Weston ENGINEERING NOTES

VOLUME 8 JULY 1953 NUMBER 2

In This Issue

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BEARINGLESS TACHOMETER GENERATOR USING A FREQUENCY RESPONSIVE NETWORK

Note: This is the first of a series of articles covering recent developments by Weston in the field of tachometry.

SINCE Dr. Weston's development of the tachometer generator for the measurement of rotational speed in 1896 (see ENGINEERING NOTES, Volume 4, No. 1), industrial users have become more and more exacting in their requirements. At first it was only a matter of accuracy. Later, the speeds became higher and higher to such an extent that the use of a d-c generator became inadvisable. The a-c generator was then developed (see ENGINEERING NOTES, Volume 4, No. 2) to avoid the brush and commutator problem at higher speeds. More recently such problems arose as: ultra high speeds—up to 80,000 rpm; very low torque burden—less than one ounce-inch; long life—as much as 30,000 hours without shutdown; axial travel of drive shaft—in large turbines sometimes as much as ¼″ or more; and space limitations which prohibit the use of a conventional generator.

Engineering efforts on these problems took on various approaches such as stroboscopes, electronic counters using pulses developed by light reflected into a photocell or by magnetic reluctance pick-ups, rotary switches which develop d-c pulses, and many others. All of these approaches left something to be desired. Problems such as difficult installation, excessive cost, large amount of equipment necessary, external power source needed, excessive maintenance required, etc., were encountered.

Bearingless Generator

The approach of the Weston Laboratory, in order to get around the basic limiting factors of high speeds and maintenance requirements, was to mount a permanent magnet rotor on an extension of the shaft of which the speed was to be measured. A pick-up coil or coils was attached to the stationary frame of the device. The stator was so located that the rotor revolved inside, resulting essentially in a bearingless generator.

Figure 1 shows the essentials required for a bearingless generator

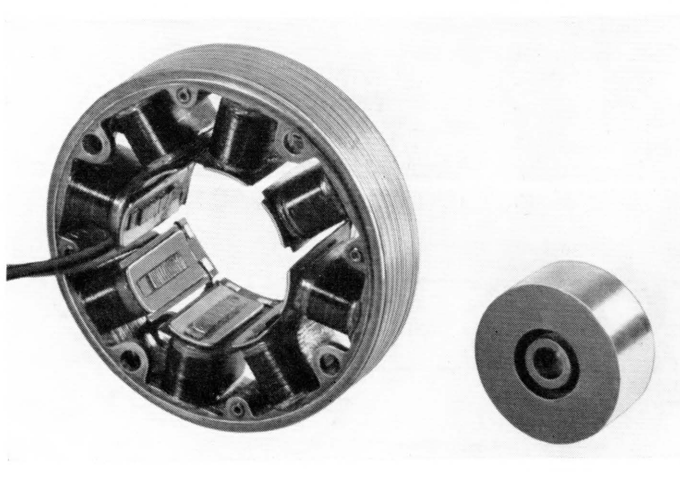

Figure 1—View showing stator (left) and rotor (right) of Weston Model 758 Type XF Bearingless Tachometer.

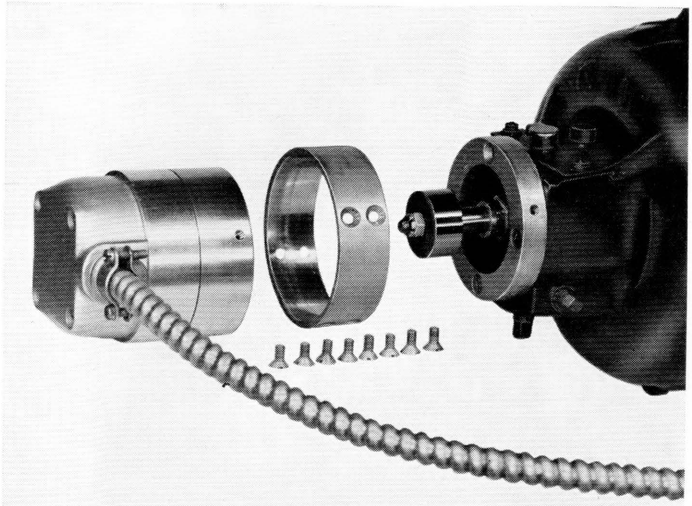

Figure 2—Exploded view of ring and sleeve mounting for Weston Model 758 Type HF Bearingless Tachometer.

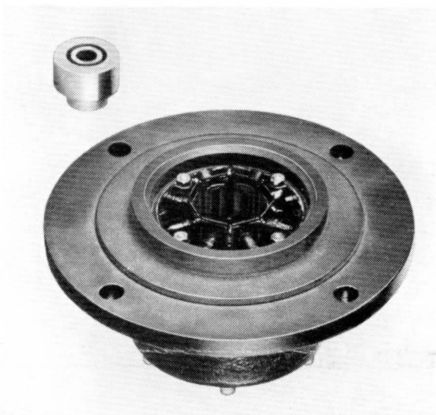

Figure 3—Rotor and flange-mounted cast iron case for stator—Weston Model 758 Type GF.

of the type described above. The stator has eight coils, and the rotor is charged to eight poles. It is used in the lower speed region of 500 to 15,000 rpm. At higher speeds, the number of coils and poles is reduced in order to keep the frequency within reasonable limits.

