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NEW *TELEPERM* EMF TRANSMITTER

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I. PREFACE

Since FUJI ELECTRIC's introduction of the TELEPERM System in 1959—the performance of which has been outstanding—many new advancements have been made in respect to this system. The FUJI ELECTRIC, being far ahead of other manufacturers in the development of this particular system, has now developed a new "dc two-wire system" utilizing semiconductors. The use of semiconductors in this equipment not only contributes to reductions in the equipment size and weight but also provides greater system reliability. Conventional transmitters at on-the-site locations require a total of four lines for ac power supply and signal wiring. However, in the dc two-wire system, the necessity of ac power supply is eliminated due to the drastic reduction in transmitter power consumption. Signal transmission and reception is possible due to a two wire connection between the dc power supply in the central control room and the transmitters on the site. Reduced labor costs and number of cables employed are outstanding features of this equipment. Operation simplicity, which is directly related to the reduction in wiring, provides increased safety against the possibility of explosions.

Some manufacturers have preceded us in the development of two-wire systems, but only in respect to balance and displacement type equipment. FUJI ELECTRIC leads other manufacturers due to the "dc two-wire system" in all site transmitters. This is one of the many outstanding advantages of the New TELEPERM System.

II. DC TWO-WIRE SYSTEM

A noteworthy feature of the TELEPERM System is that dc two-wire systems are employed in all of the site transmitters. Since this point is further stressed in a different section, other major advantages of this system will be covered in the following.

1) Since an ac power source is not required, cable costs are greatly reduced; only two cables are required as opposed to the four wires required in ac power supply dc signal systems.
2) The number of transmitter parts is greatly reduced due to the non-employment of a power supply circuit. This, in addition, also attributes to the equipment's size and weight reduction, and to the increase in overall reliability; the power supply installed in the central control room pro-

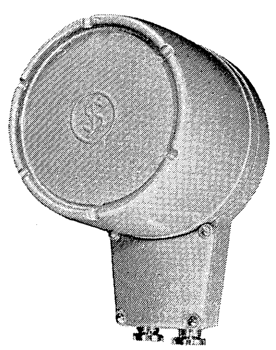


Fig. 1 TELEPERM EMF transmitter

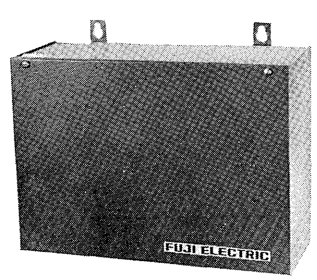
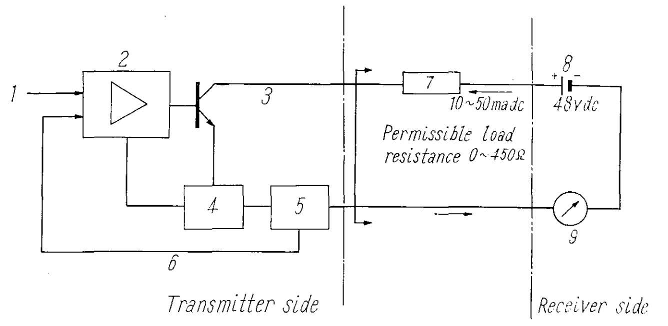
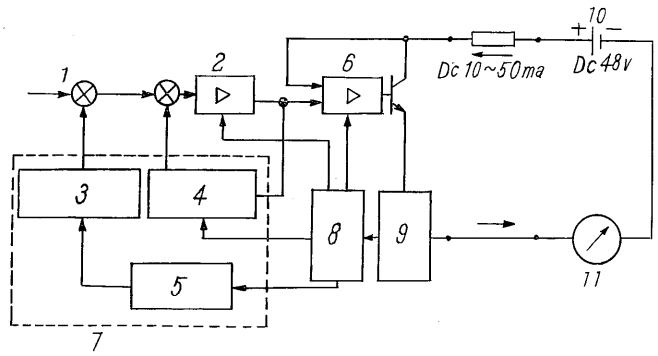


