watt transducer

type VP-840

A basic principles of operation

The measurement of single phase and polyphase a-c power has presented a problem in the past, involving the use of complicated multi-circuit dynamometer type indicating instruments utilizing currents and potentials derived either from the circuit directly, or in conjunction with current and/or potential transformers. The mechanical system in the instrument resolved these values, and produced a pointer deflection proportional to the total power input.

With the advent of modern manufacturing techniques in producing semi-conductor materials, it is now possible to utilize the well known "Hall effect" principle in conjunction with a relatively simple d-c permanent magnet moving coil instrument to measure both single phase and polyphase a-c watts.

Basically, the "Hall effect" states: "If a conductor carries a current at right angles to a magnetic field, a charge differential is generated on the surface of the conductor, in a direction which is mutually perpendicular to both the magnetic field and the current". The Hall effect semi-conductor crystal, to be suitable, should meet the following requirements:

1. Its "Hall" constant must be very large (low carrier concentration, hence a semi-conductor material)
2. Its resistance must be sufficiently low, to permit a usable amount of power to be drawn from the element
3. It should be relatively insensitive to temperature variations.

In applying these principles to an a-c wattmeter, a Hall crystal is mounted in the air gap of an electromagnet with a current circuit supplying the energy to the electro-magnet and a potential circuit connected to two opposite sides of the Hall crystal. Output of the element is derived from the two sides of the crystal at right angles to the potential input. This output is pulsating d-c, which is measured by a conventional permanent-magnet, moving-coil instrument mechanism. This output may be used with other devices for either measurement or control, within the specified ratings.

The type VP-840 watt transducer operates on this Hall effect principle, producing a d-c output which is proportional to a-c power input. Referring to figure 1, in the single phase transducer, line voltage is connected across terminals 6 and 7, causing current I_c to flow through calibrating resistor R_c and the Hall crystal. Line current is connected to terminals 3 and 5, producing a proportional flux perpendicular to the plane of the crystal. The output voltage of the Hall crystal, (E_o) appearing across terminals 11 and 12, is proportional to the current through the crystal, the flux perpendicular to it, and the cosine of the phase angle between them. Expressed as a formula, $E_o = K_1 I_c \varnothing \cos\theta$, where K_1 is the Hall crystal proportionality constant, I_c is the current through the crystal, $\ominus$ is the flux produced by the electromagnet circuit, and $\cos\theta$ is the phase angle between this current and the flux.

