ELECTRONIC ORGANS*

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THE history of organs goes back many hundreds of years, years which have seen a steady development in the scope and capacity of the instrument for producing music of many tone colours, and also in the way in which this scope can be readily and conveniently placed within the comfortable control of the player. Whatever our various tastes for music may be, it must be admitted by all, that for one instrument to be able to produce such a wide variety of tones varying from the softest strains of a flute or dulciana up to the mighty crescendos of a full orchestra, all under the control of one player, places the organ in a class of its own when the whole field of musical instruments is considered.

The advent of electricity brought to the organ builder many devices which have aided him in his endless quest for improvement of his instruments. The back-breaking job of the organ blower could be done by a small electric pump to provide wind and the heavy and cumbersome mechanical linkage between the keys and pedals and the pallets admitting air to the pipes could be replaced by fine gauge electric wires. These are two such improvements that readily come to mind.

However, the strides made in electrical research lead to the idea of not only using electricity to improve the scope and control of the pipe organ but of using it actually to produce the tones themselves and thus dispense with the necessity of large and costly pipes.

Electricity has, in fact, been used to produce music in many ways. The electric guitar and the "Novachord" are two examples of instruments using electricity within the unit generating the sound. However, it is in the field of organ building that most work has been done in this respect, as the scope made possible by producing tones electrically is almost unlimited.

Much has been written on the subject, notable amongst the publications which have appeared being the paper prepared by Winch and Midgley for The Institution in 1939 which is a comprehensive discourse on the whole subject of electronic music and the pipeless organ.

The Pipe Organ

In order that the requirements of an electronic organ may be fully appreciated, some understanding of the general layout of an orthodox pipe organ is desirable (Fig. 1).

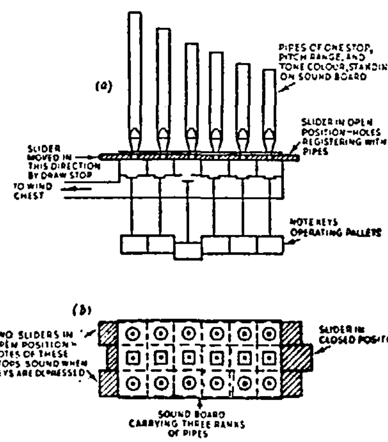

Fig. 1.—Elevation (*a*) and plan (*b*) of part of an orthodox pipe organ.

The column of air contained in a pipe is set in vibration by the flow of air, under pressure over a tongue or reed located at its lower end. The frequency of the note produced depends upon the length of the pipe and whether it is open at its upper end or closed (stopped).

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* Abstract of the Chairman's Address, which received a Letter of Commendation, read before the Bristol Section at St. James Church on 6th October, 1953, and before the Cardiff Section on 11th November, 1954.

Clearly, in order to provide notes of all the frequencies required in a 61-note keyboard, 61 pipes will be required of 61 different lengths. These are arranged on a common sounding board and, under this rank of pipes, a slider is provided with 61 holes drilled so that when the slider is critically located all holes register with their respective pipe entrances. The slider can then be moved lengthwise, closing the entrance to all pipes. The slider is operated by the familiar drawstop knobs, seen at the console. When the drawstop is pulled, all pipes of the rank are in readiness to be sounded when their respective keys are depressed.

The tone colour produced by a rank of pipes is a function of the design of the pipe, such factors as the material used, the shape of the pipe, wind pressure, type of vibrating tongue, baffling arrangements, etc., all affecting the nature of the sound produced.

In order to provide variety, a number of ranks are fitted, each giving its own particular tone colour, and each controlled by its own drawstop knob. The performer can then add or subtract the tone colours at will by operation of the drawstops, and can vary the volume of sound produced from the solo effect of one stop out, to the full organ (all stops out).