Fig. 2 L-size case for panel mounted equipment



① Input
② Amplifier
③ Power transistor
④ Voltage stabilizer
⑤ Feedback element
⑥ Feedback
⑦ Line resistance
⑧ Common power supply
⑨ Receiving instrument

Fig. 3 Principle of dc two-wire system



① Input
② Pre-amplifier
③ Reference junction compensation, fails-safe and suppression
④ Feedback unit equiped with linearizer
⑤ Reference voltage power supply
⑥ Isolation amplifier
⑦ Input unit
⑧ High frequency oscillator
⑨ Regulaled voltage supply
⑩ Common power supply
⑪ Receiving instrument

Fig. 4 Block diagram of EMF transmitter

duces regulated voltage which further adds to the equipment reliability characteristics. In view of the above, it is assumed that this system largely contributes to economy as well as reliability—two highly stressed points in the field of engineering.

Let's consider the factors that make the dc two-wire system possible. First is the drastic reduction in transmitter amplifier power consumption. Since amplifiers employ active circuits, the power source must be continuous without interruption. Up to the present, an ac power supply was required due to the large power consumption characteristics of transmitters. For this reason, the dc two-wire system was not employed in EMF transmitters. However, due to the remarkable advancements made in semiconductor products, Zener diodes, and transistors, a reduction in transmitter power consumption has been accomplished.

FUJI ELECTRIC employs a magnetic amplifier as a dc low level amplifier. From the standpoint of reduction in the power supply requirements for various types of low level amplifiers, choppers, magnetic modulators, and transistor choppers, the magnetic amplifier tends to be the most advantageous. For example, EMF transmitter (Model: E-ET1) consists of a push/pull magnetic amplifier, a transistor differential amplifier, and an isolation magnetic amplifier. Total power consumption for the magnetic amplifier is less than 20 mw. The EMF transmitter requires a reference voltage supply, which is also utilized as the power source for the transistor amplifier, magnetic amplifier, linearizer, etc. The total power consumed by all of these units is somewhat in excess of one hundred mw. Such value is readily obtained by the base current (10 ma) of the TELEPERM unified signal current of 10~50 ma dc. Therefore, even if the signal input is 0%, approximately 200 mw of constant power is obtained by means of the 10 ma base current which flows through the 20 v Zener diode. In view of this, all of the equipment power requirements are fully met. A detailed description of the small power amplifier is given in the following section.

It has been ascertained through past experience that, when the TELEPERM receiving instrument is employed, 450 ohms which includes line resistance is sufficient. A power supply voltage of 48 v dc is required due to the relation between maximum permissible load resistance, transmission current, and amplifier power supply. In addition, and not only limited to the dc two-wire system, transmission errors occur due to leakage at points along the lines. In the dc two-wire system, this can be expressed as follows:

$$\varepsilon=\frac{I(a)-I_0}{I(a)}\left\{1+\frac{1+\dfrac{E}{I(a)\sqrt{r/g}}\sinh\sqrt{rg}\,a}{\cosh\sqrt{rg}\,a+\dfrac{R}{\sqrt{r/g}}\sin\sqrt{rg}\,a}\right\} \quad \cdots\cdots (1)$$

r: Line resistance (Ω/km) in both directions
g: Line leakage conductance (℧/km)
E: Common power supply voltage
a: Transmission distance (km)
R: Receiving resistance (Ω)
I_0: Current (ma) at the common power supply output terminal
$I(a)$: Output current of the transmitter terminal

In the conventional four-wire system, which includes ac, this can be expressed as in the following equation:

$$\varepsilon=\frac{I_0-I(a)}{I_0}=\left\{1-\frac{1}{\cosh\sqrt{rg}+\dfrac{R}{\sqrt{r/g}}\sinh\sqrt{rg}\,a}\right\} \quad \cdots\cdots (2)$$

$I(a)$: Receiver current
I_0: Transmitter output current

When comparing equations (1) and (2), the dc two wire system is by far the most advantageous in respect to transmission error, which is directly due to a smaller error. If actual numerical values are utilized in the calculation and if a line equal in quality to the municipal cable is used, the transmission error becomes negligible as in equations (1) and (2) (when the transmission distance is about 10 km). However, this is confined to dc current only. For ac current, since the high frequency characteristic is not very good at the line insulator, transmission error becomes large as g becomes larger and line capacity influence becomes significant; for convenience, dc is recommended for analog signal transmision.

