センサ・コイルを持つ非線形素子の発振器における発振機構の挙動

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Oscillating Mechanisms in Oscillators Connected with Nonlinear Element and Sensing Coil

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The relaxation oscillations, which would always occur in the oscillators using nonlinear elements such as ESAKI-diode (E.D) and U.J.T, is basically important in studying the oscillating mechanisms so that there have been many research reports in this field in this past.

However, in those research papers, the researchers have rather intended to escape that they have utilized inductors as an element in the relaxation oscillators if possible, because the oscillators that have inductors as the elements of the oscillator's circuits have great tendency to increase the distortion of the output waveforms and/or to decrease the degree of the stabilities in oscillation.

In this paper, we will rather intend to challenge to study the relaxation oscillator having sensor coils, that are a kind of inductors, as nonlinear elements, because we have purposes of detecting the positions and displacements of bodies at the proximity of the sensing coil.

As a result, in the paper, we will report that the outputs in those oscillator's output waves would take the forms of P.W.M (in the case of E.D circuits) or P.N.M (in the case of U.J.T circuits) according to the distance between the sensor and the bodies at the proximity.

（Ⅰ） Introduction

In the modern industries or robot manufacturing, it is extremely very important that the engineers study and research how to detect displacements, positions and shifting distances of some bodies, for knowing the defects of the used materials and thier qualities with the procedure without contact with those bodies. We believe that,it is a new kind of detecting method that is that, when we do deposite the object of materials in the magnetic field produced, by the sensing coil and excited with high frequency exciting current, first the sensing coil in itself would detect the variation of the state of magnetic field, and then the mode of the state of electric circuit would tansformed into other mode, and the signal output necessary for detecting it would be produced.

Just recently, the above mentioned technics are utilized in the industrial fields such as the high frequency oscillating type-proximity switch and the undestructive measuring method of material, using eddy-current inductive procedure, etc. These have been useful in the industrial and manufactural processing.

This article has reported the matters that are concerned about the sensor network, which is a kind of relaxation oscillator, connecting with a near-deposited sensing coil and a nonlinear circuit element. We have constructed two kinds of relaxation oscillators, the one has used the voltage controlled element of E・D as the nonlinear element, and the other has used the current controlled element of U・J・T, respectively.

In each one of those cases, their motion mechanisms, which would be produced according to decrease the distance between the object (flat-plate type) and the sensing coil (as honeycomb coil), transform from the steady state into the oscillating state, both of which are very different from each other.

In the case of the relaxation oscillation with E・D, the oscillating state will beccome into the state of controlled or disturbed oscillation that is caused by the response of the sensor coil. On the other hand, in the case of the relaxation oscillator with U・J・T, the oscillating state has the mode of attenuating oscillation. Those oscillating phenomena have very contrast with each other, and furthermore it is possible that we can transform the mutual distance between the object and the sensing coil to the pulse width of output (P・W・M) in the former case and to the pulse number of output (P・N・M) in the later, respectively. It is, in other words, that it is possible that those oscillating systems can generate the digitalized output signal, which is to be the distance or displacement for proximity body and its shifted position transformed into the suitable form of signal processing.

This article would cover the theoretical back grounds and their experimental results concerning the above mentioned materials.

(II) Theortical considerations of noncontact electromagnetic type detecting method

We will, at first, consider the propositions mentioned above for clarifying and knowing the mechanisms of the detecting behavior of electromagnetic and proximity sensor in noncontact manner. The assumptions are such that, 1) the detecting bodies have to be placed within a magnetic space and 2) their physical natures and the physical constants (μ, ε, ζ and t etc.), which are those of the matterials placed between the near-deposited body and the sensing coil should, be kept in the time invariant or unchanged states.

And now, let us denote 'd' variable to mean the relative distance between the near-deposited body and the sencing coil in the form of face by face, and let the range within which we can use it in the d-expression be the region, in which the sensor has the detecting ability as a sensing coil, and the distance is the one that would be measured from the face of honeycomb type coil, using the sensor. Furthermore, we will denote by the symbol 'd_0' the nearest distance between the near-deposited body and the sensing coil, and we partition it into the smaller and discrete values such as

$d_0, d_1, d_2, \cdots\cdots, d_n, \cdots\cdots, d_d$: and

$\Delta d_n \equiv d_{n+1} - d_n$.

Each one of them, Δd_i, $i=1,2,\cdots\cdots,n$ means that infinitesimal distance during which the action forced by the near-deposited body is constant, in other words, within which the output of the sensors circuit maitains the equal response and we identify it a unit distance.

If we denote by P the set that contains various dimensions concerning the near deposited body as the elements, then it is $d \in P$ where d will be a subset of the set P. Furthermore we will denote ε the subset a set of element E, the total collection of constants of circuit elements, which will be influenced to be changed by the near deposited body of the sensor. Then the d would specify the value of E, it means that in other words, a function from the set P to the set ε can be definable, that is

$$f : P \to \varepsilon(d \longmapsto E = f(d)) \quad . \cdots\cdots\cdots\cdots\cdots (1-1)$$

Furthermore, the range, within which the response by the sensor would be definable, would be specified by parameters such as the inductance values, the constructed forms and the kind of wires of the coils, and resistances and permeabilities of the cores etc. Those contains such variables as $L_1, L_2, \cdots\cdots, L_n$ and $r_{L1}, r_{L2}, \cdots\cdots, r_{Ln}$ of the dissipated resistances. Therefore, these factors decidly rule various conditions for setting up the internal characteristics, the charcterized motion modes, mechanisms of the oscillations and the output characteristics.