Various methods of mounting the stator and rotor have been developed, such as ring and sleeve, Figure 2; and a flange-mounted cast iron case, Figure 3. Both of these designs allow quick interchangeability of stators. The rotor and stator could also be designed as integral parts of a machine and be located within the machine housing.

This approach is desirable because no maintenance is required for the device.

The objectionable feature of this plan of the bearingless generator was that the emf developed at a given speed depended on the physical relation between the rotor and stator, thereby necessitating the use of rheostats which required adjustment after installation. Also, if any axial travel of the shaft existed, a random error was introduced. The next step to get around this problem was to develop a circuit in which the indications of the tachometer indicator were a function of the frequency and not of the magnitude of generated voltage. The frequency of the generated voltage is proportional to the speed of the rotor. A tachometer using this principle is known as a "Frequency Responsive Tachometer System." While the frequency responsive system is essential to the bearingless generator, it may also be used effectively with the conventional a-c tachometer generator.

Frequency Responsive Tachometer Systems

The basic circuit is shown in Figure 4. It consists of four parts: (1) a-c generator, (2) saturable core transformer, (3) rectifier network, and (4) d-c indicator.

The generator has been briefly described in the preceding paragraphs. However, additional facts should be understood. The extension of the shaft of which the speed is to be measured may take on various designs. When the maximum speed encountered is 5,000 rpm or above, this extension should be an integral part of the main shaft and carefully ground to centers. Likewise, the rotor must be accurately ground to centers. Cast Alnico II is not recommended for speeds beyond 25,000 rpm, in which case sintered Alnico will serve but must be spin tested to a safe margin above the highest speed to be encountered. Since the indications are a function of frequency and not voltage, the exact location of the stator with reference to the rotor is not important. So long as the stator does not touch the rotor

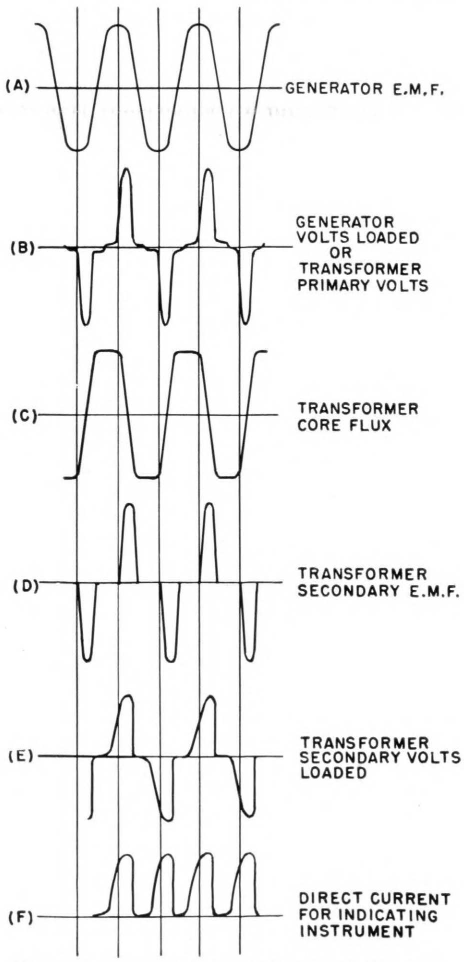

Figure 5—Graphical presentation of the basis for the operation of the bearingless type tachometer.

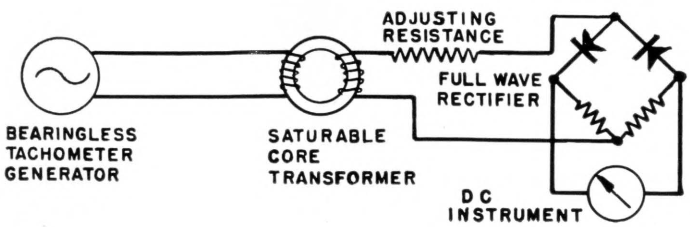

Figure 4—Basic circuit for bearingless generator type tachometer.

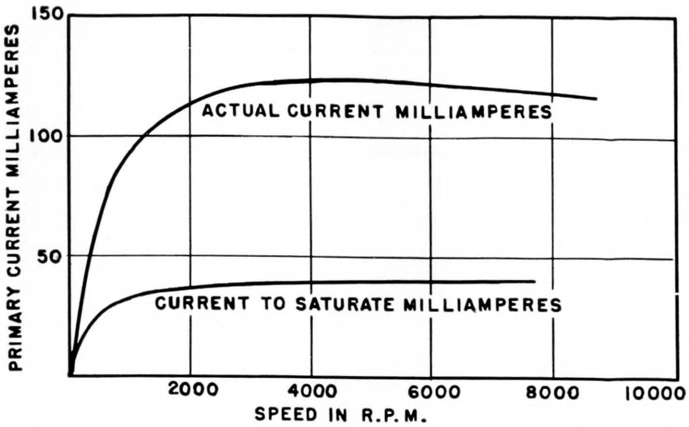

Figure 6—Graphic illustration showing the ability for retaining saturation in transformer core.