III. MAGNETIC AMPLIFIER

The following is a brief description of the mag-

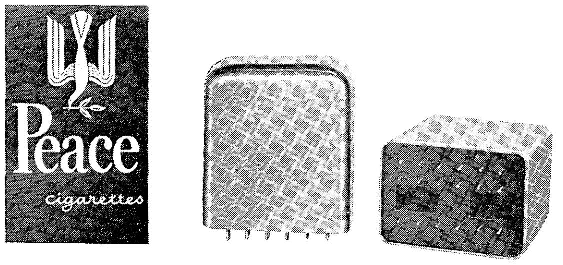


Fig. 5 Magnetic amplifier

netic amplifier. As with the conventional TELEPERM EMF converter, the magetic amplifier constitutes the main portion of the present dc amplifier in the TELEPERM EMF transmitter and computing element group. The magnetic amplifier provides many advantageous features when employed in industrial instruments.

For example:

1) Easy isolation of input and output.
2) The simplicity of associated circuits enables a reduction in the number of parts employed, thereby attributing to greater reliability.
3) Maintenance and repair are not required and the life of the equipment is almost permanent due to the non-employment of a mechanical drive section or parts subject to wear.
4) Power consumption for the dc two wire system is low.

When evaluating the performance of the dc amplifier, its low zero drift, high response speed, reliability, and ease in handling must be considered. However, when employed for industrial instrumentation where extremely high speed is not required, a maximum 10 cps cut-off frequency is sufficient. Zero drift is not, in all instances, advantageous when compared with the mechanical chopper or core chopper. Nevertheless, the assumed minimum input is 5 mv and the signal power impedance is, at the most, 20 to 30 ohms in the case of industrial instrumentation, i. e., an amplifier with drift of an approximate 10^{-12} w/10°C may be used. When the magnetic amplifier is employed with the push/pull system, drift power becomes approximately 10^{-12} to 10^{-13} w/10°C when employed for industrial instrumentation, the magnetic amplifier is not restricted in any way. For response speed, the magnetic amplifier need not be connected after the low level input first-stage magnetic amplifier; a transistor amplifier is sufficient. This system is not only more economical but is also easily stabilized when employed as a feedback amplifier.

The cut-off frequency of the transistor is far higher than that of the magnetic amplifier; the production of an amplifier with an approximate 10 cps cut-off frequency is relatively simple and is done by combining a transistor amplifier and a magnetic amplifier.

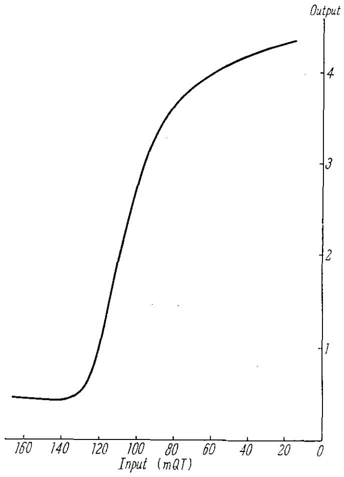


Fig. 6 Charactiristic curve input AT vs. output

For the magnetic amplifier, a special molybdenum permalloy iron core is employed. The thickness of the iron core sheet is 0.025 mm. With an iron core as thin as 0.025 mm the cut-off number of ampere-turns and the amplification factor are not deteriorated by excitation with a 400 cps power supply. For a manufacturing thickness of less than 0.025 mm, the problems encompassing the rolling technique should be considered. The magnetic amplifier is excited by ac and its frequency is directly related to response speed. The power supply frequency can be optionally designed due to the utilization of transistors. However, if the frequency is excessive, the cut-off ampere turns increase due to eddy current loss, thereby decreasing the amplication degree. It is most suitable to use an oscillator frequency in the range of 400 cps for the dc low level amplifier in industrial instrumentation.