Furthermore it could be considered that the properties of output pulse-wave that are characterized using the definable state of the above mentioned factors, would get to be the W_P range. Therefore, the mapping could be defined, as follows

$$g : E \longmapsto W_P(=g(E)) \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (1-2)$$

and furthermore using the composited mapping defined above all, it will be obtained that $h(d)=g\{f(d)\}$, and then, the mapping in other forms

$$h = g \circ f : d \longmapsto W_P \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (1-3)$$

can be defined.

As a result, we may recognize that there exists a functional relationship (and furthermore it is a mapping) with the distance d between the sensing coil and the near-deposited body and the pulsewaveform of output.

As a final concluding remark, I would like to say that there exist high possibilities of including so much informations in the pulse wave form, and so that it has high values that the output of the pulse wave form will be detected and picked up as the electromagnetic type of information.

(III) Circuit of voltage controlled nonlinear element for transforming pulse-width

(a) Relaxation Oscillator using Esaki diode (E.D)

Using a Esaki diode circuit that has voltage controlled, N-type v-i characteristics, we have a coil (L) of the circuit to be utilized as a sensor as shown in Fig. 1. Here, let us assume that the parameter explicitly unwritten in the figure could be neglected, then we would have obtained the equations as follows,

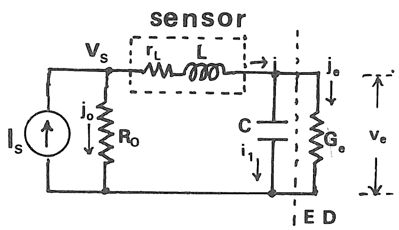


Fig — 1
Basic Circuit

$$L\frac{di}{dt} + r_i + v_e = V_s, \qquad i_1 = c\,\frac{dv_e}{dt}$$

$$i = i_1 + i_e, \qquad I_s = i + i_0$$

$$i_0 R_s = V_s, \qquad i_e = f(v_e)$$

$$\cdots\cdots\cdots\cdots\cdots \text{III}-①$$

Where

$G_e = \frac{df(v_e)}{dv_e}$, $\qquad \dot{f}(v_e) = G_e \dot{v}_e$

$I_s R_o \simeq V_s$, $\qquad v_e - V_D = v$

$\cdots\cdots\cdots\cdots\cdots$ III—②

and we denote the D.C bias voltage by symbol V_D and D.C conductance by symbol G_e, using the equation III—① and III—②, we would obtained,

$$\ddot{v} + \left(\frac{r+R_o}{L} + \frac{G_e}{C}\right)\dot{v} + \frac{1}{LC}\{1+(r+R_o)G_e\}v = 0 \qquad \cdots\cdots\cdots\cdots\cdots \text{III—③}$$

Using the equation III—③, we will gain the characteristic equation as follows, using the theory of fundamental differential equation,

$$\lambda^2 + P\lambda + q = 0 \qquad \cdots\cdots\cdots\cdots\cdots \text{III—④}$$

the equilibrium points of the above eq. III—④ are

$$P_o = \frac{r+R_o}{L} + \frac{G_D}{C}$$

$$q_o = \frac{1}{LC}\{1+(r+R_o)G_D\}\ , \qquad G_D \cong G_e$$

$\cdots\cdots\cdots\cdots\cdots$ III—⑤

Now, if we characterize the singular point as a unstabilized saddle point on a phase plane, then the circuit has become a oscillator of relaxation-type, and the constraint at the time is to be that

$$q>0,\quad p<0,\quad p^2 \geqq 4q > 0.$$

That is, in other words,

$$G_D < 0,\quad (r+R_0)G_D > -\frac{L}{C}G_D{}^2$$

and

$$(r+R_o)G_D \leqq \frac{L}{C}G_D{}^2 + 2\sqrt{\frac{L}{C}}G_D$$

$\cdots\cdots\cdots\cdots\cdots$ III—⑥

and these inequalities show that there are some relationships between the parameters in Fig. 2, showing that E.D element has a N-letter type v-i characteristic.

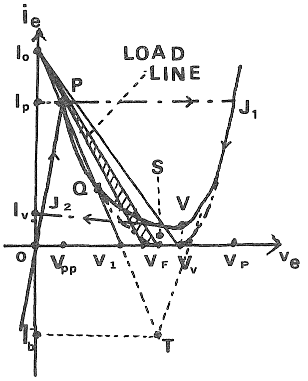


Fig — 2
Characteristic of E.D

In the figure, the range of region, being enclosed around up with the straight line connecting two points V_1 and P, and with the inclined line part between a load line and the V_v—I_0 load line, will be called a load line range in the sensing circuit.