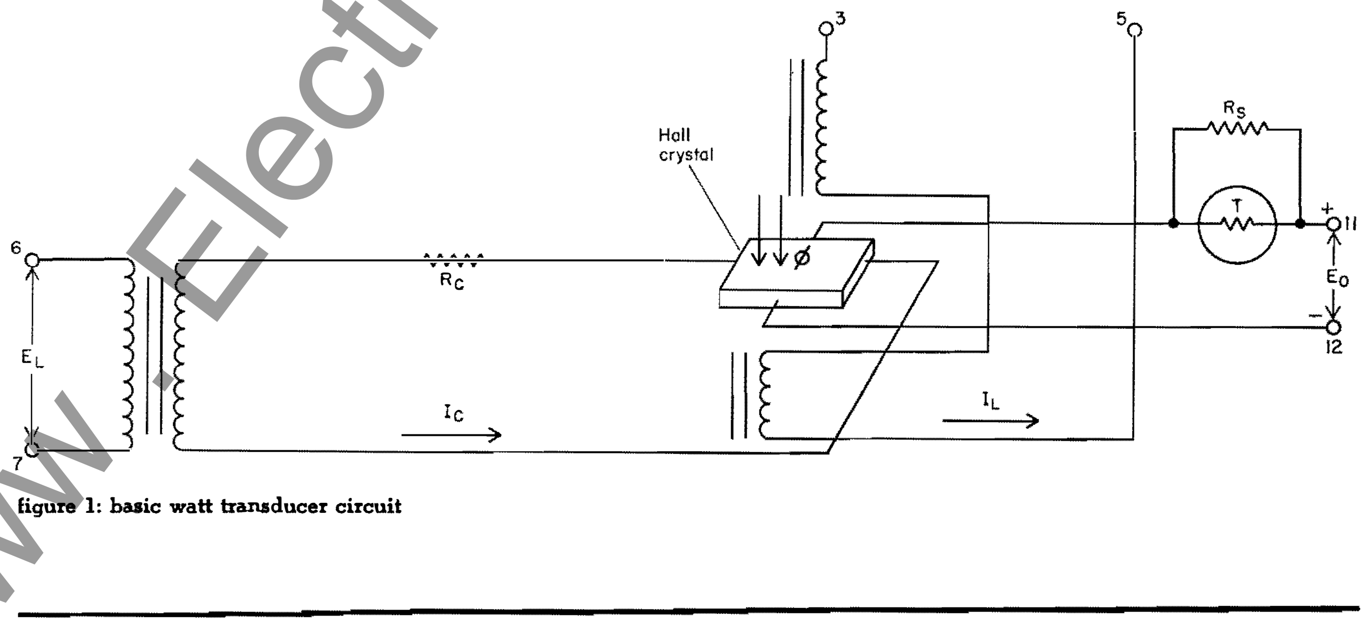

figure 1: basic watt transducer circuit

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Expressing the formula in terms of input to the transducer, it would be: $E_o = K_2 E_L I_L \cos\theta = K_2$ (power input) where E_L and I_L represent the voltage and current at the transducer input terminals. In most actual installations, the current and voltage reach the transducer through instrument transformers, as indicated in figure 2. Including the instrument transformer ratios in the above formula, it would be expressed thus:

$$E_o = \frac{K_2 E_L I_L \cos\theta}{N_1 N_2}$$

Where N_1 is the current transformer ratio, and N_2 is the potential transformer ratio.

Thus, the transducer voltage output is proportional to primary watts input.

For the transducer used in 3-phase 3-wire circuits, two separate Hall crystal circuits are used and connected as indicated in figure 3.

In effect, this circuit measures polyphase power by the conventional "2-wattmeter" method, and since the voltage outputs of the Hall crystals are connected in series, the total output is proportional to primary polyphase power.

For the measurement of 3-phase 4-wire power, a circuit, which is equivalent to a 2½ element wattmeter, is used, as shown in figure 4. Phase 1 power is measured by the lower Hall crystal, while phase 3 power is measured on the upper crystal. The current from phase 2 is "split" and contributes flux to both crystals, reacting with both phase 1 and phase 3 voltages. The net effect is a Hall output voltage proportional to polyphase power, assuming balanced system voltages.

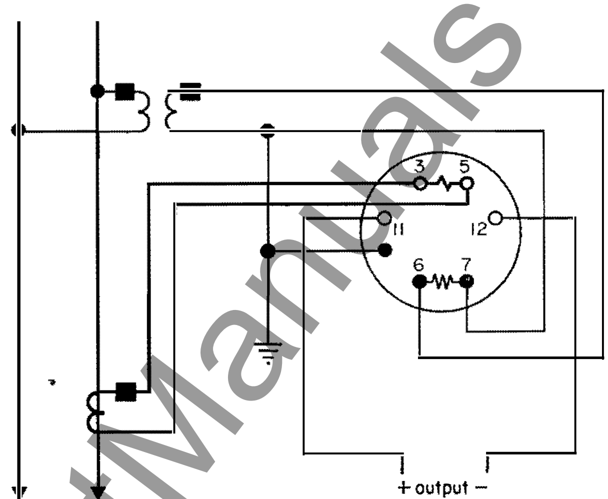

figure 2: external wiring of single phase watt transducer showing instrument transformers