Actual circuit

Circuit system:	Center tap doubler circuit
Power supply:	Approximately 400 cps, 6 v square wave
Amplification degree (Positive feedback is not included):	Approximately 0.1 v/1 maT
Temperature drift (equated to input):	0.6 maT/10°C
Voltage drift (equated to input):	Approximately 5 maT/10%

When this equipment is employed with a push/pull system, the amplification degree doubles, temperature drift becomes 1/10, and voltage drift becomes 1/20. The magnetic amplifier and amplification characteristics are shown in *Figs. 5* and *6*.

IV. EMF TRANSMITTER (MODEL E-ETI, E-ETI-Ex) AND ELECTRICAL CONVERTER (MODEL E-ETI-P)

The above models are exact duplicates in respect to specifications and are classified in three types: Site installation type (Model E-ETI), explosion-proof

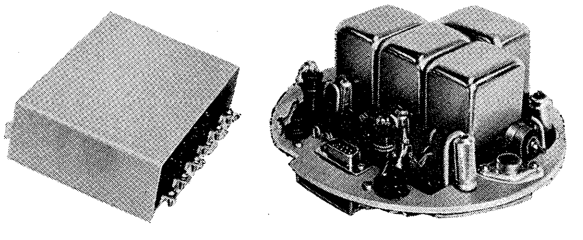


Fig. 7 Amplification and input portions of transmitter

type (Model E-ETI-Ex), and panel mounting type (Model E-ETI-P).

1) Site installation type (Model E-ETI)

Model E-ETI has a drip-proof construction and the affects of temperature are reduced due to a protective silver coating; the construction enables on-the-site installation.

2) Explosion-proof type (Model E-ETI-Ex)

The construction of Model E-ETI-Ex is such that it is explosion-proof (constructed in accordance with JIS-C 0903 "General rules for construction of explosion-proof electrical equipment) and is classified as d2 G4 (explosion class 2, ignition degree 4).

3) Panel mounting type (Model E-ETI-P)

Model E-ETI-P is contained in a large case (L-size) which is designed to also house panel mounting type TELEPERM measuring instruments.

1. Performance

The input is an electrical signal, approximately 5 mv to 100 mv. The process variables obtained from the detectors such as the thermocouple or resistance bulb are transmitted through the EMF transmitter as a 10 to 50 ma current. The relation between the detectors and process variables is not completely linear but has up to 10% non-linearity. In conventional measuring devices, nonlinearity was permissible due to nonlinear calibration of the recorder, indicator, and setter. However, due to the recent popularity of the logger, it is now a prerequisite that the relation between transmitting current and process variable be linear. At the same time, as non-linearity compensation is made at the transmitter, reference junction compensation should be made at the thermocouple input. In addition, isolation between the input and output is essential in large scale instrumentation. The TELEPERM EMF transmitter was designed to comply with these requirements.

2. Principle of Operation

A block diagram of the equipment is shown in *Fig. 4*. A 10 ma current, obtained when the signal is 0%, flows through the regulated voltage supply which is composed of Zener diodes.

By this power, an approximate 400 cps square wave exists. In the square wave oscillator circuit, a molybdenum permalloy iron ring core with a small oscillating current is employed for the coupling transformer in order to reduce power loss. The iron ring core is similar to the one employed in the magnetic amplifier. The three windings on the secondary side of the coupling transformer provide power conveyance to the first stage push/pull magnetic amplifier, transistor differential amplifier, isolation stage amplifier, and the standard voltage power respectively. The pre-amplifier consists of push/pull magnetic amplifier and transistor differential amplifier; the output current is fed back through resistance, simultaneously becoming the input of the isolation stage magnetic amplifier. At the isolation stage magnetic amplifier, the output drives the output stage transistor, with the output current negatively fed back through the other isolated winding.