In this case, it is well known that because of having the property of unstability, the oscillator is going to gradually tends to a limit cycle $P \to J_1 \to V \to J_2 \to P$. The Q of circuit is $Q = G_e\sqrt{L/C}$; and the steady-relaxation oscillation will be continued on the range of $Q \geqq 10$. In the output waveform, the time duration that is needed to jump for $P \to J_1$ and $V \to J_2$ is extremely short so that we may neglect it. Then using piecewise approximated method (refer to Fig. 2) and the equivalent circuit, we would gain the following equations,

$$T_1 = \frac{L}{R_1} I_n\left[\frac{I_o - I_v}{I_o - I_p}\right]$$

$$T_2 = \frac{L}{R_2} I_n\left[\frac{I_p - I_b}{I_v - I_b}\right]$$

$\cdots\cdots\cdots\cdots\cdots$ III—⑦

where we denote the mean-incremental value of E.D and the dynamically internal conductance by G_1 and G_2 with respect to oP duration and J_1V duration, respectively, and we put that

$R_1 = r + R_0 + 1/G_1$, $\qquad R_2 = r + R_0 + 1/G_2$

$I_0 \cong V_1/R_1$, $\qquad I_b \cong \frac{V_1 - V_v}{R_2}$

Then, the period of output wave will become

$$T = T_1 + T_2 \qquad \cdots\cdots\cdots\cdots\cdots \text{III—⑧}$$

Therfore the peak voltage value V_F of the wave form is constant, and the values, L, R_1 and R_2 specify the duty ratio and the period of the wave. In the view of the above facts, it shows that the value L of the sensor has actually got to influence the action. In this case, it would be required that the shifted value to be caused by the response of the near deposited action is dropped in within the one-cyclevalue of oscillating period. Its value can be easily specified by the design procedure of the sensor.

(b) Controlled Oscillation in Nonlinear Conservative System.

Fist we are going to develop our considerations in qualitive manner. Now in Fig. 2, the oscillating point in the phase trajectory will be transmitted into the valley point V just after it has jumped from point P to J_1. As shown in the figure, I think that the negative conductance that is exhibited to jump from V to J_2 ($V \to J_2$), can take various values different from a distinct P point of V_P, since there physically exists a excess current region in the materials, in the neighbovhood of the V point.

The neighborhood region that the oscillating point would reach on in the V valley point, is that $G_e = \pm 0$, $V_P > V > V_v$, $\frac{di}{dt} < 0$. On the other hand, inductance L and the dssipated resistance r may be changed on according to approaching the near-deposited body to sensor. Therefore the operating point places in between Q and V points, because the load line (Fig. 2) will get to cover the range of parts where hatching are written. In other words, we have come to have the equibilium point within the negative conductance.

Using the equation which contains D.C components in the eq. III—③, we obtain,

$$\ddot{v}-\left(\frac{r+R_o}{L}-\frac{|G_e|}{C}\right)\dot{v}$$

$$+\frac{1}{LC}[\{1-(r+R_o)|G_e|\}v-V_S]=0$$

……………III—⑨

Where, in the case of that

$$\frac{r+R_o}{L}=\frac{|G_e|}{C};$$

the equation will statisfy the conservative property and

$$\ddot{v}+f(v)=0 \qquad \text{……………III—⑩}$$

Here, we can put that $\dot{v}=y$, $y=-f(v)$.

Then the sloping angle of the phase trajectory in each point of the phase plane could be obtained from the equation ;

$$\frac{dy}{dv}=\frac{-f(v)}{y}$$

In this case, the singular points has the coordinate of

$(V_S/\ \{1-(r+R_o)|G_D|\}\ ,\ 0)$.

Furthermore, we would obtain the equation

$$\frac{1}{2}y^2+V(v)=K(\text{const.}) \qquad \text{……………III—⑪}$$

using integration, where the initial circuit energy is

$K_o=\frac{1}{2}y_o+V(v_o)$,

$$V(v)=-\int f(v)dv \qquad \text{……………III—⑫}$$

the equation III—⑧ could be described in the following form by calculation,

$$V(v)=\frac{1}{2LC}\{1-\frac{L}{C}|G_D|^2\}$$

$$\left[\left(v-\frac{V_S}{\{1-\frac{L}{C}|G_D|^2\}}\right)^2-\frac{V_S{}^2}{\{1-\frac{L}{C}|G_D|^2\}^2}\right]$$

Therefore the value of $V(v)_{max}$ would have become

$$v_m=\frac{V_S}{1-\frac{L}{C}|G_D|^2} \qquad \text{……………III—⑬}$$

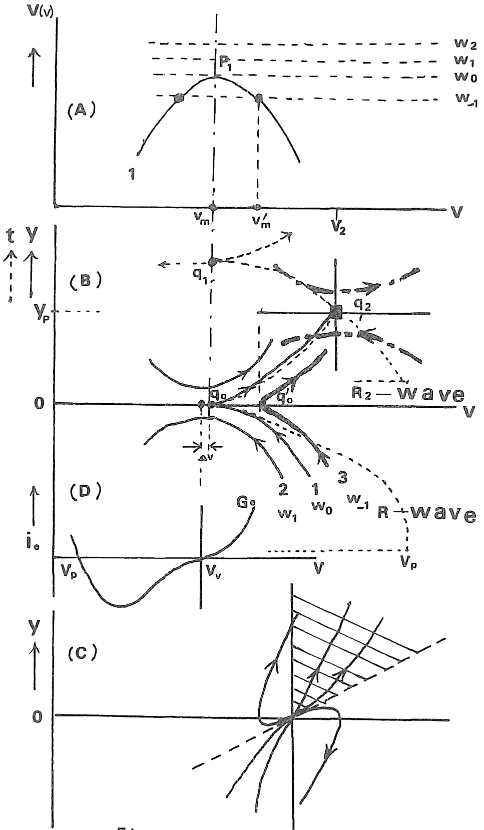
and this value shows that the point is unstability saddle point in the mean of Liapunov function. We will study in details the phenomena that will occur in the neighborhood of the point. Here the equation