For convenience in playing, two or more manuals are provided and the stops are arranged in groups, each group being associated with one manual, and a further group for the pedal notes. This permits different tone colours to be arranged for each manual so that, for example, the right hand can play a trumpet tune on one manual to the accompaniment of diapason and string tones played by the left hand on another, while the feet will provide the bass effects using a further group of pipes. Arrangements are made so that one manual can be coupled to another, and manuals coupled to pedals to provide the performer with great flexibility in the control of all pipes of the organ. Many other facilities are provided on modern organs to place readily under the control of the performer the full scope of the organ. Organs of five or more manuals incorporating many thousands of pipes have been built, on which the variety of tones available, and the number of blends of tones producing the chorus effects, seems unlimited.

This will serve to illustrate the magnitude of the job facing the electronic organ designer in his effort to provide an instrument matching its orthodox counterpart in such matters as quality of tone and flexibility of control.

The Technical Problem

Turning now to the technical side of the problem, suppose a particular musical instrument, say a clarinet, sounds a certain note. The acoustic waveform produced will contain a fundamental sinusoid modified by the presence of many harmonics of varying intensity. The presence of these harmonics in their respective strengths gives the waveform the characteristic shape peculiar to the instrument being sounded, enabling the ear to recognize the instrument as a clarinet, and not as a tuba or violin. If, now, we can design an electrical device to produce a voltage waveform of identical shape to that of the acoustic waveform mentioned, and this voltage is amplified and passed to a loudspeaker, the resulting sound we will recognize as that of a clarinet. Here, then, is the essence of the matter.

Two ways are open to us if we wish to produce electrically a certain waveform, say that of a clarinet. Either we can generate pure tones, sinusoidal in waveform, and blend these in the correct proportions corresponding to the fundamental and harmonic content of the clarinet waveform—in other words, synthesize our waveform from generated sinusoids of fundamental and harmonic frequencies—or else we can generate directly the complex waveforms we need. All electronic organs work on one or other of these two principles. Whichever method is adopted, arrangements must be made to produce the fundamental frequency, together with its associated harmonics, of all 61 notes on the keyboard, and

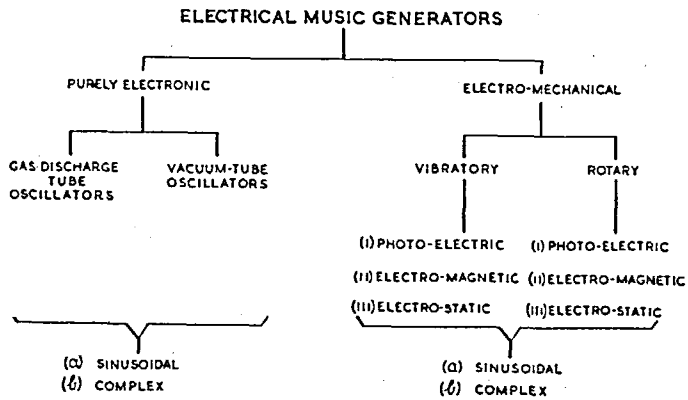

Fig. 2.—Types of electrical music generators.

when this is achieved we have an organ of one stop—the clarinet in our example. Clearly, in order to simulate a pipe organ, we must arrange for many different 61-note series of waveforms to be available, each representing a stop, or rank of pipes, on a pipe organ.

Electrical Tone Generators

Electrical tone generators can be split into two main categories—purely electrical methods such as gas-discharge tube oscillators, or vacuum tube oscillators, or electro-mechanical methods (Fig. 2). Organs using the former types of generators are correctly termed "electronic organs," whereas those employing the latter type would be more correctly termed "electro-mechanical organs." However, the term "electronic organ" is loosely used to describe all forms of pipeless organ.

The electro-mechanical method involves the use of moving parts and can be split into two sections—one where the moving element is performing a vibratory motion, and the other a rotary motion. In either case, the "pick-up," or element producing the basic voltage, may be photo-electric, electro-magnetic, or electro-static. In all methods whether purely electronic, or electro-mechanical, the generators may be designed to produce either sinusoidal or complex waveforms.