and the rotor does not project beyond the stator more than ¼", the results will not be affected. Rotor magnets are brazed to a mounting bushing, charged magnetically with the proper number of poles, and stabilized at the desired strength. They may be mounted or dismounted from the shaft without change of instrument adjustment or calibration. The following table has been established as a basic rule of thumb for the number of poles and coils:

Adjustment of the system is made by means of the series resistance between the secondary of the transformer and the rectifier. Its value is dependent on the secondary burden current required. This current is proportional to the secondary turns and frequency, and since the turns are fixed, the current is therefore proportional to frequency.

Theory of Operation

The explanation of what takes

Speed	*Rotor Poles*	*Stator Coils*		*Frequency-CPS*
		No.	*Res.-Ohms*	
up to −15,000	8	8	32	up to −1,000
16,000 to 25,000	4	4	16	260 to 833.3
26,000 to 80,000	2	2	8	200 to 1,333.3

The transformer is of the closed ring, ribbon wound, core type with toroidal windings for primary and secondary. The core is of such material that it will saturate with as little as 0.3 oersted and, when saturated, the flux density is approximately 14,000 gausses.

The rectifier is of the full-wave type with the bridge completed by resistors so as to decrease the effect of temperature and also protect the rectifiers against the peak voltage from the transformer in event of an opening in the movable coil circuit of the indicator.

The indicator is a d-c instrument of the permanent-magnet, movable-coil type having such current sensitivity and resistance as to properly match the rectifier circuit. The scale of the instrument is quite uniform, departing from linearity by about 1 per cent of the full scale length.

place in the circuit is shown graphically in Figure 5. (a) represents the generator emf, or no-load voltage. When connected to the transformer, the terminal voltage of the generator has a modified sine wave shape as shown in (b). The sharp peaked portion of the emf wave, extending for only a small part of the total wave, is that portion needed to saturate the transformer core. Graph (c) represents the core flux and (d) shows the effect of the core flux changes on the emf in the secondary winding from one saturation to the next. During the saturated portion, the secondary emf is zero. When the secondary of the transformer is loaded, the voltage wave broadens at the base and becomes shorter in amplitude (e). If loaded sufficiently, it would ultimately become a sine wave and the transformer would no longer be saturated. After rectification, the current applied to the indicating instrument is a d-c pulse as shown in (f).

The actual current in the primary winding of the transformer, together with the current necessary to saturate the core, is shown in Figure 6. This shows that the core is saturated at all speeds.

Effect of Generator Voltage Changes

For any given speed, the effect of voltage change, due to drop in flux of the rotor or shift in alignment of rotor and stator, creates a very small effect as shown in Figure 7. A drop of 20 per cent in generated voltage results in only a 1 per cent change in indication.

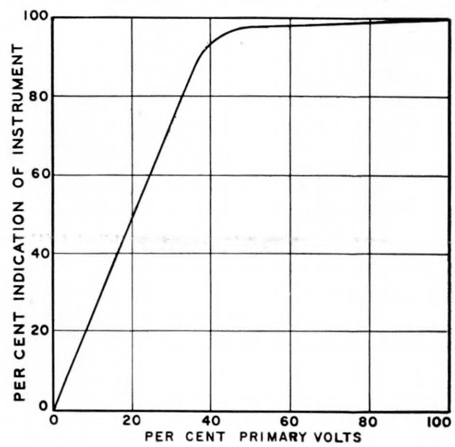

Figure 7—Graphic illustration of generator voltage effect.

Over-All Accuracy

The over-all effect of ambient temperature is within 1 per cent for any temperature from −40 to +40 degrees Centigrade.

The difference between the accuracy of this frequency responsive system and that of a voltage responsive system is the result of the elimination of the variance allowed for the generator. This results in an over-all accuracy of approximately ±1½ per cent of full scale value when used with a panel or switchboard type of instrument.

The next article will cover "Frequency Responsive Differential Tachometer Systems."

E. N.—No. 95 —*A. H. Wolferz* and *J. A. Heacock.*

A SINGLE POINT AMMETER USING A CURRENT TRANSFORMER

THE USE of current transformers with ammeters is an old but highly approved method of measuring alternating currents. The usual practice is to use a meter having a range of 0 to 5 amperes and then by means of a current transformer the range can be extended to 10, 20, 100 or any range up to several thousand amperes.

The following article deals with a special application of a current transformer which is very simple to use and which is capable of measuring alternating currents very accurately. It was developed as an answer to an interesting application which required accuracy, speed of operation and, even more important, the elimination of any possibility of the operator reading the instrument incorrectly. It is quite possible that there are many such applications, especially in production work, and, therefore, it is hoped that the following will not only prove of interest but also of value on some similar application.

