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INTRODUCTION TO SIMULATOR

〈Part 2〉

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3. Pipe Network Simulator

In order to study new planning, improvement and supplying method of water supply pipe and gas pipe, it is desirable that the relation among the pressure within the pipe, the amount of flow, etc. can be readily analysed. For such a purpose, the pipe network simulator is made. In the calculation of pressure within the pipe network and the flow, the numerical integration method based on repetitive calculations were made. This calculation which was done by the digital computer can also be called simulation, but in this article, an explanation on exclusive simulation in which direct simulation is employed will be given.

As for the direct simulation simulator, an electrical circuit identical to the pipe network is prepared and the current is made to correspond to the flow and the voltage is made to correspond to the pressure difference. There are the following advantages in comparison with the numerical integration.

(1) The calculation speed is fast. Calculations which obtain the stationary condition of the current and pressure can be obtained at once. The response of each portion in relation with the changes in load and supply conditions with the elapse of time can be found easily.

(2) The simulated circuit network is connected in the same layout (phasewise) with the actual pipe network, so the setting of problems can be done intuitively.

(3) Since the solutions appear in parallel on the meters, the overall flow and pressure distribution can be seen at a glance. In case pilot lamps are used as the pipe elements, in place where the loss is great, the lamps will shine brightly. Therefore, such places can be identified at once.

(4) It is economical (Of course this depends a great deal on the precision and the scale of the machine). From the various points mentioned above, such simulators are more suitable if the person who uses the simulators performs various trials while observing the results, then conducts the optimum designing, or makes the optimum supplying program.

On the other hand,

(1) If the system which you wish to simulate becomes large, the simulator will also become large, proportionally.

(2) It lacks flexibility, Needless to say, it cannot be used for purposes other than calculations for pipe networks. Furthermore, even in case it is applied for the calculation of pipe networks, if the accuracy or scale exceeds the limits even slightly, the problem can no longer be analysed.

In addition to the above, even if the assumption is changed slightly, it will become very difficult to analyse.

The above points are given as defects. In case of the digital computer, the advantages and disadvantages are reversed. Besides the abovementioned types, hybrid systems are also considered.

3-1. Principle of the Pipe Network

The relation between the amount of flow Q and the pressure difference H of the flow passing through the pipe can be expressed as follows:

$$H = k_p Q^n \quad \ldots\ldots\ldots\ldots \quad (27)$$

(Sometimes for H the difference between the squares of the pressures is taken) Although n varies according to the equations in most cases, 1.85 or 2 are used. k_p is a constant which is determined by experiments. For instance, in case $n = 1.85$ is used for the water pipes, William-Hagen's equation shown below is used.

$$k_p = 10.666 C^{-1.85} D^{-4.87} \ell \quad \text{.......} \quad (28)$$

where

C: Flow Coefficient
D: Diameter of Pipe
ℓ: Length of Pipe

On the other hand, as it is well known, the following relation exists between the current and the voltage in the electrical circuit network.

$$E = RI \quad \text{.......} \quad (29)$$

If the resistance changes with the amount of current, the voltages at both ends of the resistance will be non-linear function of the electrical current. If a suitable non-linear resistance is used, the following relation can be satisfied

$$E = KI^n \quad \text{.......} \quad (30)$$

and this will be similar to the relation which exists in the pipe network between the pressure difference (or the difference in the squares of the pressures) and the amount of flow. Furthermore, no matter which intersection of the pipe network is taken, there is no acculula-tion of the water or gas that the flowed in. Therefore, the algebraic sum will be zero. In electrical circuit networks, the same equation is applied for Kirchhoff's Law. The difference that lies between the electrical circuits and the pipe circuits is that the former requires a return route. However, as shown in Fig. 20, if the outside pressure (or standard pressure) of the portion used is made to correspons with the ground potential, and if the pressure of the fluid is made to correspond with the electro-motive force, one to one correspoindence can be made completely with electrical circuits.

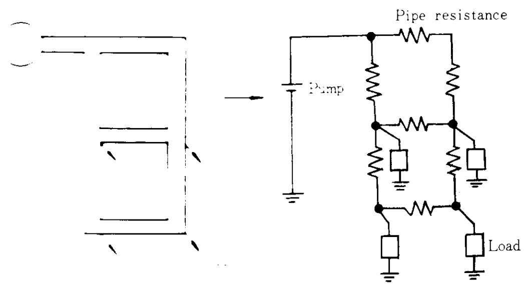


Fig. 20 Simulation of Pipe Network

3.2. Operational Element of Pipe Network

In the abovementioned way, in order to maintain the one to one correspondence, the matter which will become a problem from the practical standpoint is what to use for the abovementioned non-linear resistance. As shown below, various materials are used.

