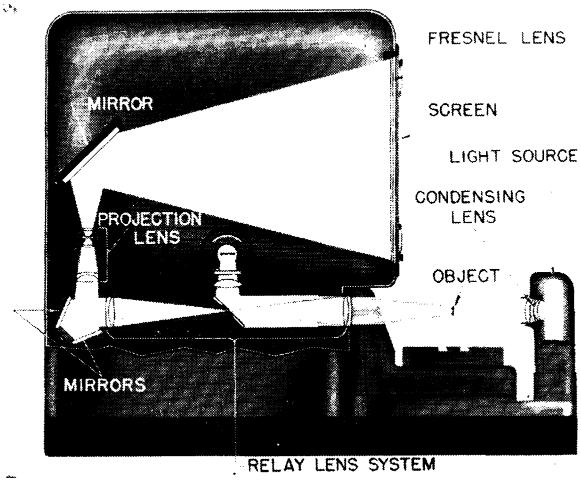

FIG. 3.

With the target at a distance of 100 ft, measurements can be made with a tolerance of ±0.003 in.

While this instrument was designed primarily for aligning planer beds, it can undoubtedly be applied to the solution of other problems involving heavy machine tools and other massive equipment.

The third major classification of optical instruments, that of contour projection, introduces the only use of optics for gaging mechanical components that has been employed to any extent in industrial inspection. However, the practically limitless applications of this tool to inspection problems have not been generally realized.

All contour projectors work on the same basic principle and are made up of a light source, object, lens, and screen. However, if this simple system is supplemented with any of several optical elements, its versatility is greatly increased. The first of these elements is a relay lens (Fig. 3) and the second a Fresnel lens, mounted behind the screen.

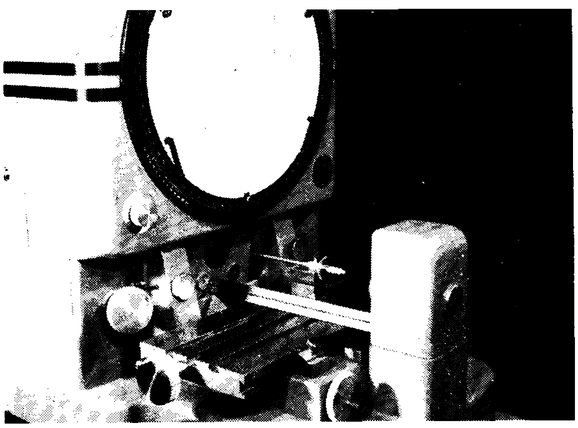

FIG. 4.

This Fresnel lens provides increased screen brightness by concentrating the cone of light coming from the screen into a cylindrical beam directed at the operator. This permits the use of the projector in lighted rooms without hoods or curtains and, with the relay lens, helps to provide surface projection of brilliance hitherto customary only in shadow projection.

There are many instances in which a work piece may be recessed or obstructed, or measurement of surface details must be made. In such cases the surfaces themselves can be projected as a bright image in contrast with the more familiar contour, or shadow, image. Here the relay lens affords a unique opportunity for obtaining maximum illumination. An elliptical mirror may be inserted in the relay lens system (Fig. 3) and light from a 1000-w lamp directed through the front lens to the object. The object reflects the light back in turn, but the reflected image converges and a hole in the mirror permits the image to pass through and be directed onto the screen.

So successful is this system that it is possible actually to project the surface of black Bakelite molded parts.

The relay lens also serves two other functions of major importance, both of which increase the scope and versatility of contour projection. It permits an 8-in. clearance between the work piece (Fig. 4) and the first lens of the system, at all magnifications, providing ample space for awkward parts or for efficient staging fixtures. It also transfers an image at 1:1 magnification to the rear of the instrument, where projection lenses of any desired magnification may be mounted.

Here again, the versatility of the science of optics is illustrated, incorporating in a single system elements which can do, not one, but a variety of tasks, with the inherent advantage of a precise, pressureless, and predictable gaging element.

The Differential Transformer as Applied to Instrumentation

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The measurement of substantially straight line motions is an important factor in the science of instrumentation: for example, the measurement of the displacement of a bellows or a diaphragm, the motion of a float, the tip travel of a Bourdon tube, and the tilt of a weigh beam. Various means have been devised for converting these displacements into signals suitable for electrical transmission, but only in recent years has the differential transformer been used to any extent in this field.

It is the purpose of this paper to treat with only two general phases of this topic: (1) the basic design of differential transformers: and, (2) the circuits which permit their application to the measurement of instrumentation variables such as pressure, flow, and force.

A differential transformer consists essentially of a primary coil, two secondary coils, and an armature of magnetic material. The primary coil is energized from a suitable source of alternating current, the two secondary coils are connected so that their output voltages are 180° out of phase and the armature is located so that it can alter the relative flux distribution which exists between the primary coil and the two secondary coils. (See Fig. 1.)