The various types of tone generator referred to are so different from each other, that a detailed examination of them all would be rather lengthy. The two types which have been utilized in two commercial organs that have become well known in this country, namely, the Hammond organ and the Compton "Electrone," are of the electro-mechanical class and both employ rotary generator elements. The Hammond generators are of the electro-magnetic type giving pure sine waves, and the Compton uses electro-static generators producing complex waveforms which are used in various ways to produce the characteristic tones found in normal pipe organs.

However, before describing these organs, it is worth glancing briefly at some of the other types of generator systems.

Taking first the purely electrical generators, Fig. 3 shows the circuit arrangement for a gas-discharge tube oscillator that was utilized by Dr. Trautwein in 1930 in his instrument called the Trautonium. A neon tube is arranged in a resistance-capacitance circuit, the charging battery B being of 200 volts. When the switch S is closed, the battery charges the capacitor through the resistor R to a potential sufficient to strike the neon tube. The capacitor then discharges through a further resistor R_1 until extinction occurs. The cycle repeats at a frequency depending upon the characteristics of the tube and the circuit constants.

Fig. 4 shows the sawtooth voltage waveform appearing across the neon tube, and the voltage pulses produced across R_1 by the discharge current. The latter are applied to the grid of a triode valve and cause damped oscillations in two resonant circuits, tuned to different frequencies, in its anode circuit. The output is taken from both resonant circuits and the complexity of the waveform is further increased by deriving the anode voltage from the point X which is itself varying in potential. All the constants of the circuit, therefore, modified the tone colour of the resultant sound.

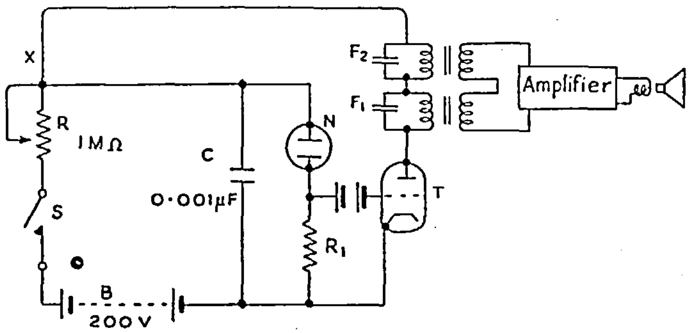

Fig. 3.—Circuit diagram of a "Trautonium."

Although the "Trautonium" was not in itself an organ, the principle was adopted by W. E. Kock in 1934 in an instrument he produced resembling an organ in tone and control.

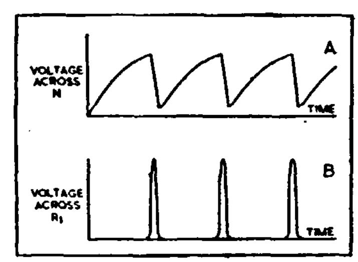

Fig. 4.—Waveforms in the "Trautonium."

The majority of electronic organs utilizing vacuum tube oscillators, use the principle of generating the higher frequency notes, and use frequency halving circuits to get the lower octaves.

Many electrical devices are used by the designer of purely electronic organs. Filter circuits are used in abundance to pick out required frequencies from the many generated in some forms of oscillatory circuit. Metal rectifiers can be used in frequency changing circuits, and for modulating one frequency by another, and so on.

An interesting organ developed by Coupleux and Givelet has been installed in many French churches, and contains 400 electronic valves.

In the electro-mechanical field several organs have been constructed using maintained vibrating reeds similar to the reeds used on harmoniums. The pick-up is electro-magnetic and consists of a permanent magnet located close to the vibrating reed, wound with a coil. Due to the type of vibratory motion of the reed the output from the pick-up is almost sinusoidal in waveform and a series of such generators, covering all the frequencies required in the range of the organ, provide the elements from which pipe-organ tones are synthesized. The reeds must be enclosed in a soundproof cabinet to prevent their vibrations being heard by direct acoustic transmission into the auditorium.