(1) The Method Using Lamps

According to McIloy's method which showed the first practical success for pipe network simulation, uses tungsten filament lamps for the pipe network elements. In this method, the change in resistance owing to temperature rise is utilized. The cost of each element is low, and there is further advantage that a rough idea of the pressure loss can be obtained by observing the brightness intensity of the lamps, as mentioned above. The disadvantage of this method is that the non-linearity is based on the physical property of the lamp. Thus, adjustments can not be made and the accuracy will be limited. Furthermore, it is necessary to prepare beforehand, various kinds of lamps which will correspond to all sorts of pipe network elements.

(2) The Method in which Two Terminal Function Generators are Used

Diode Function Generators in analog computers either combine the broken line characteristics of the diode, and give an arbitrary non-linear characteristic between the input and output, or based on the same concept, resistance of two terminal circuit can be made to be set as an arbitrary function of the voltage at both ends.

Fig. 21 shows this principle.
The diode is biased in the normal direction by the battery, the state of continuity is maintained, and the circulating current flows in the direction of the diagram. If the E for the battery of the reverse direction is determined adequately, there will be no voltage difference between terminal 1 and terminal 2, and they will act merely as a resistance in case of outside circuits. In case the voltage which is added to terminals 1 and 2 from the outside becomes large, each time it exceeds the battery voltage, the diode connected to that battery will enter a non-continuity state and the total resistance will become high.
In actual practice, alternating currents are rectified and used in place of the battery. Thus, it is necessary to maintain high precision by employing a power source stabilized by feed back. Furthermore, since this is a power sources which are insulated for direct current shall be used.

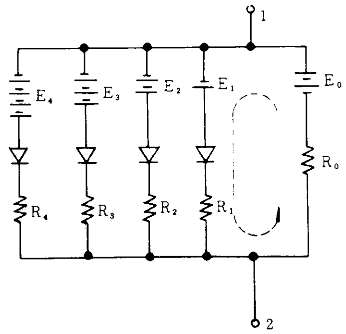


Fig. 21. Example of Two Terminal Function Generator

Fig. 22 shows an example of two terminal function generator using transistors. At this time, the saturation characteristics shown by the transistors as illustrated in Fig. 23 are utilized to maintain the relation shown in Equation (30).

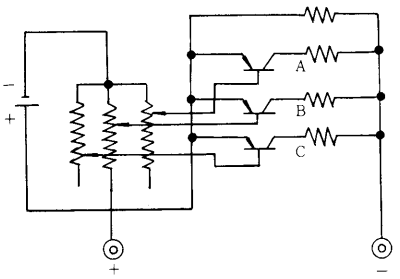


Fig. 22. Two Terminal Function Generator Employing Transistor Circuit

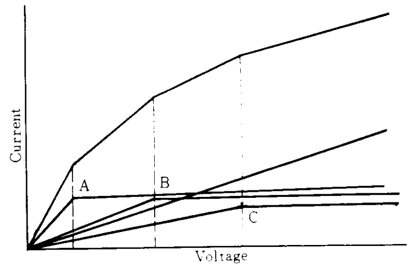


Fig. 23. Characteristics of Fig. 22

(3) In Case Function Generators of 4 Terminals are Used

Fig. 24 shows a pipe network simulator used for alternating current. The current i which flows through the pipe network is detected by current transformer, rectified, and made into a voltage which is proportional to the current. A non-linear characteristic is formed from this by the function generator SC which can be used for normal analog computers. Subsequently, it is modulated, shaped, then fed back to the original branch by transformer T .

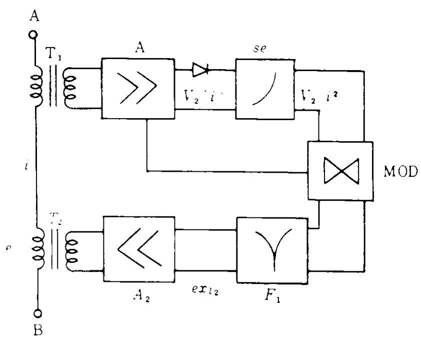


Fig. 24. Block Diagram of Pipe Element Using 4 Terminal Function Generator

Fig. 25 shows the circuit of such function generators. All diodes used are zener diodes. In this circuit, the voltage of D_1 to D_n is too high, and in order to lower this E_b and D_b are connected in reverse. If suitable Zener voltages are obtained, this may be omitted. As for the method in which function generators of (2) and (3) are used, even if battery voltage or Zener voltage is constant, by making the resistance variable, the current and the voltage characteristics can be adjusted arbitrarily. Furthermore, by increasing the number of parallel circuits, the required accuracy can be obtained. However, there is the disadvantage of the circuits getting too large.