$$y=\pm\sqrt{2(K-V(v))}$$

……………III—⑭

could be obtained and it produces a class of integral curves. Using the above mentioned procedures, v—V(v) energy-plane figure of Fig. 3 (A) could be ploted and v—y plane figure also could be written. In this case. v is output voltage and therefore comparing with the Fig. (A) and (B) of the relaxation oscillating wave, we can recognize the mutal relationships between then and have some knowledge about it.

In (B) of Fig. 3, there is a trajectory that the operating point of steady relaxation oscillation is going to move from peak value V_P to the valley point, and by



Fig—3
Saddle Point, V_V and
R—Wave

it, the value V(v) will have been reached at the maximum value in the neighborhood of value point $(q_0,\ 0)$ and it is the unstability mountain pass point, that is saddle point. In this case, all of trajectories except that only one trajectry toward the singular point, are far away from the singular point according to the time being on. Under the above mentioned conditions, the operating point does move along through the trajectory of ① (B) in Fig. 3, and it soon reach the point $(q_0,\ 0)$ and then go to rise toward the point J_1 in Fig. 2. In other words, the operating point will finally reach at the point $q_0\rightarrow q_2$, and it shows the maximum amplitude, then the amplitude will become to be $(V_2—v_m)$. Using a energy condition, the following equation can be gained

$$\frac{2(V_2-v_m)^2}{(r+R_0+R_2)}\leqq\frac{d}{dt}\left[\frac{LI_v{}^2}{2}+\frac{CV_m{}^2}{2}\right] \qquad \text{……III—⑮}$$

The operating point is going down to the valley Vv just after the operating point is going along the trajectory of R-wave, which have gone out of the cross point q_2 of R_2-wave, because the increasing of the G_e desipated part G_e of E.D element is produced by the rising up of the wave form. Therefore, that the formation of the controlled oscillation will be repeated later on and approximating the period of repeating wave, we would obtained the equation that

$$T_q \fallingdotseq 2CR_2 \ \ln\left(\frac{V_R}{V_F - V_2 + V_m}\right) \quad \cdots\cdots\cdots\cdots\cdots \text{III—⑯}$$

In the process of the wave forming in the oscillation, the time constant that influences the value of v along with the changing of $|G_e|$, satisfies the inequality as follows

$$\tau_L\left(=\frac{L}{v+R_0}\right) >$$

$$\tau_c\left(=\frac{C}{|G_e|}=CR_2\right) \quad \cdots\cdots\cdots\cdots\cdots \text{III⑰}$$

This controlled oscillation later at the point q_2 moves toward the point q_1 to follow the inequality that $(di_e/dt)<0$.

In addition, when the sensor-coil responses for a proximity body, the amplitude would increase up one oscllating period by one, towards to that the disipated energy condensed in the L would be decreased. In this case the moving point is going to jump from V_v to J_2 (Fig. 2) after t_n time in Fig. 4, and the next R-wave will be formed. The following equation would be obtained as the pulse wave.

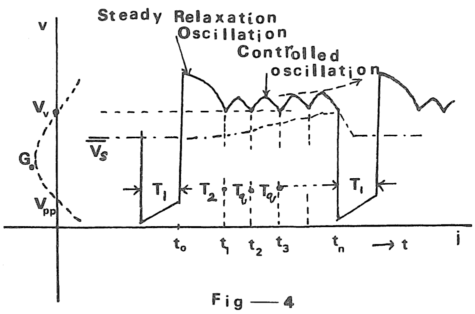


Fig —4
Controlled Oscillating Wave

$$\beta(\text{duty ratio}) = \beta_0 + \beta_{nq}(1-\beta_0) \quad \cdots\cdots\cdots\cdots\cdots \text{III—⑱}$$

n : the number of the controlled oscillating

β_0 : duty factor of the a state oscillation

Where n is specified by the factors such as sensor L, the physical quantities of near-deposited body and thier mutual distance etc. $\beta_{nq} = nT_q/T_1 + T_2 + nT_q$.

(C) Experiments and Consideration of Results.