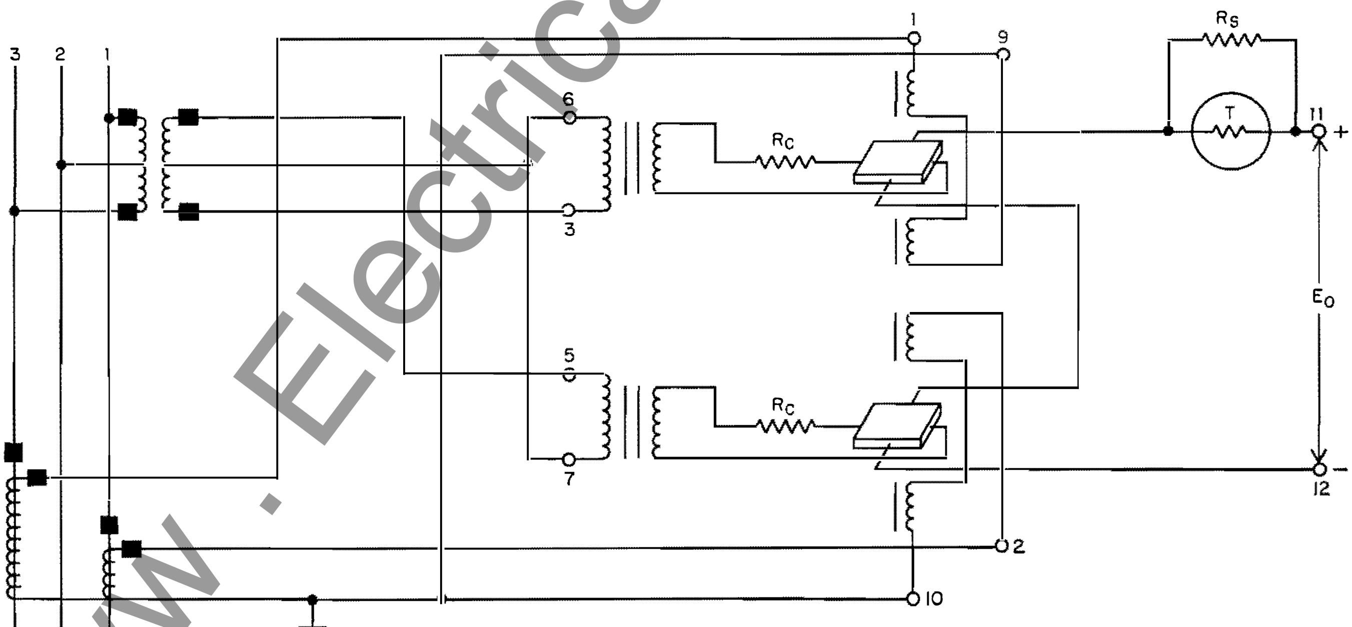

figure 3: internal and external wiring of 3-phase 3-wire transducer

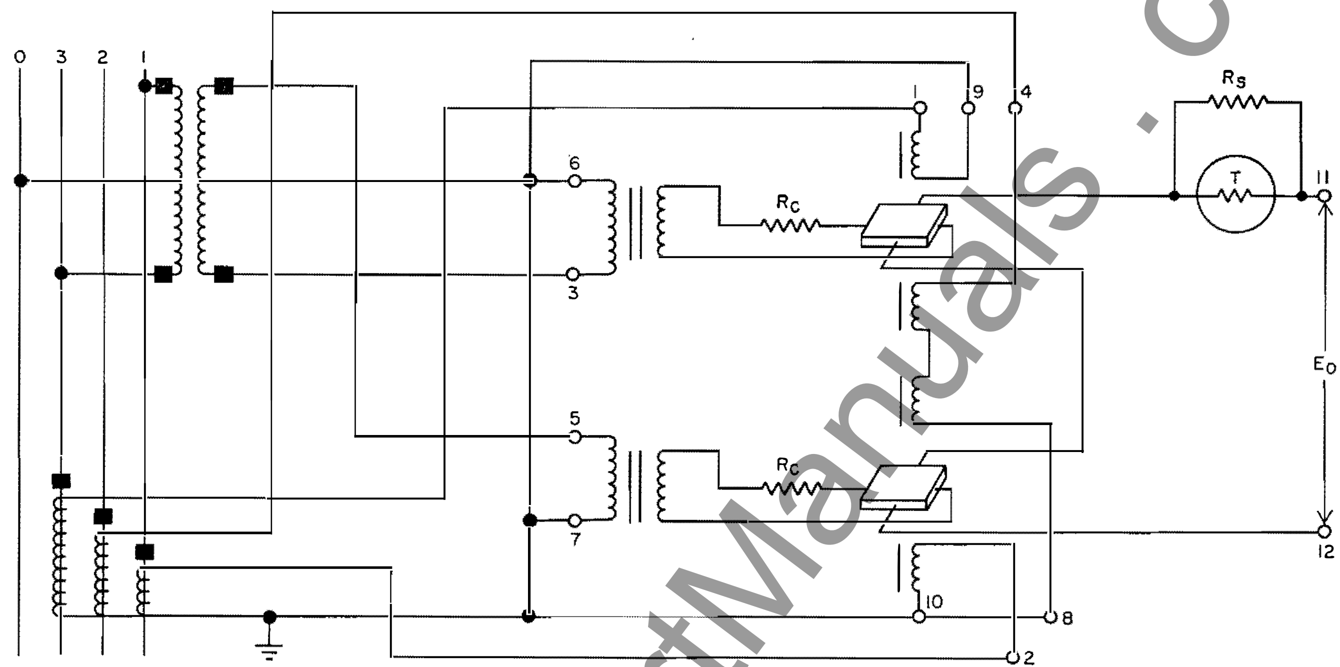

figure 4: internal and external wiring of 3-phase 4-wire transducer

B output considerations

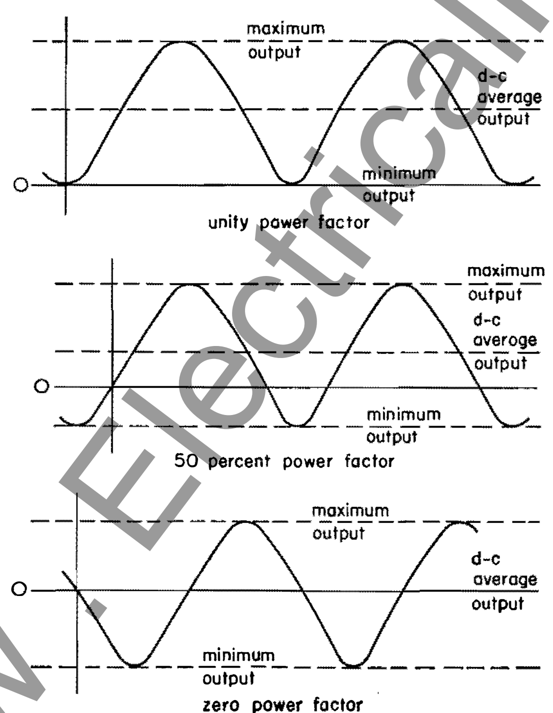

figure 5: basic output of watt transducer (unity, 50 percent, and 0 power factor)

In the preceding paragraphs we have seen that the voltage output of the Hall crystal is proportional to power input. Since the speed or response of the crystal is in the order of a few microseconds, its basic output follows the input power wave exactly. For a sine wave, this output is represented by the equation:

$E_o = KEI \cos \theta - KEI \cos (2\ wt + \theta)$ and is shown graphically in figure 5. The equation shows that the output waveform has two components: a d-c component proportional to average power, and a double frequency component proportional to volt-amperes. Figure 5 shows the complete waveforms for unity, 50 percent and zero power factor.

Temperature variations affect the output of the Hall crystal to some extent. Since the transducer is designed for use over a temperature range of 0° to 65°C, a temperature compensating network is included in the transducer output circuit, as shown in figure 6. This compensating network is designed for an output impedance of 50 ohms for both single and polyphase designs.