In this particular application the manufacturer of a certain piece of apparatus utilizes a lamp which, depending upon conditions, must be operated at various current values. At times the lamp may be operated at the same current for hours or even days. The lamp may then be changed, or the current through the same lamp may be altered. In either case, the operator, if using a conventional ammeter, must read a different value on the meter scale. Because of the prolonged readings at one value, the operator would occasionally revert to the old reading or simply make a mistake and read the wrong value. An error of this type would not show up until a great deal of work had been done, resulting in considerable loss of time and money. The problem was, how could such errors be eliminated and at the same time obtain the high accuracy of current measurement necessary, as the candlepower of a lamp varies approximately as the sixth power of the current.

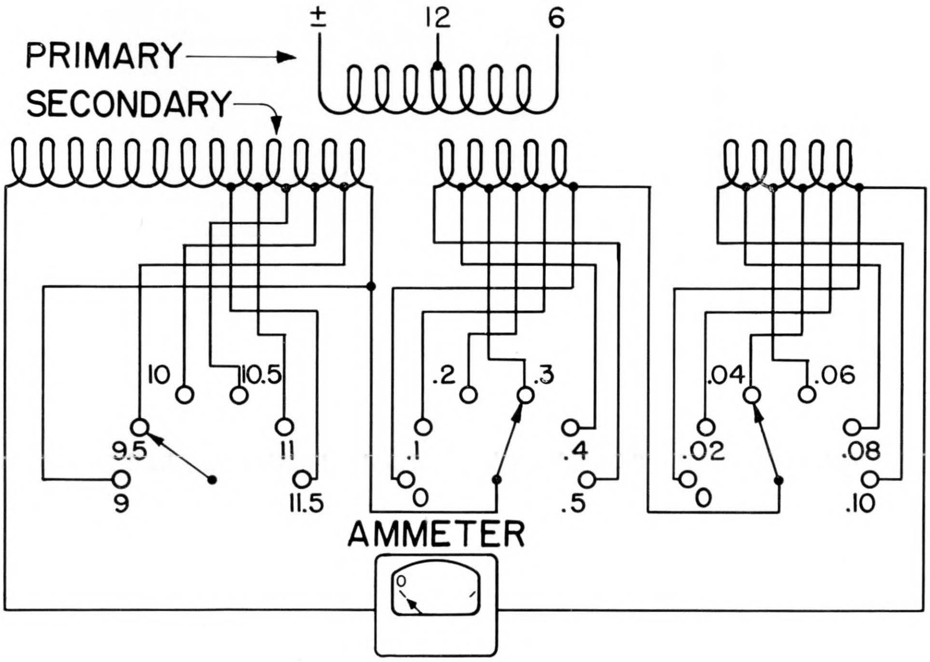

Figure 1

To state this problem in a rather simple way, our customer was asking us for a meter which the operator could read without making a mistake and at the same time obtain an accuracy of ¼ per cent or better for current values between 4.5 and 6, and between 9 and 12 amperes. After considerable discussion with two of the writer's colleagues, Mr. J. H. Miller, Vice-President, and Mr. F. X. Lamb, Chief Engineer, we decided upon the use of a single point ammeter, a tapped current transformer and suitable circuitry as shown in Figure 1.

The Meter

The meter used is a standard Weston Model 433 Ammeter having a zero line and a single fiducial line on the scale. The current required to deflect the pointer from the zero line to the fiducial line equals one-half ampere of secondary current. The secondary turns are varied so that the full scale current is always one-half ampere irrespective of the primary current. This meter is shown in Figure 2. The fact that the meter has only one fiducial line eliminates any possibility of the operator reading the wrong value. A high degree of accuracy is possible as the meter is always operated at full scale deflection.

The Current Transformer

The transformer is basically the Weston Model 604, which is a toroidal type of transformer and is approximately 4 inches in diameter. By means of a tapped primary and secondary, a large number of ranges can be obtained. In this particular design, shown in Figure 3, the primary has two ranges, 6 and 12

Figure 2

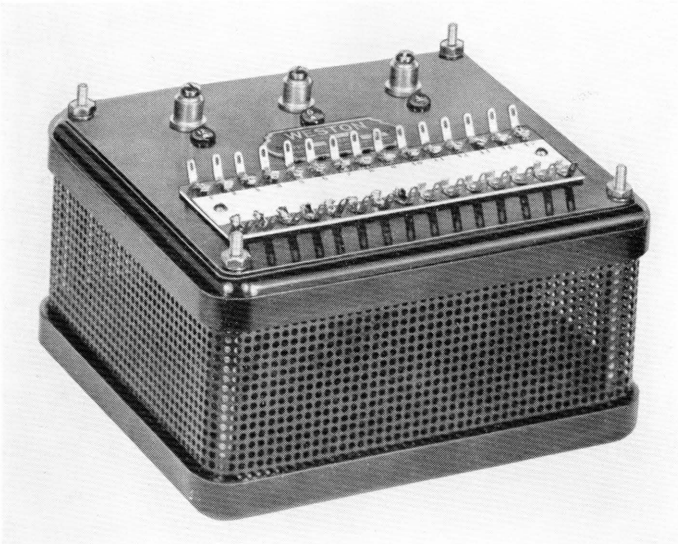

Figure 3

amperes. The secondary has ranges of 4.50 to 6.00 amperes, obtainable in steps of 0.01 ampere, and 9 to 12.00 amperes, obtainable in steps of 0.02 ampere. The desired current value can be easily set by means of the selector switches.