Using the basic experimental circuit as shown in Fig. 5, we have investigated and considered about the properties and characters of the theoretical aspects

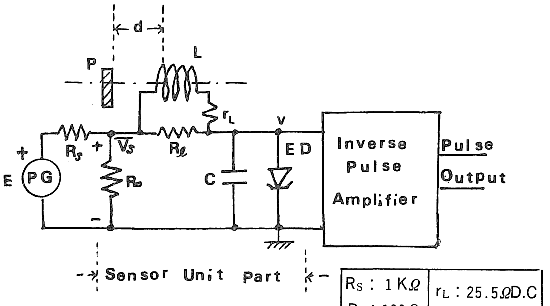


Fig —5
Experiment Circuit

Rs : 1 KΩ	rL : 25.5ΩD.C
R0 : 100Ω	ED : 1S1761
C : 200PF	

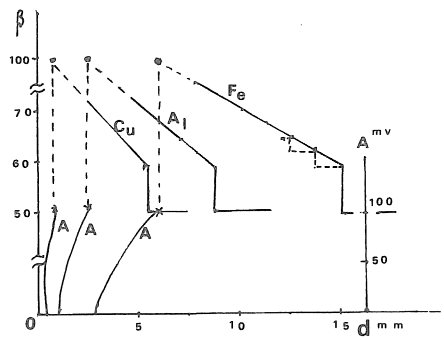


Fig —6
d - β

mentioned until here. The practical system used in the experiment could be partitioned into a unit of stabilized source, a sensing unit and a unit of signal processing. In the sencing unit the frequency of steady relaxation oscillation is 250 kHz, and we do set up that L : 1.41mH, Q : 65 and the output duty ratio is $\beta=50$ %. The variation of the relaxation frequency forced with the variation of source voltage would be measured in relation to the value V_s as shown in Fig. 7. The characteristic of Δf deviation to V_s has some linear regions. We would set up that the critical value of the neighborhood in the linear region was $V_s = 0.19 \sim 0.2$ (V).

Fig. 7 shows that how many degree the near-deposited body would give the influence on the value L. It would be recognized from Fig. 7 that the value of the influence is about $\Delta f \sim 1.3$ % untill $d_l = 15$mm, in the case of the material quantity is usual Iron,. and in the range of $d_l \leqq 15$mm, controlled oscillation would

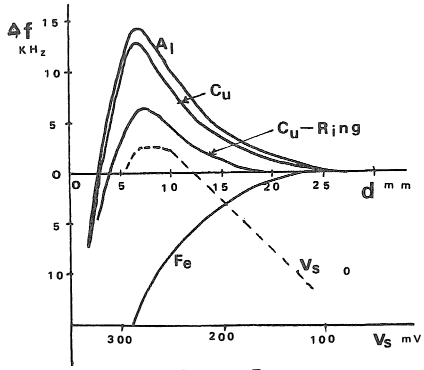


Fig —7
$d(\overline{V_s}) - \Delta f$

abruptly rise up so that pulse-width modulated transformation would occur. On the other hand, the material as Aluminum or Copper are $+\Delta f_{max} \sim 14$% within the range $d_A > 8$mm, $d_C > 6.5$mm, and the controlled oscillation would occurr as soon as the valued would begin to drop below the above mentioned value. And in that case the value of V_s would be rising up in the manner of step by step (refere to Fig.

4). After the value of V_s would drop down below V_n (that is $V_n \geqq V_s$), the controlled oscillation would be come into the state of stopping on. However, even in that state only one pulse of the relaxation ocsillation would be remained on, so for it, we could utilize it as a synchronizing pulse of signal processing. The number of the controlled oscillations would force to change pulse-width and output β of pulse-wave. The relationship of the distanced to β of the near-deposited body would be shown in Fig. 6.

(IV) Circuit of current-controlled nonlinear element for transforming pulse numbers.

(A) Steady Relaxation Oscillation using UJT.

In the basic relaxation oscillator that is a CR-circuit type and that make use of UJT as a element of the circuit, we connect it to the sensor coil between

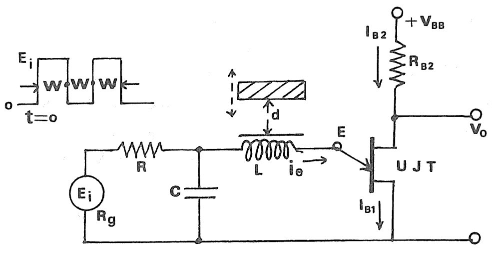


Fig 4 — 1
Basic Circuit

two terminals S and E as shown in Fig. 4—1. In this circuit, we take out of it the output wave that is in the form of mixing and combining two types of operations, the one is CR integrating operation and the other is LC oscillating one. And then, the form of electro-magnetic energy changings that the sensor (L) would be given by the near-deposited body, make the waveform of LC oscillation influence a part of the original relaxation oscillation. In that case, we must strongly mention that we would get the output in the form of attenuating the amplitude of the oscillating wave.