The standard VP-840 transducer is calibrated to provide an output of 50 millivolts per Hall element for full rated input watts.

In other words, the single phase transducer will deliver 1 milliampere to a 50 ohm load impedance, and the polyphase transducer delivers 2 milliamperes.

In order to make the temperature compensation most effective and not affect calibration, this 50 ohm resistance should be maintained as closely as possible.

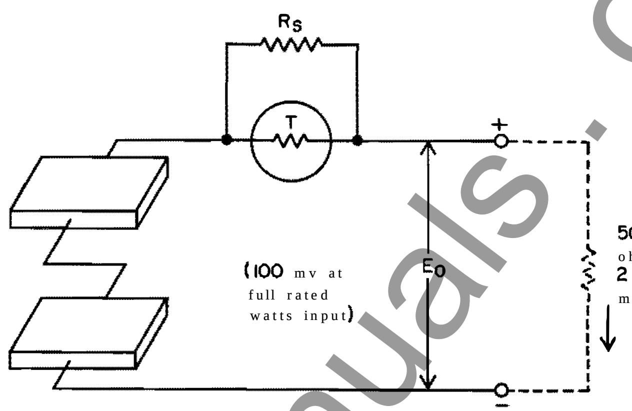

figure 6: temperature compensating network in polyphase transducer

C application of watt transducer without filter

As shown in figure 5, the basic output of the Hall generator, while having an average d-c value proportional to input watts, is far from a conventional d-c waveform. This is fine for some applications; impossible for others.

The "ideal" application for the unfiltered waveform is in conjunction with an oscillograph or oscilloscope. In this case, a true representation of the power wave can be photographed or visualized, and by analyzing this waveform, much can be learned about circuit conditions. For example, referring to figure 7, distance (a) is inversely proportional to frequency; (x), the average d-c value, is proportional to watts, and (y) is proportional to volt amperes. Power factor equals x/y.