1) Input operation resistance R is determined by the first stage amplifier.

$$\mathfrak{R}_i=(R_i+R_w+R_f)(1+K_L) \fallingdotseq (R_i+R_w+R_f)K_L \quad \cdots\cdots\cdots (3)$$

$\mathfrak{R}_i$: Input operation resistance
R_v : Signal power resistance
R_w : Magnetic amplifier winding resistance
R_f : Feedback resistance
K_L : Loop gain

In this particular case, loop gain K_L is not constant and is altered by means of signal power resistance R_v and input voltage V_{in}.

$$K_L=\frac{V_{in}/R_i+R_w+R_f}{\delta} \quad \cdots\cdots\cdots (4)$$

δ : Current flowing through the input windings changes the output from 0 to 100%.

δ is determined by the product of magnetic amplifier gain and transistor gain, and is designed to be 0.1 μa maximum. However, it is not constant due to parts dispersion, etc. In accordance to equations (3) and (4):

$$\mathfrak{R}_{in}=\frac{V_{in}}{\delta} \quad \cdots\cdots\cdots (5)$$

For example, the input operation resistance for $V_{in}=10$ mv/100% which becomes approximately 100 kilohms.

2) Output operation resistance $\mathfrak{R}_0$

The output current must be independent of the load resistance and at least 10 kilohms output resistance is obtained from one transistor alone. Therefore, with an amplifier that has a loop gain K_L of approximately 400-times, this becomes approximately 4 megohms. Hence, little influence occurs due to the load variation (0~450 ohms). The degree of amplification of the isolation stage magnetic amplifier and output stage transistor determines the output operation resistance. As a sufficiently large number of input ampere-turns is established in order to suppress drift in the stage, the loop gain is large, at least 400-times.

3) Conversion characteristics

Several linearizers may be inserted in the range unit if required. However, when linear feedback is employed, a linearizer is not used. Linearity between the input and output is desirable. For Model E-ETI, the pre-amplifier of the voltage balance type or the isolation stage amplifier of the current balance type is employed. The total non-linearity error is minimized, being at most ±0.1%.

4) Temperature characteristics

Concerning the factors which determine the temperature characteristics of the amplifier section, the drift of the magnetic amplifier and transistor amplifier becomes a problem, as well as that of the pre-amplifier and isolation stage amplifier. On the other hand, the temperature variation of Zener diode for the oscillator circuit power supply causes only slight drift. However, largest contribution comes from drift of the push/pull magnetic amplifier in the pre-amplifier. Each of the individual amplifier stages of the push/pull magnetic amplifier depends upon the degree of imbalance of the temperature drift. In the magnetic amplifier, the degree of imbalance is approximately 1/10 to 1/20. At worst, the drift of the push/pull case can be suppressed to as little as 1/10 that of the single case. In order to obtain a sufficient degree of precision in the amplifier stage, the input should be sufficiently large in comparison to the drift. Therefore, the restriction expressed by the following equation is placed upon the input voltage and the signal source impedance.

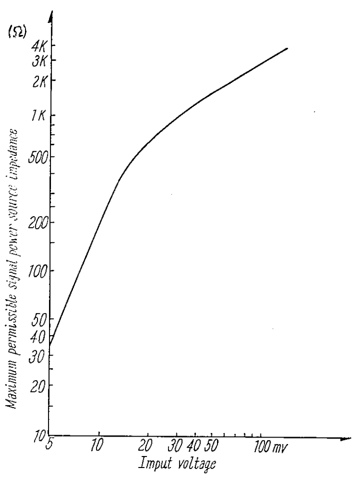


Fig. 8 Input voltage vs. permissible maximum signal impedance (TELEPERM EMF transmitter)

$$\frac{V_{in}}{V_{in}/I_0+R_w+R_i}\times T\geq [AT] \quad (6)$$

V_{in}: Input voltage amplifier
I_0: Pre-amplifier output current
R_w: Push/pull magnetic amplifier winding resistance
R_i: Signal source impedance
T: Number of input windings of push/pull magnetic amplifier
(AT): The minimum number of ampere turns required to maintain proper precision

Fig. 9. illustrates the relation between the input voltage and the maximum permissible signal source impedance obtained from the above equation.