Now, we will noticed that the UJT is a non-linear and negative resistance element having S-letter type characteristics, and we show it in the form of capable of comparing with the characteristics in Fig. 4—2. In this figure, we have to set down the load line within the region (the part of the sloped line writting) among two lines, the one is CA line and the other is CB line. The excitation of positive pulse (the pulse width=W) will be set up to satisfy the following condition for maintaing the oscillation during W-period ; that is

$(E_i - V_p/R_1) > I_p,\ (E_i - V_v/R_1) < I_v$ ……………IV—①

For the reason of it, the operating point encircles the orbit of G→H→I→J→G……, and then the output waveform correspondence to the encircling would be produced. As the orbit of simple and basic CR relaxation oscillation having no sensor is that of

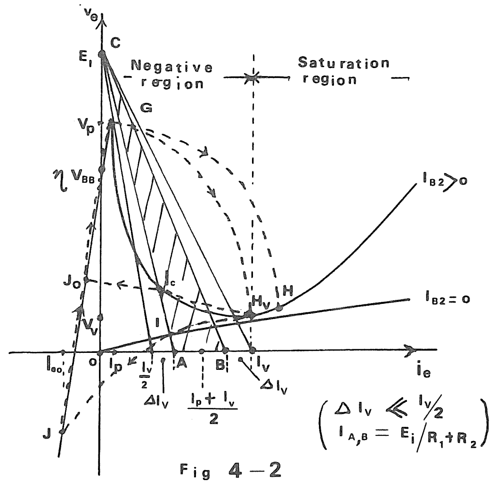


Fig 4 — 2
Load line of UJT

$G \to H_v \to I_o \to J_o \to G \to$……, we could recognize that the part of triangular HJJ_o would be added to the orbit for L connected. In other words, it could be considered that the part would be occurred by increasing the electro-magnetic energy of L. It can be recognized from seeing the i_e-v_e characteristics in Fig. 4—2. This UJT has abruptly changed to on-state just after the operating point has reached at V_p, since input E_i would be fully condensed. At that time we can obtain the formula as follows ;

$V_p = \eta V_{BB} + V_{ebD}$ ……………IV—②

$I_{B1} = I_E + I_{B2}$ ……………IV—③

$(E_i - V_v/I_v) < R_1 < (E_i - V_p/I_p)$ ……………IV—④

where η : stand off ratio

V_{ebD} : 0.6~0.7^V forword diode voltage

The charge on C will discharge through sensor (L) and UJT. In this case the time consant is very small, so that UJT will be biased in the reverse direction for being L. And again by E_i, C would start to be charged, then the equation

$V_c = E_i\{1 - \exp(-\frac{1}{R_1 C} t)\}$ ………………IV—⑤

would be satisfied.

It can be considered that the time duration T_o, which it will be needed untill v_c would have reached at a value V_p, is a period of the relaxation oscillation, and then we obtain,

$T_o = R_1 C \log_e(E_i/(E_i - V_p))$

$= 2.8 R_1 C \log_{10}(1/(1 - x\eta))$ …………… IV—⑥

where $X = V_{BB}/E_i$, frequency $f_o = 1/T_o$ ………IV—⑦

(B) Mechanism of Pulse number Transformation in the attenuating Oscillation.

We have described about the operating mode of steady state, relaxation oscillation in (A), which would occur when sensor's coil has been no influenced by the near-deposited body. For further investigating it in details, the above mentioned circuit will be exchanged into the equivalent circuit as shown in Fig. 4—3, where it would be assumed that UJT would have to take a switching motion. As S is off, the formula :

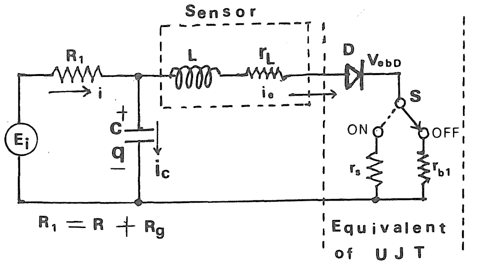


Fig 4—3
Calucuiated Circuit

$r_{b1} \gg R_1 \gg r_L, \qquad r_L \simeq r_S, \qquad i_e = 0$

$$i\,|_{t=0} = \frac{E_i - v_{co}}{R_1} \qquad \cdots\cdots\cdots\cdots\cdots \text{IV—⑧}$$

will be satisfied. And as S is on, at first we will calculate the following equations

$v_c = V_p, \qquad R_2 = (r_L + r_S - R_n)$

$i = i_e + i_c \qquad t = 0 \cdots\cdots q = Q_H$

where $-R_n$ is the mean negative resistance of UJT. Then, we would obtain the circuit equation as follows, putting here

$$P = \frac{d}{dt}(i_c),$$

$$LCR_1P^2 + (R_1R_2C + L)P + R_1 + R_2 = 0 \qquad \cdots\cdots \text{IV—⑨}$$

where we put that

$$\alpha = \frac{1}{2}\left(\frac{1}{CR_1} + \frac{R^2}{L}\right), \qquad Q_H = CV_P$$

$$\gamma = \sqrt{W_L^2 - \frac{1}{4}\left(\frac{1}{CR_1} - \frac{R_2}{L}\right)^2} \qquad W_L = \frac{1}{\sqrt{LC}}$$

and will get the solution of v_c. It is as follows,

$$v_c = \frac{R_2E_i}{R_1 + R_2} + \left(\frac{Q_H}{C} - \frac{R_2E_i}{R_1 + R_2}\right)e^{-\alpha t}$$

$$\left\{\cos \gamma t + \left(1 - \frac{5\alpha^2 + \gamma^2}{\gamma} \cdot \frac{L}{R^2}\right)\sin \gamma t\right\} \qquad \cdots\cdots\cdots\cdots\cdots \text{IV—⑩}$$

In the same way as the case of (A), we have to satisfy the oscillating condition that $\frac{1}{4}\left(\frac{1}{CR_1} - \frac{R_2}{L}\right)^2 < \frac{1}{LC}$ in the duration of W period of exciting voltage. Furthermore, in this case we will investigate the negative half wave of the oscillating wave in condition of $f_o \ll f_L$, particullary in details. Because of maximum value of v_c has to be specified by the value V_p.

