AUTOMATIC MUSICAL INSTRUMENT

in aid of Research in India

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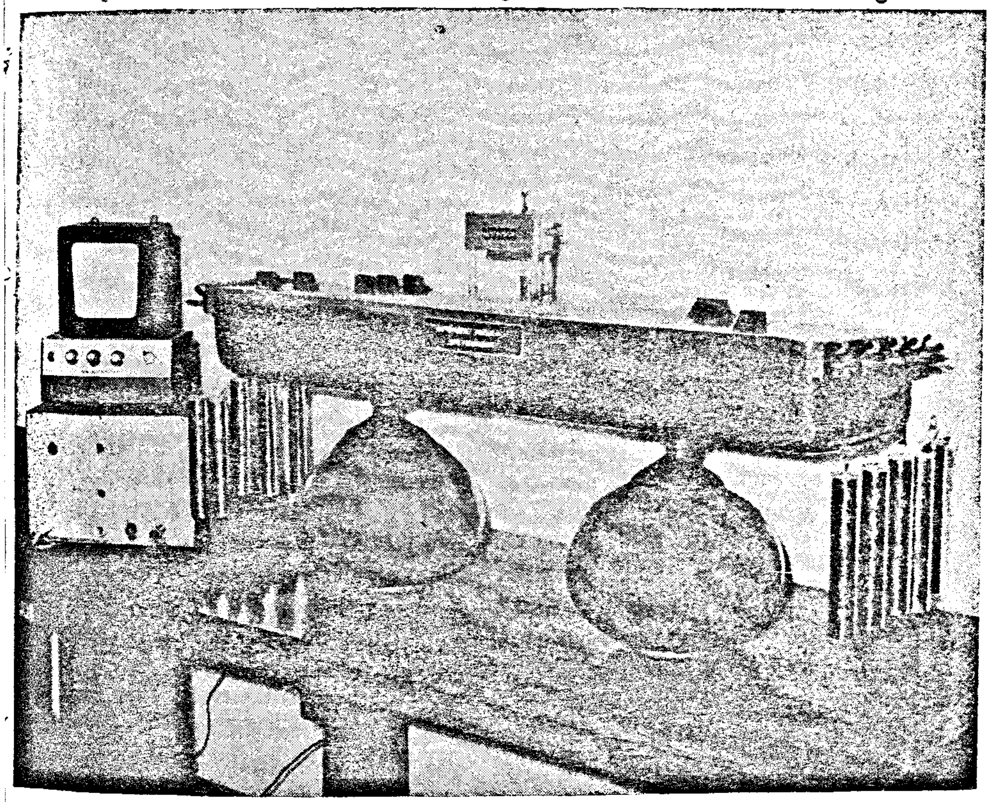
In recent years great developments have been made in the design of electro-musical instruments. A tone of any pitch, loudness and quality may be generated by electrical means. The prototype of these was the singing arc of Duddell.[1] The arc was shunted by a coil and a condenser. By varying the inductance of the coil, it was possible to play tunes on the arc. Electrical organs[2] have been built, using miniature rotating electrical alternators. A synchronous motor drives a series of ninety-one tone generators, through gears. The tone wheel is a polygonal plate of small size rotating near a permanent magnet on which a coil is wound. The speeds of rotation and the number of corners determine the pitch of the tones generated. Required timber is obtained by adding outputs from the generators. In photoelectric organs[3] a beam of light falling on a photocell is modulated by rotating transparent discs on which wave patterns are printed in black.

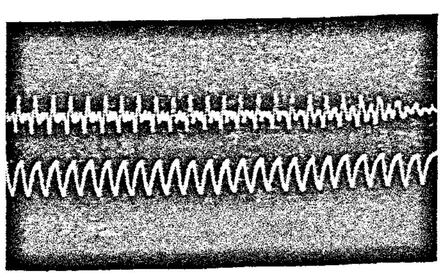
A number of electronic organs[4] employing valve oscillaors for generating tones have been commercialized. Most of the electronic organs consist of two manuals and a pedal key-board with a system of couplers. Each key connects appropriate oscillatory circuit to the loud-speaker, which finally emits the sound. Tones similar to present-day instruments are obtained by adjusting harmonic structure and growth and decay characteristics. Some of the combinations produce beautiful but hitherto unknown effects. Electronic instruments[5] have been developed in which pitch and loudness can be gradually varied as finely as in a violin.

In electro-mechanical instruments the system is essentially the same as the conventional string instrument, save that the sound board is replaced by electrical means. In Electrical Piano[6] vibrations of the string are converted into electrical variations by means of electro-magnetic transducers and sound is emitted by a loud-speaker after suitable amplification. One main



Automatic Musical Instrument

(a)
(b)



Trace (a) shows wave form of the vocal tone
Trace (b) shows corresponding saw-tooth wave-form produced by the wave shaping circuit.

advantage of the electrical piano is the wide dynamic range — the sound output can be adjusted so that it is suitable for the smallest apartment or the largest auditorium. In Electrical Guitar[7] a transducer is fixed to the bridge on which strings are stretched. Electrical variations are amplified and sound is emitted by a loud-speaker. The out-put can be made comparable to that of an orchestra.