5) Linearizer

Taking for example the case of the thermocouple, let's assume the relation between the measured temperature T and the generated electromotive force E_{th} to be as follows:

$$E_{th}=F(T) \quad (7)$$

At this time, the functional equation between the pre-amplifier output current I_0 and the feedback voltage V_f is decided as follows, where F is the same as that of equation (7):

$$V_f=F(I_0) \quad (8)$$

In the operation of a feedback amplifier with sufficiently large loop gain, the input voltage E_{th} and the feedback voltage V_f become equal. This is expressed as follows:

$$(E_{th}-V_f)\,K_L=I_0$$

$$\therefore\ E_{th}=V_f+\frac{I_0}{K_L}\fallingdotseq V_f \quad (9)$$

From equations (7), (8), and (9)

$$F(I_0)=F(T)$$

$$\therefore\ I_0=T \quad (10)$$

When I_0 and T are considered in equation (10) with % conversion, the output current I_0 and the measured temperature T have been adjusted so as to be related linearly.

The function $V_f=F(I_0)$ is approximated by several straight lines. Thus, there is an error due to this approximation as well as to temperature variation of the linearizer. The approximation error is designed to be a minimum based on all the standard specfications. The error arising from the temperature variation is caused by that of the threshold voltage of the diode due to temperature. This is approximately given by the following equations:

$$\varepsilon=\sum_{i=1}^{a}\Delta\alpha_i\,\Delta x_i \quad (11)$$

ε: Error (%) equated to input error
x_i: The position of the deflecting point (%) due to linear approximation.

α_i : Inclination from one deflecting point to the adjacent deflecting point due to the linear approximation.

Δx_i : Variation in x_i due to temperature

$\Delta \alpha_i$: Variation in inclination $\Delta \alpha_i = \alpha_{i+1} - \alpha_i$

As Δx_i is due to the temperature variation of the threshold voltage, this can be easily compensated by using the same diode and can be reduced to 1/10 that of equation (11).

As clearly seen from equation (11), the greater the non-linearity, the larger Δa_i and the number of deflecting points. Therefore, the value of n (in $i=1 \cdots n$) increases, producing a large error. In other words, FUJI ELECTRIC is not considering the linearization of a radiation pyrometer. In other cases, the PR thermocouple displays the largest curvature, but it is designed to achieve sufficient precision up to this range.

6) Dynamic characteristic

In the pre-amplifier, the time constant of the magnetic amplifier is especially large when compared to that of the transistor differental amplifier or the RC filter of the magnetic amplifier, even exceeding the crossover point by 20 dB/dec. *Fig. 10* shows bode diagram.

$$G_1 = \frac{1}{(1+ST_1)(1+ST_2)} e^{-SL} \quad \cdots\cdots\cdots\cdots\cdots \quad (12)$$

T_1 : Magnetic amplifier time constant (sec)

T_2 : Filter time constant (sec)

L : Dead time due to the magnetic amlifier (sec)