Now, as the near-deposited body (metal)is going to approach to the face-plane of sensor's coil, it will be resulted that the value of the inductance in L will be gradually decreasing and that the effective value of resistance will be increasing. Then it would has great influences to drop down the Q of coil, so that the oscillation of v_c will be attenuating along the various envelops (dotted line in the Fig. 4—4 (B)) during the W period of exciting signal, since the attenuation coefficient α will exist. The coefficient α has a inverse proportional relationship of exponential functional to d. By the reason, the value of α would be necessarily

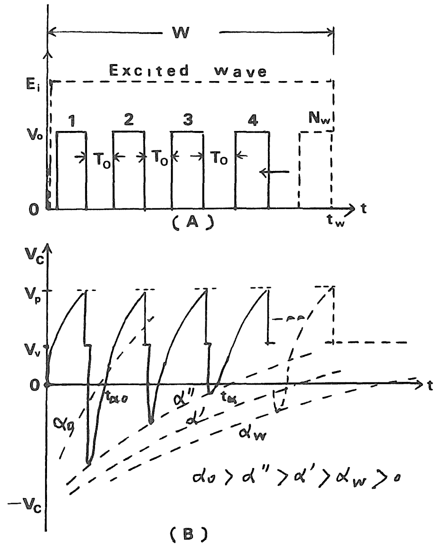


Fig 4—4
Output and Relation
of v_c, α

decided according to specify the value of d, although the value will be fluctuated with the qualities and the constructed forms of the near-deposited metals. Using the condition that $CR_1 \gg L/R_2$ and the eq. IV—⑨, we could obtained that

$$\alpha \fallingdotseq \frac{1}{4} \cdot (R_2/L) \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{IV—⑪}$$

If $\alpha \leqq \alpha_w$, then we obtain that the output pulse number is $N_W = W/T_o$, where N is a positive integer. On the other hand, when it is satisfied that $\alpha > \alpha_w$, since the attenuation of the envelope of negative-ward oscillating wave in v_c will become a great value, its value will reach at the equibilum voltage V_o of UJT at the time T_o during the W period. This equibilum voltage would be decided by the factors such as V_{BB}, the constant parameters of elements used, and V_{sat}, and it will be dropped duration of V_{sat} and V_v, and finally it would be specified within the region of saturating currents.

As a result, we would obtain the formula as follows

$$\frac{R_1}{R_{2v}} = \frac{E_i}{V_v} 1 \qquad \cdots\cdots \text{IV—⑫}$$

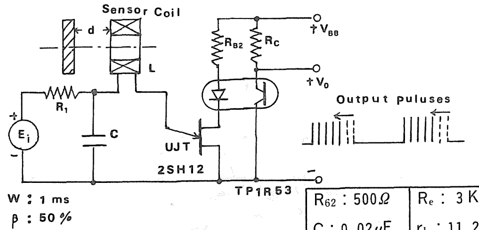
$$L'(I_p + I_v)^2 = C(V_p + V_v)^2 - 2R_2'(I_p + I_v)^2 \qquad \cdots\cdots \text{IV—⑬}$$

Therfore, on the duration of $t > t_\alpha$, the energy for risng up the waveform would be disipated with increasing the effective resistance. In other words, as shown in Fig. 4—4 (A), the fourth pulse N_4 in the output pulse would become the final pulse, and the pulses $N_5 \sim N_W$ would dissipated in the time duration.

As previously mentioned, the output pulse would be decided with that is at what time the envelope of $e^{\alpha t}$ ne would identify to the value of V_v. It means that the distance d between the near-deposited body and sensor's coil is correspondence to the value of α. If it is α_{max} at d = 0, then it will get only the N_1 out put pulse. Along to that α is decreasing to smaller than the value of α_0, the output pulse is going to increase the pulse numbers one by one and the maximum pulse number N_W will be obtained at the point the exciting voltage become W.

(C) Experiments and Considerations

In the experimental circuit used (Fig. 4—5), the



R_{B2} : 500Ω	R_e : 3KΩ
C : 0.02μF	r_L : 11.2Ω
R_1 : 1KΩ	L : 180μH

Fig 4—5
Experiment Circuit

sensor (L) was made of honeycomb type coil (diameter is 20mm), and we used the near-deposited body made of the same type of plane plate. The output of sensing circuit would be coupled with the next stage by the photocoupler, since it could be separated from the signal processing network so that the load effect could be neglected. As it will be seemed from the eq. IV—⑦, the exciting voltage E_i would force to change the output pulse-numbers. (Fig. 4—6). In this research-