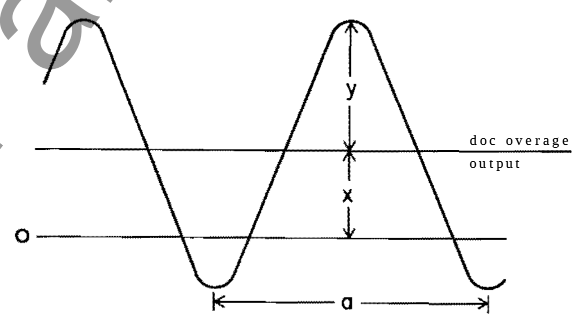

figure 7: unfiltered output of watt transducer

Another frequently used application for the unfiltered transducer is with a direct acting instrument for power indication, such as Westinghouse types KP-231 and KP-241 wattmeters, or with a relay for control. In these cases the individual cycle-to-cycle waveform variations must be dampened out, or violent pointer oscillation or relay chattering will result. This is done by providing enough mechanical damping in the d-c instrument or relay mechanism so that it serves as its own "filter" and indicates or responds to only the average or d-c output value.

Figure 8 shows a typical unfiltered watt transducer being used to energize an indicating instrument, with the dial presumably calibrated in watts. The important thing to remember here is that, for the unfiltered transducer the load it sees **MUST** be 50 ohms, or the calibration will be affected.

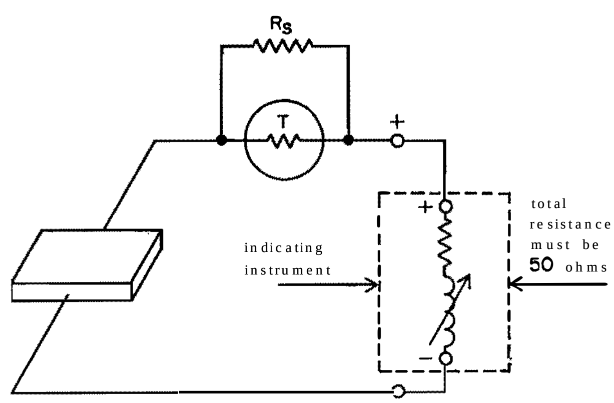

figure 8: output circuit of unfiltered transducer with indicating instrument

D application of pseudo filtered polyphase watt transducer

An interesting aspect of the unfiltered polyphase transducer is that, under balanced load conditions it does its own filtering. Figure 9 shows the vector diagram of the circuit conditions shown in figure 3 at unity power factor. In this transducer, $E_{2\text{-}1}$ reacts with I_1 to produce a Hall voltage on the lower crystal, while $E_{2\text{-}3}$ reacts with I_3 to produce the upper crystal Hall voltage.

The resulting Hall output waveforms are shown in figure 10. Since the individual waveforms are exactly 180° out of phase, there is no ripple in the output. It can be proven mathematically or shown graphically that this will be true AS LONG AS THE LOAD IS BALANCED, AND REGARDLESS OF ITS POWER FACTOR. Also, although figure 9 shows the conditions for a 3-phase 3-wire transducer, the 3-phase 4-wire connection shown in figure 4 would also give an output with no ripple under balanced load conditions.

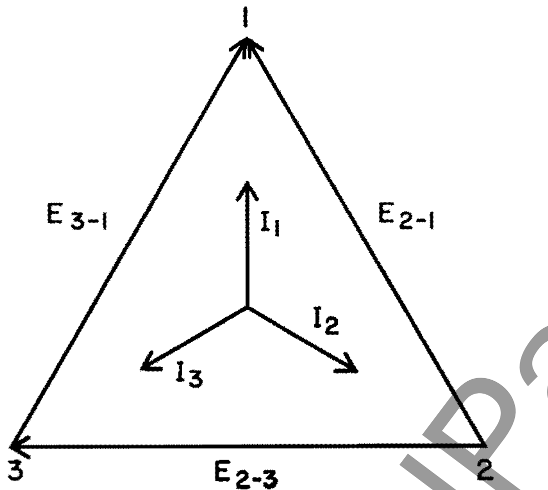

figure 9: vector diagram of 3-phase, 3-wire system (figure 3)