Many attempts have been made to construct organs using the photo-electric cell, some of which have been very successful. In one such

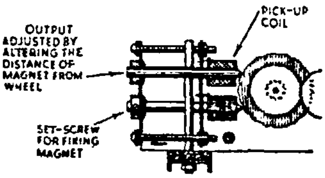

Fig. 5.—Magnetic generator of the Hammond organ.

instrument, named the "Photo-Tone" organ, developed by Mr. Edwin Welte, of Freiburg, Switzerland, the waveforms desired are photographed in concentric rings on a large disc of transparent material, and by rotating the disc, a beam of light passing through the disc is modulated in intensity by the waveform.

In another organ slits are cut through a metallic disc. The disc is circular, and the slits are arranged radially in concentric rings. A beam of light, controlled by a shutter operated by the keyboard note, is allowed to fall on them. A photo-cell is located behind the disc and the light transmitted through the slits is directed on to the cell by a system of lenses. When the disc is rotated, the cell is thus intermittently illuminated, and pulses of voltage are generated at a frequency dependent upon the number of slits and the speed of rotation. The waveform of this generated voltage depends upon the way in which the slits interrupt the beam of light and by suitably shaping the edges of these slits some control can be exercised over the tone of the sound.

The Hammond Organ

The Hammond organ is of American origin, named after its inventor, Laurens Hammond, and patented in this country in 1936. The generator consists of a small disc of ferrous material with an undulating periphery (Fig. 5). This disc is rotated at a constant speed and the pick-up is an electro-magnet located close to the edge of the disc. The disc, or "tone wheel" as it is called, is so cut that the output of the pick-up is substantially sinusoidal as the disc rotates, the frequency of the sine wave depending upon the number of high points on the disc, and the speed of rotation.

In all, 91 generators are provided involving 7 different types of tone wheel, having respectively 2, 4, 8, 16, 32, 64 and 128 high points. These are rotated by a system of gearing, the constant speed drive being obtained from a synchronous motor. By suitably designing the gear ratios, all frequencies of the organ range in semi-tone intervals can be generated.

The result of applying these generated frequencies to the amplifier and loudspeaker, via keying contacts, would be to produce sinusoidal, or "tuning fork" tones, and the depression of a number of keys simultaneously would simply result in the effect of an ensemble of tuning-forks which would quickly become tedious to hear.

The synthesizing of these basic sinusoids to produce the complex waveforms required is done in the primary of a mixing transformer, the fundamental tone, and its harmonics being fed into it from their respective generators via the key contacts and harmonic adjusting slide bars.

The key switches have seven contacts and are fed from generators delivering 1st harmonic (fundamental), 2nd, 3rd, 4th, 5th, 6th, and 8th harmonic frequencies of the key in question. These frequencies are fed onto the movable slide bars associated with each harmonic, which contact onto busbars feeding direct into tappings arranged on the primary of the mixing transformer. By pulling out the slide bar for any particular harmonic to one of the eight notches provided causing it to contact on a certain busbar, the strength of that particular harmonic can be adjusted.

The instrument is provided with two manuals and a set of pedals, the manuals having access to the full range of seven harmonics, and the pedals, 1st and 2nd harmonics only. The outputs from the three sets of busbars are respectively paralleled. The tappings on the primary of the mixing transformer, connected to the busbars, are arranged at intervals of turns in geometric progression, so that the increments of output from the transformer as one harmonic slider is notched from one busbar to the next, are logarithmic in progression, which, owing to the logarithmic response of the human ear to levels of sound intensity, gives uniformly increasing steps of loudness.

The harmonic adjusting slide bars are arranged in front of the player for his use, but it will be apparent that in order to obtain a tone similar to that of, say, a clarinet, the player must be acquainted with the Fourier analysis of the clarinet waveform if he is to correctly set his harmonic adjusters to give this tone. While this knowledge may be possessed by some organists, it is only of academic interest to the majority, and for this reason at the lower end of the manuals are provided nine reversed colour keys, which are not notes at all in the playing sense but act as "stops" providing certain instrument tones. Depression of one such key (which is then mechanically held down until released by depression of another), causes a particular pre-set combination of harmonics, each in suitable strength, to be fed direct onto the busbars and mechanical switching disconnects any combination that had previously been set thereon with the slide bars. The performer is thus provided with nine different available tone colours on each manual representing nine different musical instruments or blends of them, in addition to the wide variety of tone colours that can be synthesized using the harmonic adjusting sliders.