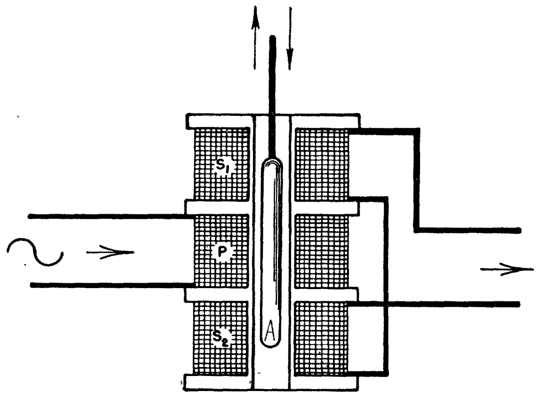

FIG. 1. Differential transformer.

Motion of the armature *A* toward secondary coil *S*1 results in an increased output of one phase and motion of *A* toward *S*2 results in an increased output of the opposite phase. If *S*1 and *S*2 are identical coils and *A* is located so that each receives an equal amount of flux, the voltages induced in these secondary coils will be equal and out of phase and a theoretical output of zero will result. This condition denotes the null, or balance point of the differential transformer.

Obviously, the electrical energy could be applied to coils *S*1 and *S*2 and the differential output obtained from coil *P* without basically altering the transformer structure or the results obtainable. This has been done in some designs.

In accordance with the previous descriptive data, the differential transformer becomes essentially a self-contained device for producing an electrical output, isolated from the source of power, which may be controlled in both amplitude and phase by an adjustment of the flux distribution within the transformer. It should never be considered as part of a bridge circuit, but only as an isolated source of controlled alternating current.

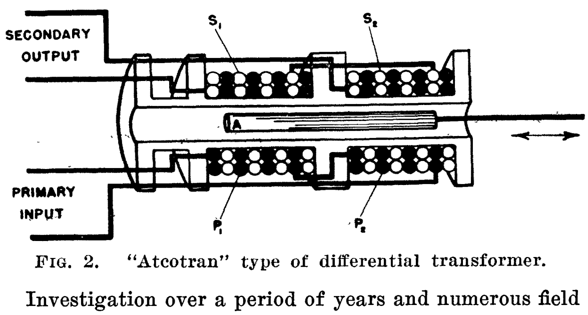

FIG. 2. "Atcotran" type of differential transformer.

Investigation over a period of years and numerous field tests have led to a design which combines the desirable features of a differential transformer into a structure which can be reproduced accurately. This device is shown in Fig. 2. The coil structure, divided into two main sections, contains four windings, two of which serve as the primary while the remaining two act as the secondary. The small section at the left end of the coil form is used to house the necessary interconnections and lead wire terminations.

A design of the type shown in Fig. 2 insures equal and stable electrostatic coupling between the primary and secondary windings and minimizes temperature drift due to changes in such coupling. Uniform magnetic coupling is also insured on this same basis and this factor makes it possible to maintain reasonable linearity without a large number of turns. This in turn means that a coil of relatively low impedance can be produced which will adequately match into standard audiofrequency transformers and allow the use of relatively long transmission lines without danger from stray pickup and phase shift due to line capacity.

A coil structure of this type is also quite versatile. Although the unit is normally used with the primary coils connected series aiding and the secondary coils connected series bucking, this condition may be completely reversed, or the primary coils may be connected parallel aiding and the secondary coils parallel bucking, etc. Also, since the unit is essentially a two-coil balanced structure, it is quite possible to bring out a center tap between the two adjacent windings and use one section as an induction bridge. There is an almost endless list of workable combinations when one considers that more than two windings can be placed in each section.

Some advantages inherent in a well-designed differential transformer are:

(1) Negligible phase shift throughout the operating range. In inductance bridge circuits the resistance of the coils remains constant while the inductance of these coils varies over a considerable range. The resulting shift in the resistance and inductance vectors causes a very substantial phase shift which must be taken into consideration in the design of any indicating circuits. In a differential transformer such as the "Atcotran,"[1] the change in inductance for an armature motion of ± 0.1 in. (twice the normal range) is entirely negligible. Therefore, servomechanisms operating with these transformers need not be compensated for phase shift throughout the indicating range.

(2) The source of power is isolated from the output circuit. This feature allows units to be combined in various ways and to perform many useful mathematical functions.

(3) A high degree of linearity and reproducibility of output with respect to armature displacement is obtainable. A linearity of better than ± 0.05% may be expected from standard production run Atcotrans, and these units will match each other within ½% without the use of calibrating resistors, or other means of compensating for normal irregularities in materials and in winding.