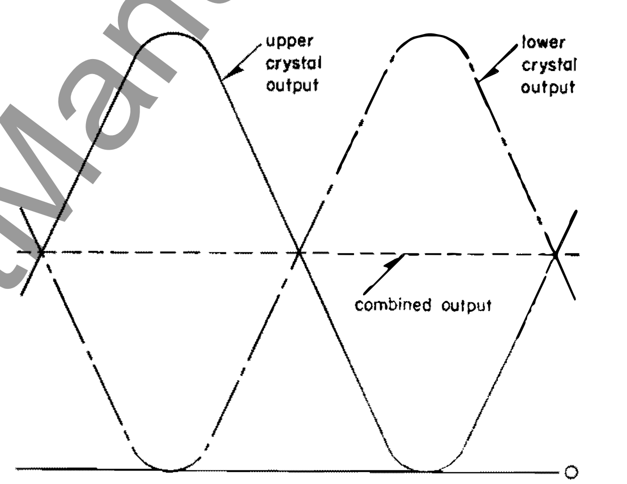

figure 10: output of polyphase transducer under balanced load condition

E application of watt transducer with filter

There are many applications of the type VP-840 transducer where an unfiltered output is unsatisfactory. Section D has shown us that, with balanced load conditions on a polyphase system, the construction of the transducer is such that it does its own filtering. However, many polyphase systems are not always balanced, and in the single phase transducer, there is no "self-filtering" effect whatever.

Where is the unfiltered output most objectionable? Generally in circuits involving amplifications, where the unfiltered waveform will overdrive the amplifier and not produce a true average d-c output. Typically, these circuits occur in telemetering transmitters, potentiometric recorders, data processing equipment and computer circuitry. For these applications, an L-C low-pass filter is used to reduce the a-c component of the output waveform by a factor of 200.

We have seen in Section B that the unfiltered transducer output must look into a 50-ohm load circuit in order to be properly temperature compensated. In the filtered unit two potentiometers are provided, one coarse adjustment, and one fine adjustment, with a combined total resistance of 52 ohms. The L-C filter network is connected to the output side of these potentiometers as shown in figure 11. The transducer is calibrated to provide an output of up to 50 millivolts (100 m.v. on polyphase units) into an external load circuit of 50,000 ohms or higher.

The most important single characteristic of the device which the filtered transducer feeds, is that it must have a HIGH D-C INPUT IMPEDANCE. See figure 11. If this impedance is not high, it will affect the transducer calibration and the temperature compensation. For example, a load with a d-c impedance of 50,000 ohms will change the total impedance seen by the Hall crystal output circuit by approximately 0.12%, and so will affect its calibration by that much. A 25,000 ohm load would double this deviation.

With the potentiometer adjustments, it is quite easy to change the actual transducer millivolt output corresponding to full rated input. This may be desirable in many applications, but is particularly so where totalization is required. The totalizing function is performed by merely adding the outputs of the transducers in series, and as each transducer must contribute the same millivolt output for a given wattage in its measured circuit, mis-match of current and/or potential transformers in the various circuits being totalized, can be compensated for by adjustment of the transducer output potentiometers. The adjustment range is from 0% to 110% of rating. Since each filtered transducer has, in effect, its own self-contained 50-ohm load, changing the millivolt output of one by adjusting its potentiometer has no effect on the others in the totalizing circuit.

Some applications may require totalization of a number of circuits, and while this can be accomplished by using filtered transducers in each circuit as explained above, some saving can be accomplished by using special type VP-840 transducers, unfiltered but equipped with the adjusting potentiometer. To obtain the required filtered output, a type VF-876 filter is added. This combination provides the same filtered output and individual adjustment facilities, as using all individually filtered transducers. A typical circuit is shown in figure 13.