Electromechanical instruments[8] have been constructed in which 'reeds', 'springs', 'tubes', 'rods' or 'bars' ae set into vibrations by hammers actuated by keys forming a key-board; vibrations are converted into corresponding electrical variations by suitable transducers and sound is emitted by a loud-speaker after amplification.

Key-board instruments with arrangements for tuning all the keys or instruments in which there is a provision for changing the pitch gradually will be found ueful for Indian melodic music. With these instruments it will be possible to generate music with new and radical tone complexes. In fact the electro-musical instruments, as they have less limitations, can outperform the conventional instruments in many ways.

These electro-operated instruments, however, differ from the author's invention in this respect that they are not automatic in action. Artists have to play on them.

The Automatic Musical Instrument[9] is an electro-mechanical device. It is a stringed instrument — which provides automatic accompaniment to any vocal (or instrumental) music. The instrument requires no artist to play on it; but the strings are set into vibrations by the musical notes of the singer/player.

The notes of the music are picked up by a microphone which converts sound waves into corresponding electrical variations. Microphone current is then passed through a wave shaping circuit which removes non-musical (consonant and high pitch sounds) sounds and gives a saw-tooth wave shape to the current. Out-put from the wave shaping circuit is amplified and passed through a 'reed vibration unit' which converts electrical variations into mechanical vibrations. Vibrations of the reed are communicated to a set of tuned strings through a small mass. The mass is held in suspension by all the strings and forms a common nodal point to all of them. When a note is sung, only the string tuned to this note vibrates while other strings practically remain stationary. As the singer sings in the microphone, the corresponding tuned strings resound in the same sequence and produce pleasing accompaniment. Vibrations of the reed are also loosely coupled to the sounding board which emits sound for intermediate tones and there is no sharp cut-off in intensity in passing from one note to the other. With the help of a single audio oscillator two strings tuned to *Sa* (Do) and *Pa* (Sol) or *Sa* (Do) and *Ma* (Fa) can be sent into continuous oscillations. This gives musical background[10] to the singer.

Apart from this novel use, the instrument can find a number of applications. The instrument works on resonance principle, and therefore, the strings stop vibrating when the notes sung are out of tune. The instrument can, therefore, serve to examine how correctly one can sing in tune[11]. This becomes easier with the help of indicator lamps electronically coupled to the strings. When a note is sung the string tuned to this note vibrates and the corresponding lamp glows. If the note is sung out of tune the lamp does not glow or becomes dim, depending upon the deviation. For taking intonation tests it is of course necessary that the strings of the instrument are correctly tuned.

A method has been developed for accurate tuning of the strings, using an audio oscillator — which need not be a calibrated one — and a simple harmonic generator circuit. This method also dos not require any musically trained ear. As the frequency of the oscillator is slowly reduced the strings are set into oscillations by the harmonics in the oscillator tone. If two strings are adjusted so that they are set into vibrations for the same setting of the oscillator, the first by the *pth* harmonic and the second by the *qth* harmonic of the oscillator tone, then the strings are correctly tuned in the ratio of p/q. Tuning of all the strings is possible because the notes in musical scales are inter-related by simple frequency ratios.

The most characteristic feature of the Automatic Musical Instrument is, that it plays as the monitor not only to the observer but also serves as a monitor to the singer, while he is actually singing. There is no need of any laborious observations of frequency but the instrument tells the observer and the singer straight away whether the correct scale is followed or not for the whole of the song.

It has been found that the method of tuning the strings can be applied for tuning all the basic scales which cover about 170 *raga-s**. The method of tuning throws light on '*Sruti* Scales' and explains in a new way the propriety of diving an octave into twenty-two parts.[13] Tuning of the strings is easily possible when different notes in a scale are represented by *Sruti* numbers (with few modifications) in place of relative frequencies.

Frequency ratios and corresponding *sruti* intervals are as follows:

Frequency ratio	*Sruti interval*
2/1	22
3/2	13
4/3	9
5/4	7

Multiplication or division of relative frequency by a frequency ratio corresponds to increasing or decrasing the *sruti* number by the corresponding *sruti* interval. This is possible provided the numbers 22, 13, 9 and 7 are proportional to the logarithms of 2/1, 3/2, 4/3, and 5/4 respectively, and actually it is very nearly so. More exactly we get

$$\frac{\text{log. } 2}{22} = \frac{\log 3/2}{12.869} = \frac{\log 4/3}{9.131} = \frac{\text{log. } 5/4}{7.082}$$

Sruti numbers can, therefore, be considered as one or two figure logarithms for convenient representation of the frequency ratios. There is, however, no rounding off of the actual frequency ratios, or there is no equal temperament. For example, a frequency ratio 9/8 = 3/2 x 3/4 corresponds to the interval of (13 — 9) = 4 *sruti-s*.

*Frequencies allotted are taken from the existing literature.[12]

If keynote frequency is taken as 240, then frequency of the note of *sruti* number 4 is 240 x 9/8 = 270. Frequencies of other notes in a scale can be found in a similar way. In some cases, however, a note denoted by a certain *sruti* number can be obtained in two different simple ways. The actual frequency that can be assigned to the note depends upon how this note is interrelated in a scale. For example a note of *sruti* number 20 can be obtained from the key note (*sruti* No. 0) in two ways and can have two different assigned frequencies.