The Selector Switches

The selector switches should be so designed that the circuit is not opened when the switch positions are altered. Also the switch positions should be indexed so that the contacts will be properly located without danger of a permanent short circuit between adjacent contacts. The transformer taps are connected to the selector switches so that the value of any desired current in the above ranges can be easily and conveniently set, as shown in Figure 1. For example, if the switches are set, as shown, for a value of 9.84 amperes and the current is adjusted so that the Model 433 pointer is on the fiducial mark, then the primary current will be 9.84 amperes. For any other value of current it is necessary merely to set the switches to the desired primary current and in all cases adjust the current until the meter indicates to the same mark. The numerals at the switch positions in Figure 1 indicate the amperes necessary for deflection to the fiducial mark when the primary connections are made to "±" and "12"; if the primary connections are made to "±" and "6," these currents should be divided by two. In this particular application the laboratory technician would set the switches to the correct lamp current value and the operator can then adjust and read the correct current value without even knowing the actual value.

Summary

The use of a tapped current transformer, a single point ammeter and suitably marked selector switches offers a simple and accurate method of standardizing desired alternating current values. The range of standardizing currents can be varied by means of both the primary and secondary taps. Since a transformer is an extremely stable piece of apparatus, standardization or checking of the equipment consists merely of a single point check of the ammeter and this can be done on either alternating or direct current.

E. N.—No. 96 —*A. T. Williams.*

THE WESTON MODEL 1446 INDUCTRONIC® CONTROL UNIT

IN THE application of a control system to any process, the resolution or "sensitivity" of the system is naturally important. Most systems have a so-called "dead-zone" width, which is a region wherein the variable will not occasion corrective action on the part of the responding mechanism. A dead zone is in no sense fundamentally desirable, and in the Model 1446 has been avoided to provide an actual "knife-edge" type of control action.

The Model 1446 Control Unit was developed as an accessory to the Model 1411 INDUCTRONIC D-C Amplifier for precise control applications. In combination with the Model 1411 Amplifier, a substantially unlimited resolving power is available for control operation against whatever primary reference is indicated by the application. The Control Unit furthermore is designed to be free of critical adjustments, and contains only components of unlimited life expectancy to promote its use in reliable industrial service, as does the Model 1411 Amplifier.

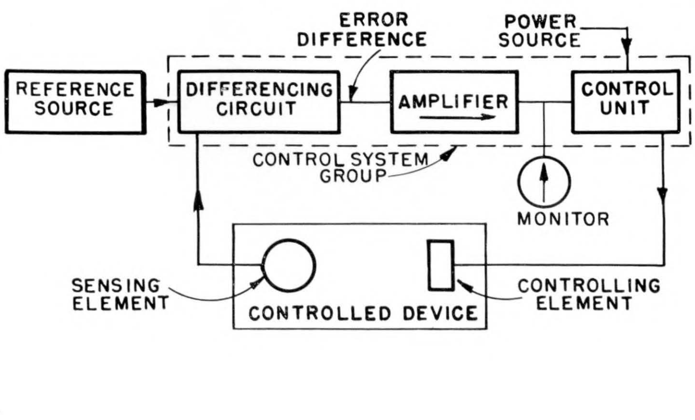

Figure 1—Basic control system.

Application to a system to be controlled is similar in general to other control methods as shown in the block diagram of Figure 1. The magnitude-sensing element is subjected to the factor to be controlled, to provide a d-c level that is a reliable function of the controlled factor. This is compared to a suitably stable reference source, for example, a standard cell, through a comparing network, and the differ-

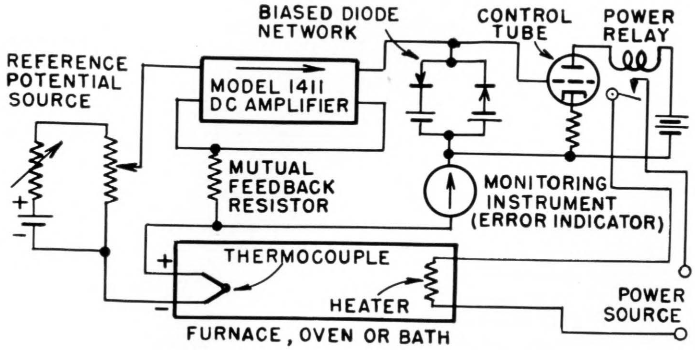

Figure 2—Inductronic control system applied to temperature using a thermocouple.

ence, or error, is amplified to operate a control mechanism. The control mechanism in turn exerts a corrective influence upon the factor being controlled, to reduce the error difference. For example, the controlled factor may be the temperature of a vessel or object, the sensing element a thermocouple, the reference source and comparing net-

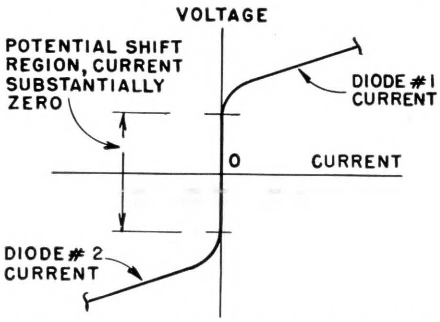

Figure 3—Potential shift in biased-diode circuit.

work a precision potentiometer, and the amplifier and control mechanism the Model 1411-1446 Amplifier-Control Unit combination. The Amplifier-Control Unit combination then determines the resolving power of the control system.