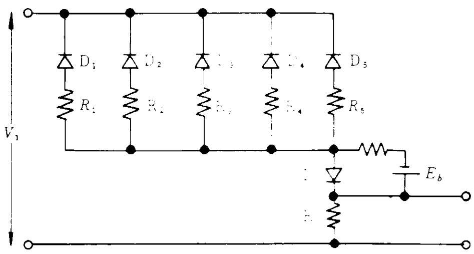


Fig. 25. Circuit Drawing of the SC Portion (Function Generator) Shown in Fig. 24.

Besides the pipe network elements, load, pump and tanks can also be connected like the actual system. The load can be simulated by the resistance or constant current device.
Simulation made by resistances is directly analogues to the opening of the faucet being fixed, and the outflow will change in accordance with the changes in pressure at both ends.
Simulation made by the constant current device is directly analogues to the user adjusting the opening of a faucet in accordance with the amount of flow.
From the abovementioned standpoint, the latter is used a great deal. In addition to the above, by inserting function generators having the same pressure flow characteristics as the pump, tank, and valves at their respective positions, the pipe network containing such items can be analysed.
The abovementioned simulators are normally used for simulation of constant state, and mathematically speaking, it is similar to obtaining the solution of a non-linear algebraic equation. Even in case of what is called dynamic simulation, if the conditions change together with time, in other words, in case the coefficient and constant terms of the algebraic equation changes with time, in most cases calculations to see how the solutions follow, are made.
Problems of transient conditions in their true sense can be analysed by combining capacitors with the abovementioned static operating elements. In such a case, good frequency characteristics are required for the pipe network elements, and the No. 2 method is the preferable method.
As for the simulators for this type that are manufactured in Japan, those having variable functional forms have several tens of pipe elements. The functional forms can be changed arbitrarily according to the problem. This simulators using lamps have several thousands of lamps prepared, and suitable types are selected according to the problem.

4. Voice Simulator

Needless to say, the most natural and convenient method of exchanging information among human beings is to emit voice and talk, and to listen to what is spoken. As a means to communicate between distant people, the telephone is much more conveneient than a letter or telegrams.
Not only is it faster but the content is much more abundant.
The intention and information can be transferred much easier. Even between the computer and the human being if information can be exchanged directly by voice, the work will be much faster and the computer will be easier to use. The utilization value will not doubt rise considerably.
Not only computers but also the other machines and equipment will increase efficiency considerably if they can understand what the human being say, and also respond to it. The convenience in this case is beyond our imagination. Of course, there have been some machines which can talk.
If the same sentence is to be repeated, the tape recorder can record and reproduce the voice.
If you wish to change the sentence from time to time, you can break up the sentence into elements and combine them adequately.
In case we are informed of wrong telephone numbers or given time service over the phone, it

does not mean that a nice young lady is talking at the other end of the phone. "The time now is .... " "That number has changed .... Please re-dial." The dotted line portion is changed, and it is a recorded tape that is giving the information.

As for more complex usage, the sentence is broken up into words, then the words are reassembled again to form sentences and reproduced.

In case of the stock exchange in New York, if the security dealer who is outside wishes to know the stock value of a certain machine company, he can get the information from a talking computer by dialling a specified number. For instance a masculine voice will answer back "........ Machineries, Opening Quotation 83, Highest Price 85, Lowest Price 82, Turnover 7000." In order to really utilize voice as a means for conveying information instead of the system which is like cutting takes and putting them together, the voice emitting mechanism should be controlled by the "brain", and complicated voices should be synthesized.

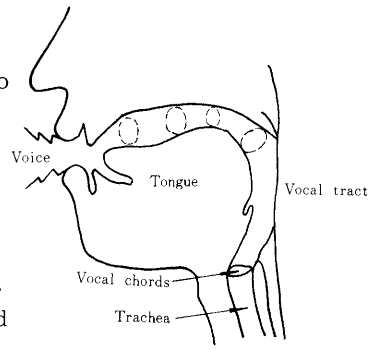


Fig. 26. Voice emitting mechanism.