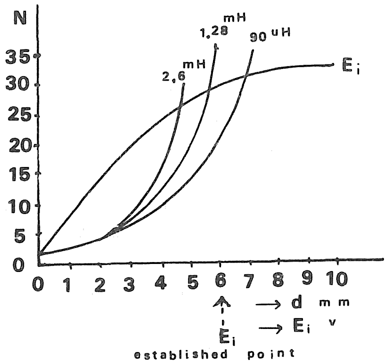


Fig 4—6
d and E_i — N
Characteristic

ing paper, we would set u a pulse width is 1_{ms} in E_S and E_S would be set up 6(V), so that group maintaing oscillation (burst signal) of wave having $N_w=30$ as the pulse-numbers, would be possible. Furthermore, considering that the degree of temperature stabilization of UJT would be controlled by the temperature characteristics of V_p, R_{B2} would have to be specified from the equation that $dV_p/dT=0$. Then we would obtain that

$$R_{B2}=\frac{0.1312 r_{BB}}{\eta V_{BB}} \quad \cdots\cdots\cdots\cdots\cdots\cdots\text{IV—⑭}$$

where r_{BB} is resistance between two biases of UJT. This means that it is the composted value in dividing ratio with positive temperature coefficient since V_{ebD} is a negative temperature coefficient. Although it would be allowed that duration of the value is about 400~500Ω, we would specify it 500Ω. Here we would plott the characteristic of pulse number (N) to the near-placed distance of sensor (d), which is very useful from the practical point of view. The value of L would be specified at the value 180μH since it would be fairly fitted with the value between 100μH and 1.5mH. In the case of Fig. 4—4 (B), we would experiment the characteristics of the attenuating coefficient to distance (d—α) as a experimental value. (refer to Fig. 4—7).

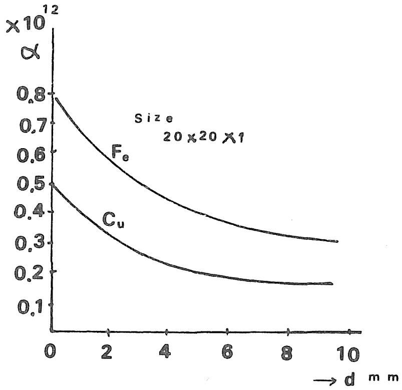


Fig 4—7
d — α characteristic

Now,it would be hoped that, there was the relation of $d \propto N$ when we desired to used it as a transducer of the near-deposited body displacement. However, it would be clear that it had exponential functional features and in that case it had the advantage of the same direction of the relationship between the changing-directions of N and d. Nextly, the oscillating wave of v_c is an attenuating oscillation so that the envelope curve of $v_c|_{min}$ is a exponential function of α.

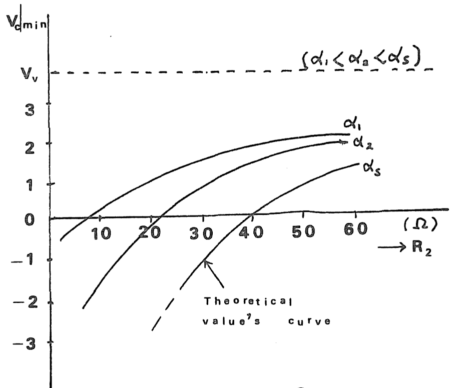


Fig 4 — 8
Relation of R_2 — $V_c|_{min}$

In such circuit of having the form of operating, that is to have the UJT sensor's circuit, the value variation ratio of effective dissipated resistance is greater than the variation ratio of inductance of sensor (L) influenced by the near deposited bedy.

Seeing from the experiment, it can be decided how many the output pulse numbers change by the degree of changing dissipated resistance in outer side. On the other hand, the effect of the inductance can be detected ouly in the final pulse wave, as changing of pulse-width. Fig. 4—8 shows the characteristics of envelope that is the relationship between the dissipated resistance by parameter α and $v_c|_{mim}$, and using it. It is possible that we recognize the value R_2 by knowing the zero cross point of the curve.

(V) Concluding remarks

we have constructed and investigated the relaxation oscillating circuit, which a nonlinear element is used with and a sensor's coil is connected with as a circuit element, for purposes of detecting the position and displacement etc. of the near-deposited body. We could have clarified the material as follow, by the investigatings of oscillating mechanisms mentioned through whole of the paper :

(I : We have recognized that, it is fully possible to do detection of the transformation of pulse-width by the method of the relaxation osillating method using E.D element, and also it is fully possible to detect the transformation of pulse-number by the method of using UJT element.

(II : A controlled oscillation is produced at the valley point of characteristic curve of E.D element, and in that case, the pulse-width is increasing step by step successively. The phenomena can be fully described by the theory of satisfying a nonlinear conservative system.

(III : In the valley point of the characteristic curve of UJT element, the abruptly rising up of pulse can not be occured at that point, since the point is equibilium point. The pulse-number until reaching that point is decided by the time duration from the biginning to the time at which the envelope line has to reach the equibilium point.

(IV : In any nonlinear element used on those circuits, the key point of the operating behaviour is essentially to be the valley point in the characteristic curve.

(V : In the case of using a electromagnetic sensor and E.D element in practice, it is the serious problem that whether the stability of the circuit would be provided. On the other hand, in the case of using UJT or PUT, we have confidence to say that the circuit has full stability for practical using in any real applicating circuits.

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