the class described, the combination of a plurality of bus-bars for collecting pulsations utilized as fundamentals and the various harmonics respectively, in the tones to be produced, an output circuit having terminals for producing intensity gradation, a plurality of manually operable elements adapted to be connected respectively to said bus-bars and selectively movable to connect their associated bus-bars with any one of said terminals, and a manually operable multiple switch for effecting connections between said bus-bars and said members respectively.

69. In an electrical musical instrument, a mechanism for altering the tone quality of the instrument comprising a plurality of manually movable members for controlling the proportionate intensity of the fundamental and various harmonics in the tone produced, respectively, each of said members being mounted for independent motion to a number of successive positions corresponding to progressive degrees of intensity of sound contributed to the whole by the particular harmonic or fundamental which said member represents, means to indicate the respective positions of said members, and semi-permanently connected means for maintaining connections corresponding to a determined setting of said members available for instantaneous use at will.

70. In an electrical musical instrument of the class described, a mechanism for altering the tone quality of the instrument comprising a plurality of manually movable members corresponding to the fundamental and various harmonic frequencies of which any tone is composed, each of such members being adapted for independent motion to a number of successive positions corresponding to progressive degrees of intensity of sound contributed to the whole by the particular harmonic or fundamental which said member represents, and means to render any particular setting of said members instantaneously effective.

71. In an electrical musical instrument for producing tones of complex timbre by combining pulsations of different frequencies by the depression of a single key, a series of generators for producing electrical pulsations at different frequencies corresponding to the notes of a musical scale, a keyboard comprising a plurality of keys, a plurality of switches for each key, and a plurality of circuits arranged to be completed by said switches, each of said circuits extending through the generator to one of the contacts of said switches and having a resistance high relative to the inductive impedance of the generator.

72. In an electrical musical instrument for producing tones of complex timbre by combining pulsations of different frequencies by the depression of a single key, a series of generators for producing electrical pulsations at different frequencies corresponding to the notes of a musical scale, a conductor connecting a terminal of each of said generators, a keyboard comprising a plurality of keys, a plurality of switches for each key, a plurality of connections between said conductor and each of said switches respectively, said connection including a current-limiting resistance of value which is high relative to the inductive impedance of the generator, and a common load for said generators having an impedance which is low relative to the impedance of said current-limiting resistance.

73. In an electrical musical instrument in which currents of different frequencies having the relation of fundamentals and their harmonics may be combined to produce complex musical tones, the combination of separate bus-bars for currents utilized in the tones sounded as fundamentals and each of the various harmonics respectively, a graded volume output device, and selectively operable elements for simultaneously connecting said separate bus-bars to predetermined different points of gradation of said output circuit, the points of gradation being arranged such that an increase in intensity will be obtained with increases in the impedance of the output device.

74. In an instrument of the class described, the combination of a plurality of bus-bars for collecting pulsations utilized as fundamentals and the various harmonics respectively in the tones to be produced, an output circuit having points of intensity gradation, a plurality of multiple switch contacts engageable with said bus-bars respectively, and movable conductors for semi-permanently connecting said contacts respectively, with selected ones of said points in the output circuits.

LAURENS HAMMOND.