In order to accomplish this, the mechanism from which voice is emitted, and the elements which compose it must be checked. As a synthesizing method based on laws, the so called hybrid computer system in which the analogous synthesizing device is controlled by the computer output is considered to be the common sense concept.

As for the analogous synthesizing device, there is the spectrum analog system (Up to quite recently, this was called the terminal analog system, and the VOCODER system is included in this) which simulates the sound as a phenomenon and the configuration analog system (This used to be called the vocal tract analog) which simulates the vocalization movement of the mouth by tracing back to the physiology and physics of vocalization.

The spectrum characteristics of the voice wave have been studied a great dial in the past and if necessary, it can be measured directly and confirmed. Therefore, the knowledge that we possess is abundant, and a lot of quantitative analysis data have been accumulated. The hardware is also comparatively simple in case of the spectrum analog system. Consequently, it is more economical.

On the other hand, the research work on vocalizing organs and vocalizing movement have been chiefly based on the personal views and personal observations of the vocal specialists. As a result, most descriptions are qualitative descriptions, and with the exception of a few foresighted research work, objective and quantitative observations based on X ray or X ray movies have just begun. At present, we still lack knowledge and quantitative data. Furthermore, as for the configuration analog method, it is very complicated as mentioned later, and there are still many technological difficulties. Therefore, the price is very high.

However, if we take up the problem of making laws for the synthesis, it will be more substantial (i. e. The description of law will be more simple, and there will be less exceptions.) to go back to the cause or vocal movement rather than to think in the dimension of spectrum characteristics or phenomenon. In addition to the above, judging from the ability of synthesizing continuous vocal sounds, it may be said that the configuration analog system which has limitations necessarily imposed on vocal waves owing to the utterance of the human beings set into the operation of the synthesizing device, has a higher potential capacity.

(a) Spectrum Analog System

The research on synthesis based on the laws of spectrum analog system is being done at various places in Japan such as Tohoku University, NHK General Technological Labs, Oki Electric Co., and Tokyo University.

Among such research works, the work of Holmes of Great Britain on the Joint Speech Research Unit has shown quite a success by concluding it in the form of a law.

As a synthesizing equipment, parallel spectrum analog as that shown in Fig. 27 was used, and control was performed on the following nine parameters.

- F_0 : Basic frequency of voiced sound source.
- S : Selection of whether the sound is voiced or unvoiced.
- F_1, F_2, F_3 : Formant frequency from No.1 to No. 3
- A_1, A_2, A_3 : Intensity of each formant component.
- A : Intensity of high frequency energy.

As an example of synthesis, "A bird in the hand is worth two in the bush" was shown in the following three steps.

(i) The values of all control parameters were extracted as a result of analysing the live human voice, and control and synthesis was done accordingly.

(ii) The continuing time of each syllable which greatly influences the naturalness, and the pitch frequency F_0 of the vowel portion have been controlled by the results obtained from the analysis of the live human voice. Only the control of the formant characteristics was done in accordance with the calculations based on the law.

(iii) The control of all parameters were done in accordance with the law. Although it is quite natural that the quaity of the synthesized voice will drop in the order of (i) (ii) and (iii), the meaning of (iii) was quite understandable. However, it was recognized that the naturalness was lacking.

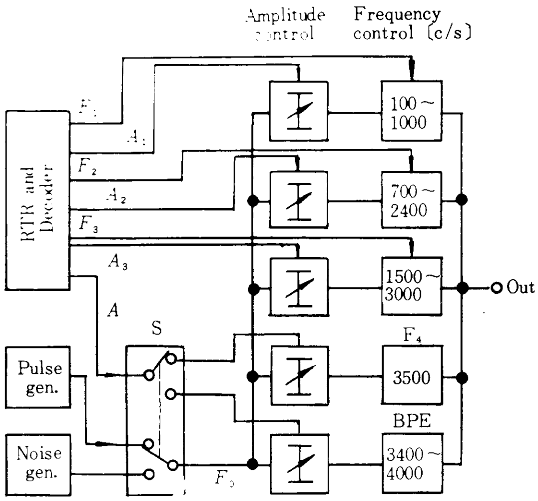


Fig. 27. Composition Drawing of Synthesizing Unit for JSRU

(b) Configuration Analog System

The research work based on the configuration analog system is also being done in Japan at the Electro Technical Lab., Meiji University, etc. The recent results obtained at the Acoustic Research Group of the Electro Technical Lab., are quite remarkable. The external view of the equipment is shown in Fig. 28, and the block diagram is shown in Fig. 29. If we give a brief explanation of the principle, it will be as follows: The channel from the glottis to the lips is considered as an irregular sound tube having a length of about 17 cm. This is simulated by seventeen round tubes with variable cross section areas and a length of 1 cm each. According to the sound engineering, the characteristics of sound for each round tube can be expressed by the following equation, and this relation is composed by an analog computing circuit shown in Fig. 30.