Three other reversed colour keys are provided at the left-hand end of each manual, making one octave of them in all, and provide other quick harmonic switching arrangements to aid the player in flexibility of control of the instrument.

One interesting point in connection with the loudspeaker equipment is worthy of note. In a normal pipe organ, there is a certain "build-up" time taken for a pipe to "speak" once air has been admitted to its lower end. During this time, which may be three or four tenths of a second for a bass pipe, the intensity of sound is building up from zero to its steady state value. This is acceptable, and in fact is a pleasing effect in a pipe organ as it gives a "shading" effect to the entry of each pipe voice. With nearly every electronic organ the alternating voltage from a generator is ever-present, and the depression of a key causes the sound to be instantly produced in the loudspeaker. This gives a rather sudden attack to the music, which is not altogether pleasing, and is a characteristic of nearly every elec.ronic organ.

The Compton "Electrone"

The inventor of the Compton "Electrone" organ was Mr. L. E. A. Bourn, of the John Compton Organ Co., Ltd., and, as previously mentioned, it also works on the rotary electro-mechanical principle, but this time the generators are of the variable capacity type.

The Compton instrument is, perhaps, one of the best examples of an electronic organ yet produced, in that the tones very closely resemble those of a pipe organ in nature.

The tone generator in essence consists of a stator and a rotor, the stator being a disc of insulating material sprayed with a metallic film on one side to a thickness of several thousands of an inch. Concentrically, on this metallic surface are engraved a number of waveforms cut to sufficient depth to isolate electrically, areas of metallic surface. Each area so produced is scanned by a metallic rib, or pad, integral with the rotor, so that as the latter is rotated, a periodically varying capacity is set up between each metallic area on the stator and its associated rib or pad on the rotor. If this varying capacity is charged from a d.c. source through a resistance an alternating voltage will appear across the resistance, which is fed into the grid of an amplifying valve. The sound produced when the output is passed into a loudspeaker will correspond in waveform to that of the metallic area on the stator. This is the principle of the electrostatic generator.

The actual generators in the instrument have

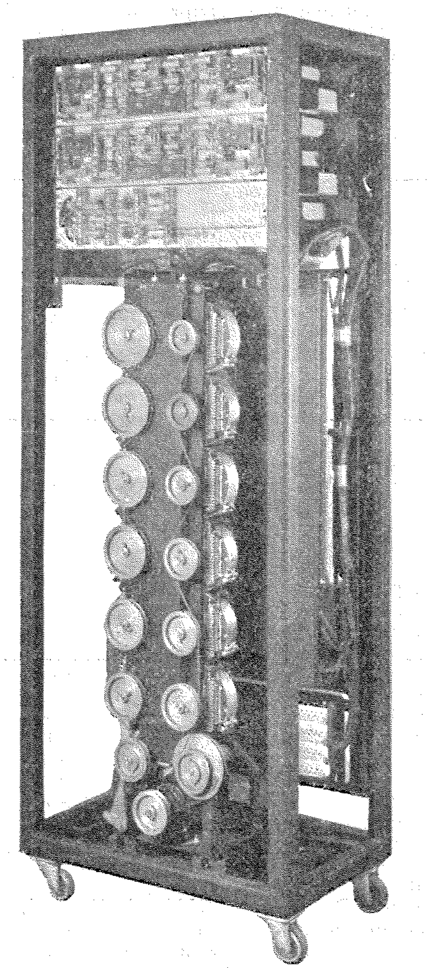

Fig. 6.—The generator cabinet of a Compton "Electrone." The twelve pulleys driving the generators are at each side at the top, the tensioning and motor-driven pulleys being at the base.

stators 5 in diameter and the waveform areas are bounded on one side by the engraved waveform line and on the other side by an engraved circle. The "negative" area on the remote side of the waveform line is kept at earth potential, and the scanning rib or pad on the rotor overlaps this area also, so that it is the differential capacity between these two areas when scanned by the rotor that is the capacity used. This enables the two wires leading to the generator to be solidly connected to the stator areas, and obviates the necessity to have slip-ring connections to the rotor.