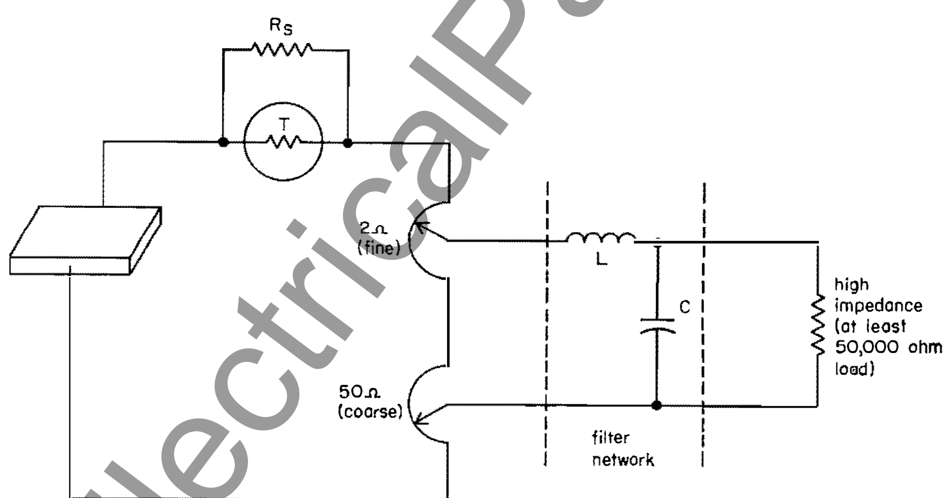

figure 11: output circuit of VP-840 transducer with filter

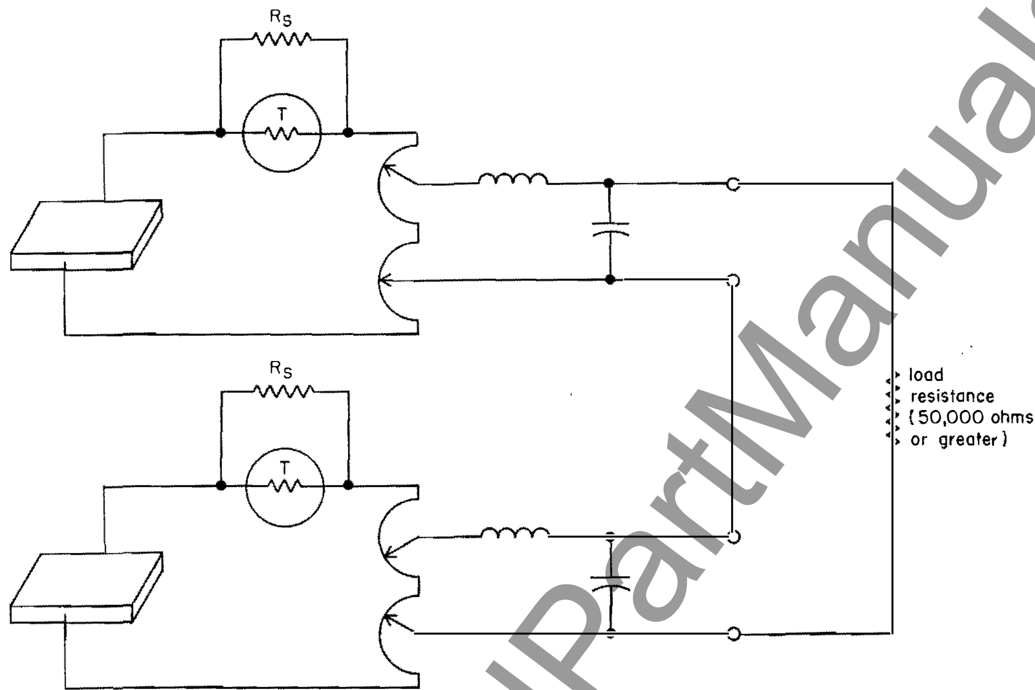

figure 12: totalizing two filtered transducers

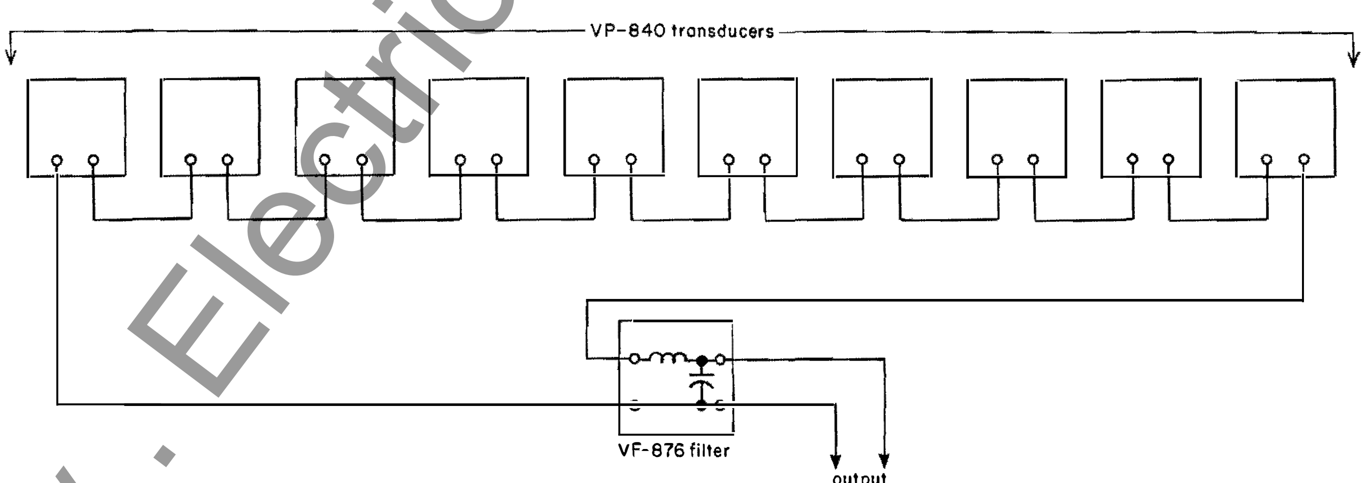

figure 13: totalizing ten transducers using special unfiltered transducers and a common filter unit

F application of KP2-241 wattmeter transducer

In some applications, it is desirable to have a transducer output feeding a control initiating device and, in addition, giving a simultaneous indication. The Westinghouse types KP2-241 and KP2-231 wattmeters are available for this type of service.

Figure 14 shows the schematic diagram of the Hall crystal, output terminals, and D'Arsonval instrument mechanism for the single phase type KP2-241 device, which is fundamentally a self-contained Hall generator wattmeter with output terminals. The Hall crystal delivers 1 milliampere d-c to the moving coil when the instrument indicates full scale deflection of 250°. This current also passes through a 20-ohm swamping resistor, and the output terminals are connected across this resistor. Consequently, 20 millivolts are available at the output terminals corresponding to full scale instrument deflection (15 mv on 180° type KP2-231 instruments). The swamping resistor has virtually zero temperature coefficient so the output is unaffected by temperature variations.

Note that the output across the swamping resistor is UNFILTERED (unless the transducer is polyphase and the load is balanced). Since there is not enough room inside the KP-2 instrument case to include a filter network, an external type VF-876 filter should be used if a filtered output is required. With this application it is again necessary that the d-c load impedance, which the output terminals see, be high (20,000 ohms will affect the calibration by 0.1%).