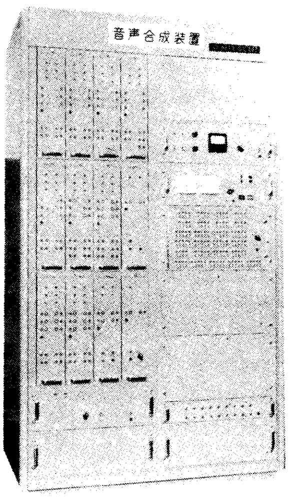


Fig. 28 Voice Synthesizing Unit (Configuration Analog System)

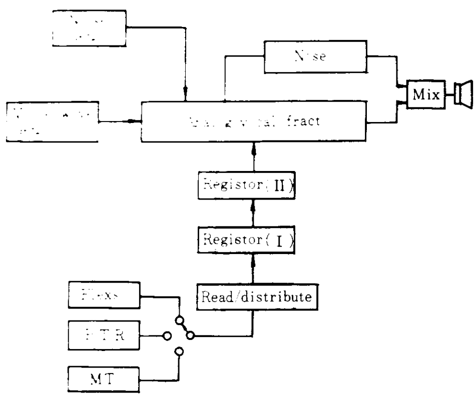


Fig. 29 Configuration Analog System

$$\begin{cases} U_{m-1} - U_m = \dfrac{h}{\rho c^2} A_m \dot{P}_m \\ P_m - P_{m-1} = h\rho \dfrac{\dot{U}_m}{A_m} \end{cases}$$

where

U : Volume speed of air inside of the cylinder
P : Sound pressure
h : Length of the cylinder (cm)
p : Density of air (g/cm^3)
c : Speed of sound (cm/sec)
A : Cross Section of Cylinder (cm^2)

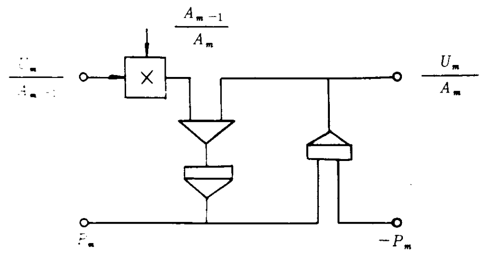


Fig. 30. Basic Block Diagram

The cross section A will have to be controlled in accordance with place and time. (Actually, this is controlled by the area ratio.) The multiplier will perform D-A conversion at the same time it conducts multiplication. However, in order to prevent the flick caused by the digital control signals, the multiplier is designed for a smoother characteristic against control signals.

5. Simulator in Relation with Medicine

It has been known from olden times that living bodies are gatherings of complex control systems which is composed of multi-feed back loop. However, the analysis of the system was quite qualitative. Together with the development of the control theory, quantitative analysis was begun from very simple feedback loops.
Since the control loop of the living bodies contain a number of non-linear elements, simulation is indispensable for their analysis. The development of simulators is being advanced for nerve cells and certain functions of the organs.
At first, the purpose of developing such simulators was for obtaining an auxiliary means for studying physiology, but now some are being studied for the development of control equipments for living bodies, and for engineering means. As simulators for living bodies, there are various kinds such as nerve system, respiratory circulating system, metabolism are exactly the same as those used for chemistry, they will be omitted here, and explanations shall be given on nerve system and respiratory circulating system.

5-1. Simulator of the Nerve System

The nerve cell which composes the nerve system is composed of the cell body, dendrite, and axon. The axon is also called the nerve fiber, and the end of it is branched. The branched portion is called synopsis and it connects with another cell body or dendrite of other nerve cells. The information transmission of such nerve cells can be detected from the outside as electrical impulses. Thus signal input from other nerve cells to the synopsis, and its relation with the cell output, the signal transmission characteristics inside of nerve fibers, etc., have been made clear, and simulators have been proposed. In the following paragraphs examples of simulators are shown by discriminating the former as nerve cells and the latter as nerve fibers.