For comparison let us assume a single bonded type strain gage, connected into a bridge circuit and strained to approximately 0.003 in. per in. (about 100,000 psi stress in steel); it would yield an output of 0.0015 v per volt input for this range. A differential transformer over its normal maximum range of 0.300 in. would yield an

[1] Trade mark registered. Automatic Temperature Control Company, Inc.

output of .075 v, or an output advantage of 50:1 on a range basis of comparison.

To apply the differential transformer to a measuring problem a null type of circuit is recommended. (See Fig. 3.) In this circuit the output from the transmitting unit, $T1$, is 180 degrees out of phase with that of the balancing transformer, $T2$, and the difference voltage is fed through an amplifier to one phase of a two-phase servomotor. The other phase of this motor is energized continuously from the line. When both differential transformers are producing equal, out-of-phase voltages, there will be no input to the amplifier and the motor will be at rest. However, if the armature of transformer is displaced slightly, a restoring signal will be produced which will cause the motor to rotate and return the system to balance.

The reasons for using a null balance system are:

(1) It is unaffected by line voltage changes. If there is no stray 60-cycle pickup in the system, it will be unaffected by normal line voltage changes and even an excessive pickup voltage, equal to 10% of the total signal at full scale, would only cause a 1% change in reading for a 10% change in line voltage. In normal systems the pickup voltage will always be less than 1% of the full scale signal.

(2) It is relatively unaffected by resistance changes in the connecting leads. The addition of resistance to either the primary or secondary circuit will have little effect on the balance of the circuit, although its sensitivity will be affected. This means that changes in coil resistance due to heating will not unbalance the circuit.

The following information may be of value in the application of null balance circuits:

(1) Electrical zero check. If a shunt is connected across terminals 3 and 4 of the transmitting differential transformer (See Fig. 3), its output will be zero and the

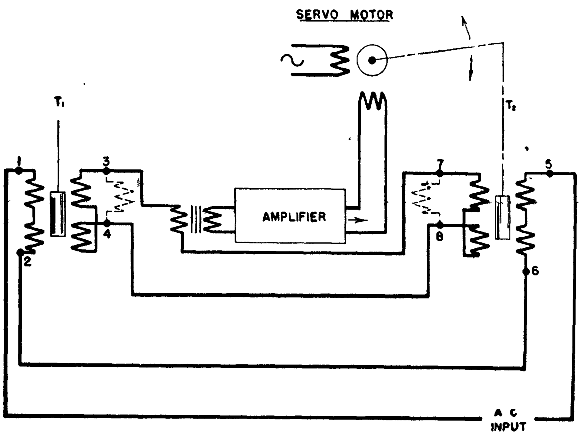

FIG. 3. Null balance circuit for differential transformers.

servo system will come to balance at the null position of the balancing differential transformer.

(2) Electrical range change (ratio control). If a resistor is connected across terminals 7 and 8 of the balancing transformer, $T2$, (See Fig. 3) its output will be reduced. When the output of $T2$ has been reduced in this manner, the servomotor will now have to move far-

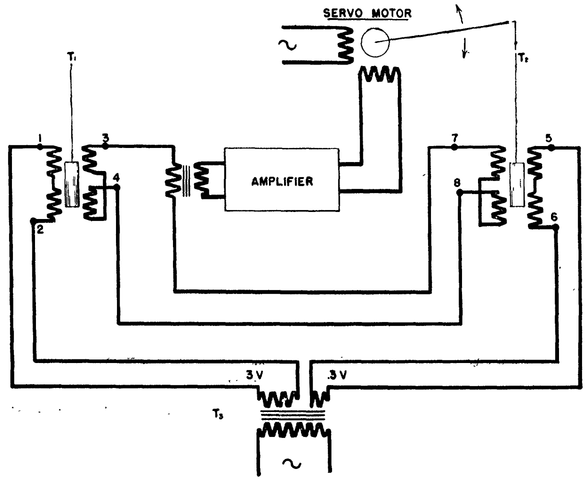

FIG. 4. Null balance circuit with transformer type range change.

ther to balance a given change in input voltage from the transmitter and the effective sensitivity of the servomechanism will have been increased. This method has been successfully used for sensitivity ratios up to 10:1 and may also be used as a calibrating means.

It is possible to obtain similar results by means of transformers instead of by means of shunts. See Fig. 4. Here the input voltages to the two differential transformers are set up as a predetermined ratio by the supply transformer, $T3$. Ratios as high as 40 to 1 have been used with a circuit of this type, although changes in lead resistance affect the ratio to a certain extent.