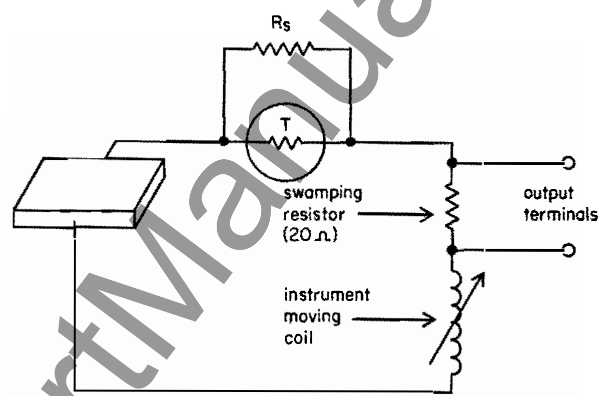

figure 14: output circuit wiring diagram of KP-241 single phase wattmeter-transducer

specifications

accuracy

±0.5% of standard rated output at standard reference conditions.

temperature influence (typical)

±1.0% of standard rated output over the temperature range from 0 to 65 degrees centigrade.

response time

without filter: A few microseconds.
with filter: 200 milliseconds

insulation test

between independent circuits: 1800 volts.
from terminals to case: 2600 volts.

burden (per element)

current coils at rated current: 2 va at 20% power factor.
potential circuit at rated voltage: 1 va at unity power factor.

power factor influence

±1% of standard rated output at 50% lead or lag.

standard ratings

5 amperes • 120 volts • 60 cycles

	a-c input watts	d-c output m.v.
single phase	500	50
polyphase 2-element	1000	100
polyphase 2½-element	1500	100

Other current ratings are available, from 50 milliamperes to 10 amperes. Input watts are proportional to current and potential ratings.

The filtered type VP-840 transducer is equipped with potentiometers, which permit adjustment of the output from 0% to 110%.

weight

net: 2 to 3½ pounds

shipping: 5 to 7 pounds

additional information

construction, dimensions, and wiring diagrams: db 43-840

ratings, style numbers, ordering information and prices: price list 43-840

other Westinghouse instruments: selector guide 43-000

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