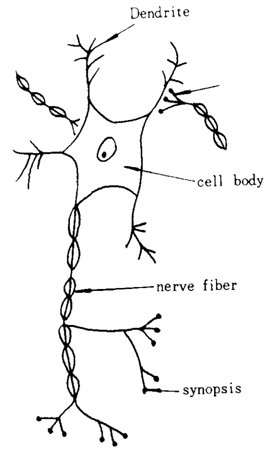


Fig. 31 Nerve Cell

5-1-1. Cimulators for Nerve Cells

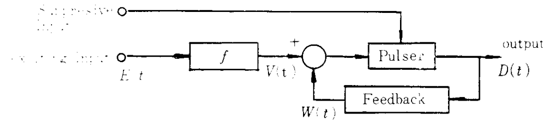
The nerve cell receives the output of other cells as input, via the synopsis. There are two types of inputs. One which will excite the cell and cause output (i. e. exciting input), and another which is reverse and which has suppressive effects. Over ten different properties between the output and input have been made

clear. Since it is very difficult to develop a simulator which can satisfy all of the conditions simultaneously, simulators possessing the major properties have been developed.
For instance, Harmon of the Bell Telephone Labs. assumed the following properties, and developed a simulator illustrated in Fig. 32.

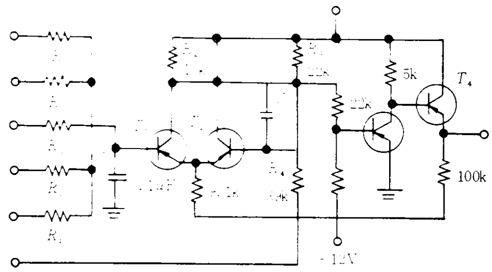
(i) In case a stimulus exceeding a certain limit is given within a limited time, the cell will be excited and send out pulsive output. No matter how long a stimulus below a certain level is given, the cell will not become excited. This limit value will change as a function of the elapsed excitation of the cell.

(ii) In case the cells become excited, no matter how large the stimulus is, the cell will not become excited for about 2 - 3 m sec as if the threshold value has become infinite (This period if called the period of non-response.)

(iii) In case two or more stimuli less than the threshold value is given to one cell, those stimuli will be added, and if the sum of the stimuli exceed the limit value, the cell will be excited.



(a) Block Diagram of Nerve Cell Model



(b) Model Circuit of Nerve Cell

Fig. 32 Simulator for Nerve Cell.

(iv) In case the suppressive synopsis is stimulated, even if the exciting synopsis is stimulated at the same time, the cell will not be excited. As shown in Fig. (a) of the block diagram, in order to obtain properties (i) and (iii) an incomplete integrator is used, and feedback is employed for obtaining (ii). Furthermore, suppressive input is given to obtain property (iv).

5-1-2. Nerve Fiber Simulator

The nerve fibers which transmit the output of cells have attracted the attention of people engaged in engineering since they possess an idealistic electrical pulse transmission system for forming waves.
There is an excellent mathematical model of Hodgikin-Huxley for this transmission characteristic, and Nagumo et. al. have proposed a simulator using tunnel diode as shown in Fig. 33 by studying the above mentioned mathematical model. As shown in Fig. 34, this transmission system has an excellent wave forming property in which the amplitude and pulse width can be made identical. Besides the above, a large number of simulators have been proposed, but they will be omitted here.

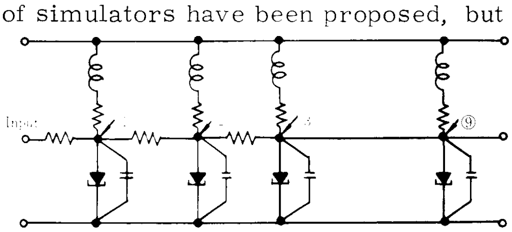


Fig. 33 Simulator of Nerve Fiber

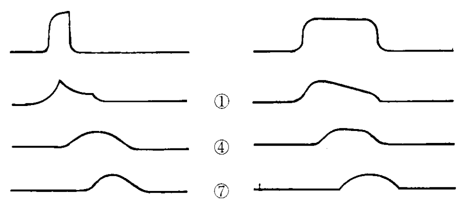


Fig. 34 Output of Simulator

5-2. Simulator of the Circulating System

The circulating system which is composed of the heart to send out blood, large and small arteries, capillary tubes and veins with the circulation of blood, metabolism of components within the blood, and their control system. For instance, as a simulator for circulating dynamics, Mcleod developed one which is shown in Fig. 36. For instance the heart is composed of left and right arteria and ventricles of the heart, and the blood circulates in the order of right atrium, right ventricle, lung, left atrium, arteries, viens, and right atrium. Thus, it can be expressed by the block diagram shown in Fig. 35(a). The valves shown in the diagram are valves to prevent backflow, and they are quite indispensable. However, on account of this, blood flow resistance will form. The thickness of the heart muscles for the left ventricle and the right ventricle are thicker than those of the arteria, and the compliance increase of decreases in proportion to the volume. Thus, an electrical equivalent circuit shown in Fig. (b) can be made.