In usual control systems of nominal resolution, two influences fundamentally present are simply minimized to an acceptable degree; the "dead zone" or inoperative region about the control point, and the residual displacement of the system from the true control point. These are usually reduced by critical adjustment. However, in precise systems, these influences usually determine the practical resolving power of the control function to limit the effective precision. Moreover, as parameters of adjustment, they are subject to drift.

The INDUCTRONIC control system is functionally free of these influences by virtue of a feedback "potential-shift" principle illustrated by the circuit of Figure 2 and the curve of Figure 3. Figure 2 shows a control system arranged in the manner of Figure 1, and including a d-c amplifier with current feedback through a mutual resistor. The error difference between the sensing element, in this case a thermocouple, and the reference source is balanced by this feedback path. An indicating instrument responsive to the output current may be included as shown to monitor the control error.

In addition, the amplifier output circuit is passed through a parallel pair of diodes back biased so that the output circuit will only develop current when the output potential exceeds the bias level. The biased-diode circuit has a volt-ampere characteristic somewhat as shown in the curve of Figure 3, wherein the potential swings a substantial amount, for example several volts, without permitting circuit current. As output current is blocked over this region, the degenerative feedback through the mutual resistor is blocked, and the full undegenerated potential output of the amplifier is available over the potential shift region. A simple triode having the control power relay in its plate circuit is operated by this shift potential.

Note that a primary condition for proper operation is that the power relay operate somewhere within the potential-shift region, which is readily assured without adjustment. Another condition is that the diodes have substantially infinite reverse resistances, which is characteristic of thermionic diodes with low back voltages.

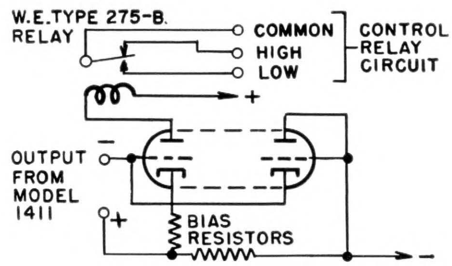

Figure 4—Basic Model 1446 circuit.

The Model 1411 D-C Amplifier has a substantially infinite gain when undegenerated over open-circuit output voltage excursions of about 20 volts from zero. The shift potential is made about 4 volts either side of zero to stay well within this region. The shift region is therefore about 8 volts wide whereas the power relay will operate on a differential equivalent to about 1 volt at the triode grid. These operational ratios preclude any expectancy of misadjustment

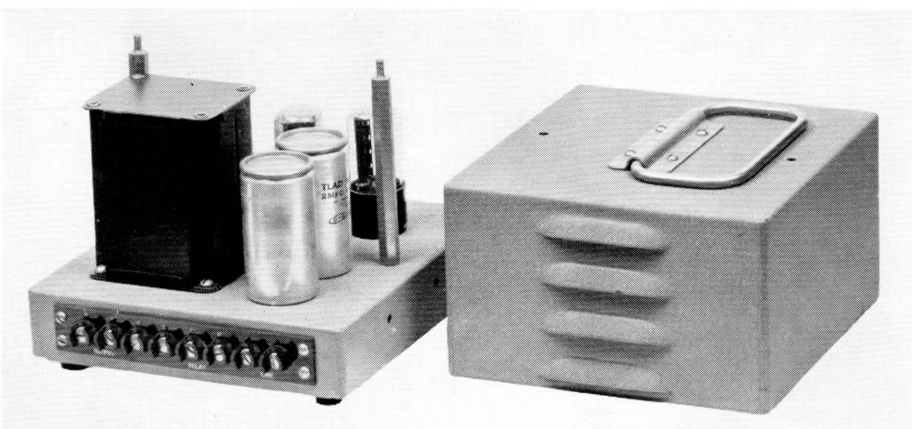

Figure 5—Weston Model 1446 Inductronic Control Unit—cover removed.

beyond outright failure of circuit components.

The indicating instrument may be used as a monitor and calibrated in terms of the factor being controlled by specification of the mutual feedback resistor. The monitoring range has no influence upon the control resolution because of the feedback block over the control region as described. The feedback resistor is the Model 9914 Range Standard with which the Model 1411 Amplifier is normally equipped.

The circuit of Figure 4 is that actually used in the Control Unit. A medium-mu dual triode has one triode connected as the relay-operating element, and the other triode diode connected as one diode element. The grid of the relay triode serves as the other diode by swinging into the positive grid current region. The bias potentials are obtained from the resistor network in the cathode circuit.