(3) Algebraic summation. See Fig. 5. The use of more than one differential transformer as a transmitter

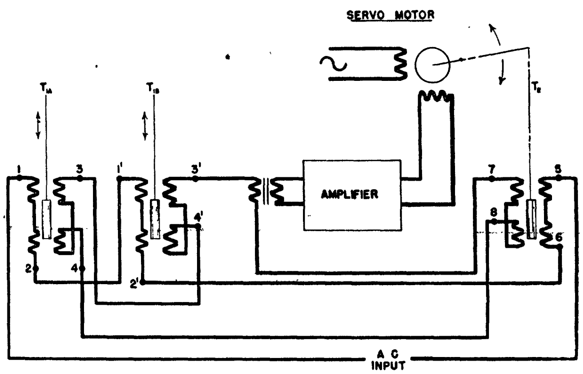

FIG. 5. Algebraic summation circuit.

is both feasible and useful. When transformers $T1a$ and $T1b$ are properly connected, their outputs are algebraically summated in such a way that their output voltages represent the magnitude to be measured and their phase becomes the plus and minus sign for this magnitude. The servomechanism balances out the resulting signal and indicates the algebraic sum of the two variables controlling transformers $T1a$ and $T1b$. Up to six transmitters have been successfully summated by this method without difficulty. A typical application is the use of four Atcotran load cells to support a weighing platform and a weighing servo to indicate the average signal from these cells. In this way the weighing platform becomes independent of load position.

(4) Multiplication. If the input of one differential transformer is used as a source of input voltage for a second differential transformer, multiplication results. Since adequate power is not available in one transformer to drive another, the use of an electronic amplifier is recommended. See Fig. 6.

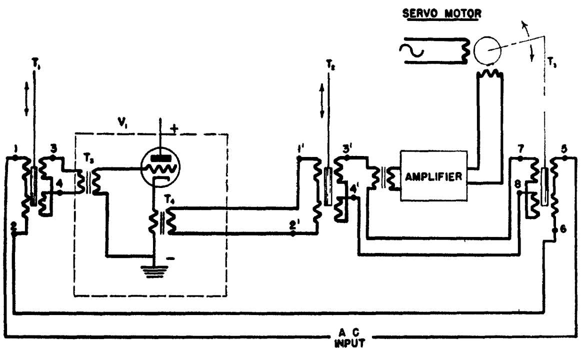

FIG. 6. Multiplying circuit.

This device has been used for compensating the output of a flow meter for changes in pressure and for other similar uses.

(5) Use of null balance circuits. In making connections between the various components of differential transformer null balance circuits, the author has standardized on the following procedures: (a) use of twisted pairs for all primary circuits; (b) use of shielded, twisted pairs for all secondary circuits, for runs over 50 feet; (c) number 20 BS gage, stranded wire is of ample size for most installations. The wires should be run in conduit but never in the same conduit with power lines.

If properly installed, transmitters and receivers may be several thousand feet apart. Special 400-cycle systems requiring only a *50 millivolt input* signal to the transmitter have been used for hazardous locations.

Although the differential transformer is still a newcomer in the instrument field, there are some standard instruments available. These include circular scale indicators with $\frac{1}{4}$% of reading accuracy (above 10% of scale) and a ten-to-one sensitivity switch; multichannel optical indicators with three automatically selected scales, a scale length of 84 in. and a 2-sec speed of response; strip chart, round chart single and multipoint recorders, controllers, etc. The switching of various input circuits into one indicator, or recorder, such as is normally done with thermocouple circuits, is standard practice with most differential transformer instruments. Transmitters. for pressure, flow, density, level, motion, etc., are also available as either standard. or custom built devices.

While it is obvious that a direct indicating, meter type of instrument may be used with a differential transformer instead of a servodriven, null balance device, no time will be devoted to these units at this time. It is only with the null balance systems that the remarkable accuracy and stability of the differential transformer can be realized.

In general, differential transformer instrument systems should be used (1) whenever highly accurate measurements of motions are required, (2) where minute forces are available and friction of any kind would be a disadvantage, (3) where electrical transmission of various variables is a requisite, and (4) where it is desired to express certain mathematical functions electrically.

Summaries of Selected Papers on Instrumentation Presented at the 1949 Gordon Research Conferences

X-Ray Powder Diffraction Analysis Film and Geiger Counter Techniques[1]

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In this note a few of the techniques and new instrumentations for X-ray powder diffraction which have been developed at this laboratory during the past six years will be briefly outlined. General descriptions of the applications of the powder method are given by Bunn (*4*), Guinier (*7*), Hanawalt, Rinn and Frevel (*9*) and Straumanis (*12*).

In the Norelco X-ray diffraction apparatus the X-ray tube is sealed off, thus eliminating vacuum problems, vertically mounted, water cooled and full-wave rectified to aid Geiger tube work. The voltage and/or current may be continuously varied. One feature of the apparatus is that four pieces of accessory apparatus, including one or two spectrometers, can be operated simultaneously.

Powder Cameras. The design and use of Debye-Scherrer powder cameras are deceptively simple. In order to ob-

[1] Based on papers given at meetings of the American Society for X-Ray and Electron Diffraction, 1947–49.