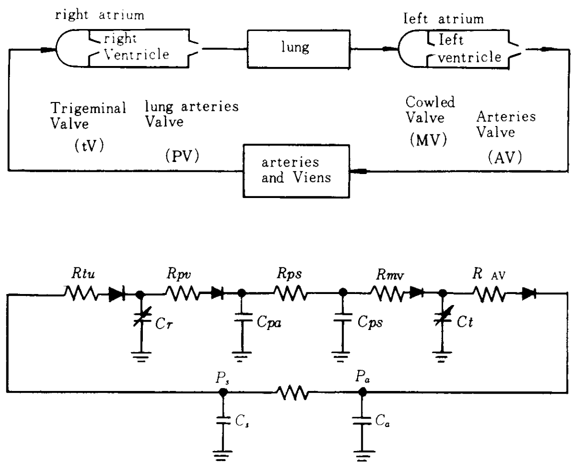


Fig. 35 Simulation of the Circulating System

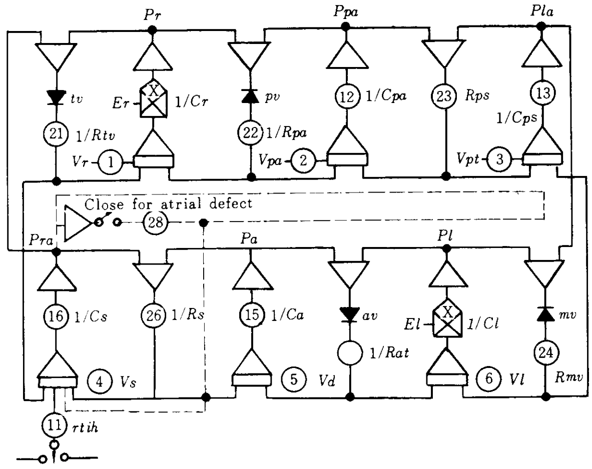


Fig. 36 Simulation Circuit Diagram of the Circulating System

Fig. 36 shows the abovementioned equivalent circuit simulated on an analog computer. The responses of various circulating system diseases are being studied by employing this simulator. Therefore, various functons corresponding to the various diseases are added as shown by the dotted lines in Fig. 36.

Although there are various proposals for the control system of the circulating system also, in this article, the writer would like to show a nerve control simulator versus heart beat which was reported by Gardner.

In other words, heart beats originate at a portion called the trunk nodule located on the right atrium, and the rate of stimulus is controlled by the sympathetic nerve and the vagus which gives the input. In order to find this transmission characteristic, Gardner stimulated each nerve of a dog and investigated the response. As a result he found that the heart beat can be given by the following equations.

$$HR = \frac{HR_0 + G(s) f_1}{1 + H(s) f_2}$$

$$G(s) = [Ae^{-\tau s}(1+\tau_3 s)*]/(1+\tau_4 s)(1+\tau_5 s)$$

$$H(s) = B(1+\tau_1 s)*/(1+\tau_2 s)$$

where

HR : Heart beat at the time when there is no stimulus.
f_1, f_2 : Stimulus frequency of sympathetic nerve system and the vagus system.
A, B : Non linear characteristic shown in Fig. 37.
$*$: This term will become effective only when the stimulus frequency of the nerve system has increased.

In case the abovementioned transmission characteristics are simulated, relations shown in Fig. 38 can be obtained. Although the response of this simulator is not complete, it is very interesting because it suggests the research trend in the future, and by the development of such independent simulators, the analysis of even more complex phenomenon can be made possible.