The power relay is a Western Electric Type 275-B mercury-wetted reed relay having a contact rating of 5 amperes and 500 volts, with a 250-volt-ampere maximum. This type of relay is particularly reliable in high-speed service, and is sealed and plug connected. It is rated for a useful life expectancy at 60 operations/second, whereas in normal high-speed control service speeds usually do not exceed 1 operation/second.

The complete Model 1446 Control Unit, including an individual power supply, is illustrated in Figure 5. The case is a design match to the Model 1411 Amplifier except that the width is 7¼ inches whereas the Model 1411 Amplifier is 9 inches wide. It is supplied with universal mounting brackets similar to the Model 1411 Amplifier for wall or surface mounting. In operation, it is simply connected in series with the output circuit of the amplifier, and functions without disturbance to the normal operation of the amplifier.

The feedback network shown simply as a mutual resistor in Figure 2 may, when required, include reactance to develop time-derived control influences such as derivative and/or reset functions. The feedback circuit is then usually an R-C network having reactance and resistance parameters appropriate to the specific controlled systems. It is not particularly constructive to attempt to generalize such circuits, but specific recommendations may be determined in particular cases.

E. N.—No. 97 —*R. W. Gilbert.*

A LINEAR SCALE FEEDER AMMETER

CONVENTIONAL a-c ammeters as used in feeder circuits are usually of the iron vane type operated in conjunction with current transformers and having full scale values somewhat above the rating of the feeder and commonly in ranges of 100 to 500 amperes. While the values indicated by the instruments are readily seen when there is considerable load, at times where the load is very small or down to the magnetizing current on the distribution transformers, the characteristics of iron vane instruments are such that almost no indication exists.

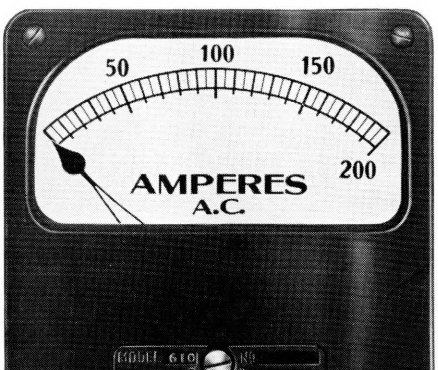

Figure 1—Weston Model 610 A-C Rectifier Type Linear Scale Milliammeter for operation with 200/0.1 current transformer.

And yet, if it were possible to get a clear indication of one or two per cent of full load current, such an indication would be an excellent check of the feeder and show an intact circuit with no open disconnects or breakers.

Since an iron vane meter develops a torque proportional to the square of the current, it seemed almost impossible to obtain the wanted result using any modified form of such an instrument. Much the same thing applies to instruments of the electrodynamometer type, as well as the induction type.

But the development of rectifier type instruments where the indication is linear, even though on an average rather than an rms basis, appeared to indicate a possible solution. Of course, such instruments normally are made only in ranges of a few milliamperes, and they will not withstand high overloads which might be encountered in feeder operation under fault conditions, particularly where breaker settings are such as to require some 20 to 30 cycles for operation.

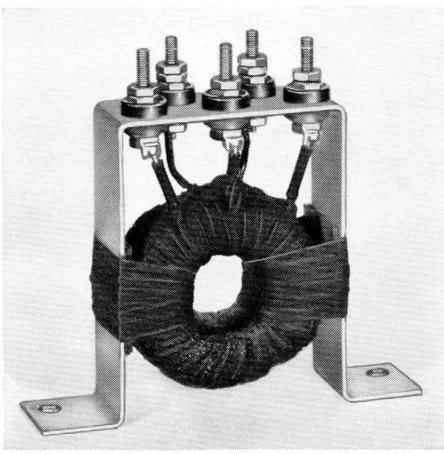

Figure 2—Weston Model 604 Type 12 Saturating Current Transformer. Five and 2.5 amperes primary, 0.1 ampere secondary, for use at 60 cycles.

However, the overload condition could possibly be handled through the use of a saturating current transformer with a nickel alloy core (Hipernik, Numetal or Permalloy) whereby the secondary current would be held to less than double full scale value even though the primary might rise to forty times normal.

Accordingly, a study was made

of the possibility of a co-ordinated rectifier meter-saturating current transformer combination for this application.

The final instrument developed was an a-c rectifier type ammeter, Figure 1, with a full scale value of 100 milliamperes or 0.1 ampere. The associated saturating current transformer shown in Figure 2 is wound with a tapped primary for 5 and 2.5 amperes and a secondary for 100 milliamperes.

Saturation of current transformers occurs when the voltage burden of the load—the instrument in this case—exceeds that which can be supplied by the current transformer in terms of its secondary winding and its saturation flux. To make this more readily accomplished, the instrument rating was determined as 100 milliamperes and 30 volts. Effectively, the instrument is a rectifier type voltmeter consisting of a conventional d-c milliammeter, a small copper oxide bridge rectifier and suitable series resistance. Adjusted to a full scale value of 30 volts, it takes, in the instrument circuit proper, a relatively few milliamperes. Its terminals are then shunted with non-inductive resistance to develop a current requirement of 100 milliamperes at the 30-volt rating, giving the finished instrument a resistance of 300 ohms.