(i) Key note———▷Note of *sruti* number 20.
$0 + 13 + 7 = 20.$
(240 x 2/3 x 5/4 = 450)

(ii) Kenote————▷Note of *sruti* number 20.
9 + 9 + 9 — 7 + 7 9 = 20.
(240 x 4/3 x 4/3 x 4/5 x 4/3 = 455 $\frac{1}{9}$)

It is, however, desirable that the cases of duplicate frequency values should be minimum. This is possible provided the logarithms of the basic frequency ratios are very closely near to whole numbers. This was fairly achieved by the ancients by correctly choosing the number twenty-two for dividing the octave.

With this division the exact log numbers are very close to the whole numbers (12.869 close to 13 etc.) The greatest percentage error is only 1.4. Division of the octave must be such that the number of intervals should not be too large and the percentage error should be least. Calculations were made to see whether there was any other number which more suitable for the division of the octave:—

No. of intervals in the Octave	*Greatest percentage error*
12	3.4
19	1.9
20	7.3
21	3.4
22	1.4
23	5.8
31	1.0
34	0.79
53	0.36
65	0.35

It was seen that the percentage error decreases in an oscillatory manner, with increasing number of intervals and therefore no purpose is served merely by dividing the octave into larger number of parts. If the octave is to be divided into some other number of intervals, then as can be seen from the accompanying table, the suitable numers will be 31, 34, 53 and 65; but these numbers will no more be 'small' numbers. The number twenty-two satisfies both the required conditions and so it is the most appropriate number for dividing the octave.

The interval one *sruti* can be found in three simple ways (without using any basic interval more than three times).

Interval of one sruti	*Corresponding frequencies ratio*
(i) 7 + 7 — 13 ≐ 1	5/4×4/5×2/3 = 25/24
(ii) 13 + 13 — 9 — 9 — 7	3/2×3/2×3/4×3/4×4/5=81/80
(iii) 9 + 9 + 9 — 13 — 13	4/3×4/3×4/3×2/3×2/3=256/243

The successive frequency ratios between twenty-two notes in an octave are not, therefore, equal and can have one of the above values.

Some authors express the view that twenty-two notes in the octave are insufficient. This remark does not require any additional explanation because as has been shown, notes denoted by certain *sruti* numbers can have two slightly different relative frequencies. The number of *sruti*-s in an octave, however, remains *twenty-two*.

The Automatic Musical Instrument has been used for recording Melody-plot (time-pitch curve). For this purpose the indicator lamps which are electronically coupled to the strings of the instrument are arranged in a column. As notes are sung the tuned strings vibrate and the corresponding lamps glow in the same sequence. A photographic record of these lamps on a moving film gives 'Melody-plot' of music actually sung[14]. Study of these curves may reveal secrets of artistic beauty in music. Extensive work is now being conducted for improving this method for recording melody-plot. By replacing indicator lamps by relays it may be possible to play automatically other key-board musical instruments in unison or harmony with the vocal music.

As a result of tone analysis of certain musical instruments (like *tambura*) it has been noticed by the author that the richness in tone quality is due to constant phase fluctuations between fundamental and harmonics.[15] It is marked that the tones produced by electronic musical instruments, in spite of large harmonic content, apper dull[16]. This is perhaps because this particular factor governing the tone quality has been ignored.

An electronic apparatus is being developed by the author, to produce this phase modulation, for obtaining the peculiar richness in tone quality synthetically. The apparatus may be useful for artists for enriching their own voice.

Acknowledgement

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REFERENCES

1. W. Duddel, The Singing Arc, *Electrician* 46 (1900).
2. L. Hammond, The Novachord, *Electronics* 8 (1935).
3. P. Toulain, The Electronic Musical Instruments, *Revue d'Acoust* 3 (1934).
4. Olson, *Musical Engineering*, pp. 182—190.
5. F. Trautwein, Electro-music Instruments, *Funk* (1930).
6. Olson, *Musical Engineering*, pp. 182—190.
7.
8.
9. Government of India Patent No. 37672 granted to Shri H. V. Modak, A method of improving musical quality of the Automatic Musical Instruments, *Journal of the University of Bombay*, Nov. 1955.
10. H. V. Modak, *Continuous Musical Background in aid of 'Automatic Musical Instrument'*, Paper, Indian Science Congress, 1957.
11. H. V. Modak, A method of testing musical tuning and intonation with 'Automatic Musical Instrument' *Journal of the University of Bombay*, March 1968.
12. Firoze Framjee, *Text Book on theory and practice of Indian Music*, p. 108 to 116.
13. H. V. Modak, Propriety of dividing an octave into Twenty-two *Srutis*. *The Journa of the Madras Music Academy*, 1967.
14. H. V. Modak, *A new method for recording Melody-plot*, Paper — Indian Science Congress, 1959.
15. H. V. Modak, *Dependence of musical quality on relative phase of harmonics*, Paper, Indian Science Congress, 1960.