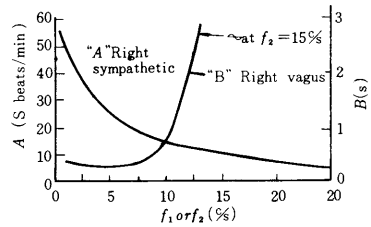


Fig. 37 Static Characteristics of Heart Beat Control System

5. 3. Simulator of the Respiratory System

The simulation of the respiratory system also consists of the intake of oxygen into the blood, and discharging of carbon dioxide (i. e. gas exchange function), breathing dynamics of the lung, and the control system for the above. As an example, an explanation will be made on the respiratory dynamics system proposed by Yoshimoto, et. al.
In other words, the exchange of gas is done between the lungs and the outside air via the bronchial tube and branch. Consequently, the pressure of the lungs will balance with the inside pressure of the chest which surrounds the lungs and the compression force of the lungs owing to its elasticity. Furthermore, the amount of gas that will be exchanged will be determined by the inside pressure of the lungs and the impedance of the bronchial tube and branch.

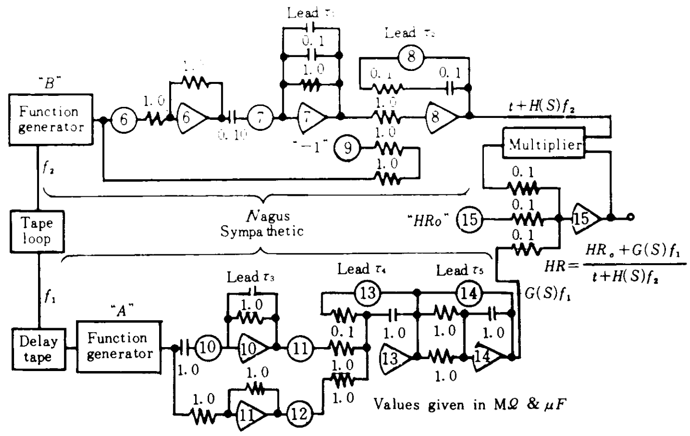


Fig. 38 Simulator of Heat Beat Control

On the other hand, since it is clear that the compression force of the lungs based on their elasticity and the impedance of the bronchial tubes are non-linear. The simulator shown in Fig. 39 was developed under the assumption that the admittance will be proportional to the difference between the bronchial tube branch and the inside pressure of the chest.
As shown in the drawing, this simulator consists of the left lung, right lung and the bronchial tube.
In accordance with the change in chest pressure caused by the stimulus from the respiratory control center, the change of inside pressure in the lungs will occur. As a result, the gas exchange flow amount can be obtained as an output of the admittance determining portion of the bronchial branch which is determined by the Summer A and the Multiplier M.
The integrated value of this exchange gas flow will change the lung volume and return the inside pressure of the lungs to the original level.
By improving this simulator slightly, a simulator which combines the breathing number and control system are also developed.

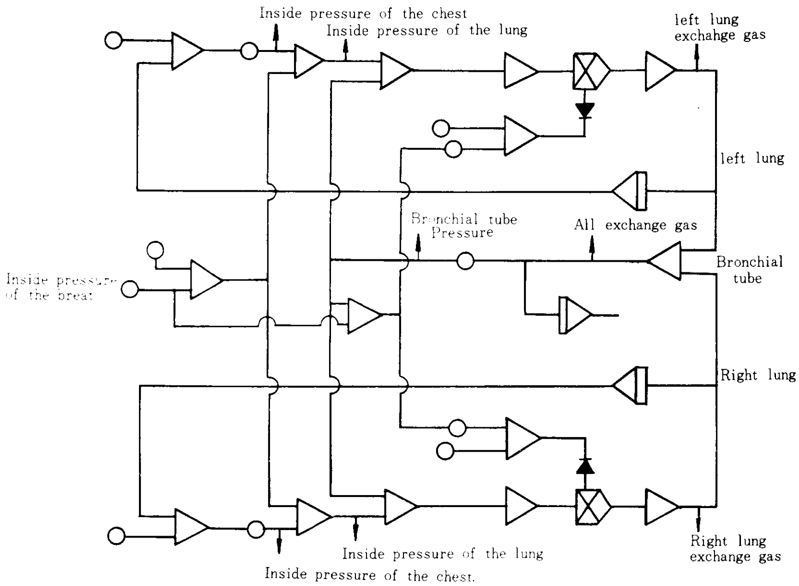


Fig. 39 Simulators for the Respiratory System

Simulators for gas exchanging functions are also developed by Grodin but this matter will be omitted here.

5. 4. Other Simulators

Besides the above mentioned simulators, there are various other simulators such as body temperature controlling system, osmotic pressure adjustment system for the kidneys, and the blood sugar controlling system.
Owing to the limit in space, such matters will be omitted. Since the functions to be simulated in the living bodies are non-linear, the simulator is becoming an even more important tool for the analysis of such phenomena.
A great development can be anticipated for the future of simulators.