One generator unit consists of two rotor elements back to back, mounted on the same shaft, and two stator elements on the outside of these, so that two sets of waveform areas are available in each generator unit.

Sufficient waveforms are engraved on the pair of discs in one such generator unit to provide five different basic tones or "ranks" (to use the pipe organ term) for each octave in the range of the organ, say all the C's. Another identical generator unit rotating at a speed $\sqrt[12]{2}$ times faster provides the same five basic tones for all the C sharps and so on, so that there are, in fact, only twelve generator units in the complete organ (Fig. 6).

The fact that all twelve are identical is a great advantage from a production standpoint, and the twelve different speeds in geometric progression with common ratio $\sqrt[12]{2}$ are obtained by an endless belt running over twelve pulleys of suitable diameters at the end of each rotor shaft. The constant speed drive is from a single phase induction motor, with voltage speed control which serves as the tuning adjustment.

The five basic waveforms or "ranks" are so designed that the normal pipe organ tones can be readily obtained by feeding direct into the grid of the first amplifying valve, the output from one or more disc circuits in proportions selected electrically by depression of the stop key at the console.

The first "rank" contains fundamental sinusoid modified slightly by the presence of some third harmonic. The second rank contains second harmonic modified by some sixth harmonic and, as this is, in effect, the octave of Rank I, economy in waveform areas is achieved by using the octave area for Rank I which, of course, has to be provided in any case. Rank III is termed "short odds" as it contains third harmonic in abundance with decreasing quantities of fifth and seventh. Rank IV is termed "long evens" and contains second harmonic with proportions of 4th, 6th, 8th, etc., up to the 32nd and Rank V, the "long odds" contains 3rd harmonic with proportions of all odd harmonics up to the 31st.

By using these ranks either singly (the flute tone, for example, which has the most nearly sinusoidal waveform of all musical instruments, uses Rank I alone) or in combination, the normal pipe organ tones can be very closely simulated. The clarinet waveform, for example, has only odd harmonics present and is rich in 3rd harmonic. This is achieved by using Rank I (1st with 3rd), Rank III (predominantly 3rd with 5th and 7th) and Rank V (3rd with odds up to the 31st). The 3rd harmonic is thus emphasized, while the other odd harmonics are suitably present.

It can be seen from this, that only the organ designer requires a knowledge of the Fourier breakdown of the various tones wanted, and the player has arrayed before him stop keys designated in terms standard to pipe organs, so that normal playing and control technique only is necessary.

The difficulty mentioned earlier regarding the sudden "attack" of tone as keys are depressed is to a great extent overcome in the Compton by the presence of resistance-condenser networks associated with the generator circuits, the time constants of which give a certain "build-up" delay to the generated voltage simulating the effect of the tone "build-up" delay observed in wind-blown pipes.

The console is of standard pipe organ layout, with two manuals and a set of pedals with stop key control. All the usual control devices found on a modern organ are present. The generator units, control gear and amplifiers are housed in the generator cabinet which can be located away from the console, and the loudspeakers (one for bass and one for treble) are situated to suit the acoustics of the building.

Acknowledgments

I would like to express my thanks to the John Compton Organ Co., Ltd., and in particular to Mr. L. E. A. Bourn, for their kindness in supplying Fig. 6 and other information regarding their organ. I would also like to thank, on behalf of The Institution, Rev. Whitehorn for the privilege of using St. James Church for our meeting, and for placing the organ there at our disposal.

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