A saturating current transformer

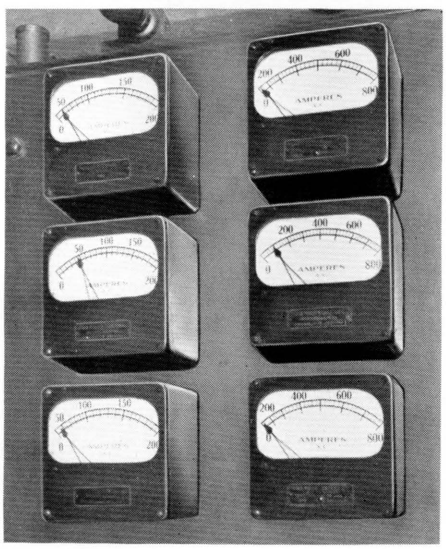

Figure 3—Control panel in Mechanic Street Substation of Public Service Electric and Gas Company, Newark, N. J., showing linear scale feeder ammeters in phase two, 26-kv feeders.

can readily be designed for such a range and with practically linear output, and which will still saturate and limit the effective output current to less than double scale or 200 milliamperes, even when the primary current is as high as 200 amperes under short circuit conditions, thus effectively protecting the instrument for periods of up to two seconds.

The instrument scale is perfectly linear and will thus show, by a definite though small deflection,

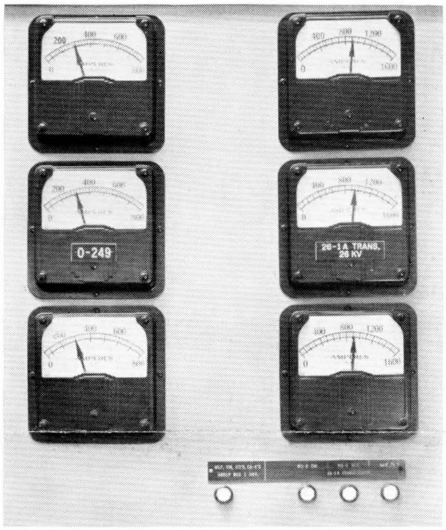

Figure 4—Sewaren Switching Station of the Public Service Electric and Gas Company, Sewaren, N. J. Conventional iron vane instruments at left; linear scale rectifier type ammeters at right on transformer bank. Instruments are Weston Model 924 and 922, respectively, with special transparent plastic fronts.

small currents on the feeder of the order of one or two per cent and indicating the feeder is ready for operation.

Figure 3 shows one of the early installations of this type of instrument in the Mechanic Street Substation of the Public Service Electric and Gas Company, Newark, New Jersey. Only the instruments in phase two of a pair of 26-kv feeders are of the rectifier type. Although the currents in the three lines are approximately equal, the considerably increased deflection on the rectifier instruments in the center will be noted.

Figure 4 shows a panel in the recently opened Sewaren Switching Station of the Public Service Electric and Gas Company, Sewaren,

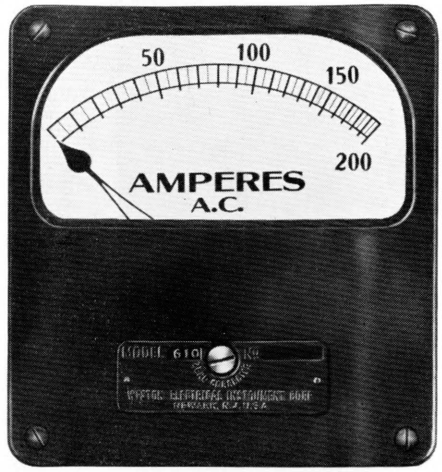

Figure 5—Modified rectifier type feeder ammeter with cut pole piece in d-c system to open scale at the left.

New Jersey. Conventional iron vane instruments at the left are used on a feeder circuit, whereas, at the right, rectifier type instruments are used on a transformer bank. This photograph also shows a modified six-inch rectangular instrument front having the transparent plastic window carried back over the upper portion to secure improved illumination of the scale.

Experience has indicated that an open feeder can be spotted by a complete lack of indication on the linear scale instruments. This check against such possible open conditions is particularly appreciated by the operating crews.

Maintenance of the instruments has been very low, and apparently the saturating current transformers fully protect the instruments against burnouts under fault conditions and at the same time maintain intact the 5-ampere secondary circuits from the main feeder current transformers.

It might be noted that such rectifier instrument scales can be opened still further at the low end through the use of cut pole pieces as shown in Figure 5, but it seems rarely necessary to use this extreme degree of expansion. In all cases considered so far, the lowest currents encountered due to distribution transformers and other miscellaneous light loads were always enough to be clearly indicated on the linear scale instruments.

E. N.—No. 98 —*John H. Miller.*

Printed in U.S.A.