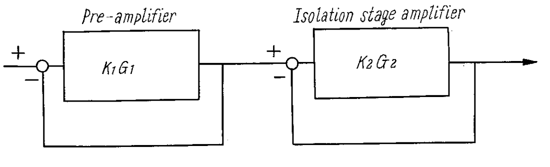


Fig. 9 Block diagram of TELEPERM EMF transmitter

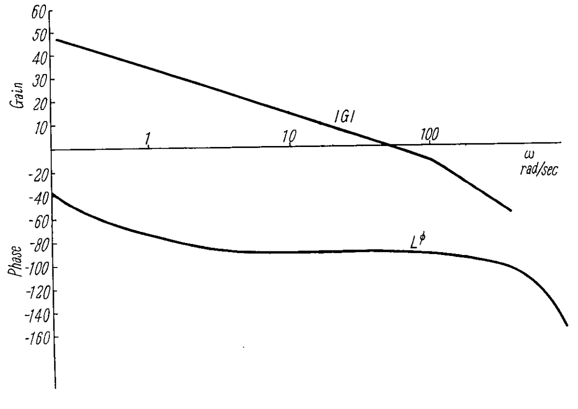


Fig. 10 Bode diagram of pre-amplifier

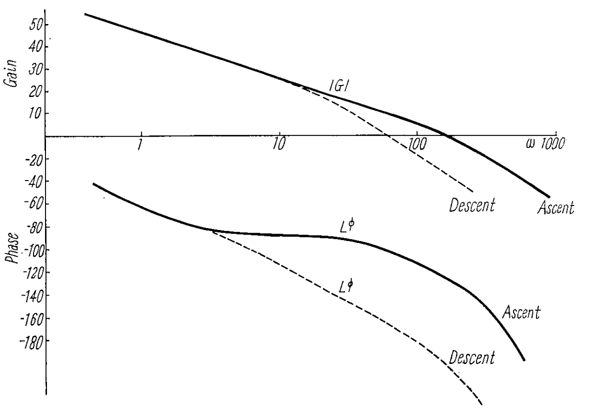


Fig. 11 Bode diagram of isolation amplifier (TELEPERM EMF transmitter)

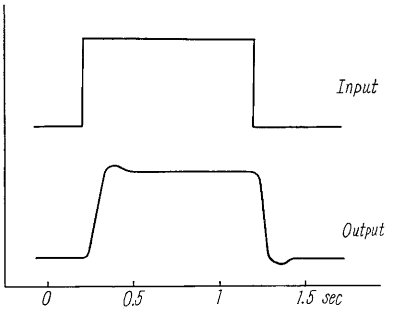


Fig. 12 Indicial response, TELEPERM EMF transmitter

T_1 is given by the following equation:

$$T_1 = \frac{1}{2f} \cdot \frac{K}{N_p} \sum_{i=1}^{n} N_{ci}^2 \times \frac{1}{R_{ci}} (\text{sec}) \quad \cdots\cdots\cdots \quad (13)$$

f : Oscillator frequency (cps)

N_p : Number of turns in C_p winding

N_{ci} : Number of turns in each control winding

K : Magnetic amplifier proper amplication degree V/AT

R_{ct} : Total resistance of control windings Ω

A short ring is added to the magnetic amplifier in order that T_1 does not vary excessively due to the total resistance $(R_w + R_{tn} + R_f)$ of the input windings. A sufficiently large time constant for attaining stability is obtained.

In the isolation stage amplifier as well, the response is determined by the magnetic amplifier time constant and the filter time constant. However, this differs from the previous example in that the time constant of the filter differs between ascent and descent.

$$G_2 = \frac{K}{(1+ST_1')(1+ST_2')} e^{-SL} \quad \text{ascent}$$

$$G_2 = \frac{K}{(1+ST_1')(1+ST_2'')} e^{-SL} \quad \text{descent}$$

$$T_2' \ll T_2''$$

When observed only during ascent, the damping is rather defective, becoming oscillatory. Actually, there is no problem, however, because the damping is proper during descent and the waveform of the current entering this isolation stage has been smoothed corresponding to the step input by the pre-amplifier. The overall speed in the pre-amplifier and isolation stage is shown in *Fig. 12*.

7) Reference voltage supply

A reference voltage supply is employed for zero suppression, zero elevation, and the power source for bridge circuit of the resistance bulb and the reference junction compensation of thermocouple in the case of the temperature measurement. Compensation type high precision Zener diodes have appeared on the market recently. However, these are not suitable if there are strict limitations on the power available as is the case with a dc two-wire system, since these diodes require considerable power. One which is temperature compensated by applying copper wire to the usual Zener diode is used.

3. Construction

The input unit and amplifier unit are independent. In addition, they are interchangeable. The input unit can be removed by using a screwdriver. The amplifier unit can be removed by taking out one screw and one pin.

The volume control for zero adjustment and span adjustment is attached to the amplifier unit, providing easy adjustment, maintenance, and inspection.

All items included in the input specifications are provided in the input unit, such as the reference voltage supply feedback unit equipped with linearizer, reference junction bridge, and the fail-safe circuit put into use in the event of burnout of the thermocuple.

The amplifier unit includes the power supply Zener, oscillator circuit, pre-amplifier (push-pull magnetic amplifier and transistor differential amplifier), and output stage transistor.

In addition, a check terminal is provided for external checks to be performed conveniently without removing the case cover or terminal box cover.