

SPECIFICATION

A Wattmetric Transducer

This invention relates to a wattmetric transducer.

According to this invention there is provided a wattmetric transducer comprising a first, E-shaped core; a second, I-shaped core secured across the free ends of the arms of the first core; a bobbin mounted on the middle arm of the first core; an input voltage coil of insulated wire wound on the bobbin; an input current coil of insulated wire wound longitudinally about the middle arm of the first core; a first output coil of insulated wire wound in two slots in the second core the first slot being located centrally of the free end of the middle arm of the first core and the second slot being located substantially midway between the middle arm and one end arm of the first core; and a second output coil of insulated wire wound in said first slot in the second core and a third slot in the second core located substantially midway between the middle arm and the other end arm of the first core.

This invention also provides a wattmetric transducer comprising a first, E-shaped core; a second, I-shaped core secured across the free ends of the arms of the first core; a bobbin mounted on the middle arm of the first core; an input voltage coil of insulated wire wound on the bobbin; an input current coil of insulated wire wound longitudinally about the middle arm of the first core; two identical output coils of insulated wire wound in three slots in the second core, the first slot being located centrally of the free end of the middle arm of the first core and shared by the coil sides of the two identical output coils and the remaining two slots being located substantially midway between the middle arm and the two outer end arms of the first core and occupied solely by the other coil sides of the output coils.

The input voltage coil and the input current coils are designed to carry voltage and current signals which could differ significantly in amplitude and phase angles.

The transducer of this invention has the advantages that it is a static electromagnetic device, this making the transducer accurate, and is capable of transducing the real power of a single phase A.C. circuit at power frequency into output signals in the millivolt range which can easily be measured by commercially available voltmeters. Further, the output signals can after further processing be made linearly proportional to the input real power. The positioning of the output coils in close proximity to the input current coil and the input voltage coil ensures maximum flux linkage and hence results in relatively high amplitude output signals from the output coils.

This invention will now be described by way of example with reference to the drawings, in which:—

Figure 1 is a side elevational view, partly in section, of a transducer according to this invention;
Figure 2 is an end elevational view, partly in section, of the transducer of Figure 1;
Figure 3 is a plan view of the transducer of Figure 1;
Figure 4 is a diagram illustrating the flux paths occurring in the transducer of Figures 1 to 3 during use thereof;

Figures 5 and 6 are diagrams illustrating operation of the transducer of Figures 1 to 3;
Figure 7 is a diagram illustrating the dimensions of a practical embodiment of the transducer shown in Figures 1 to 3, and

Figure 8 is a circuit diagram illustrating a use of the transducer of Figures 1 to 3.

The transducer shown in Figures 1 to 3 comprises a first, E-shaped core 1 of soft ferrite material, and a second, I-shaped core 2 of the same material, the core 2 being secured across the free ends of the arms of the first core 1 by an epoxy resin adhesive. A plastics material bobbin 3 is mounted on the middle arm of the first core 1, and this bobbin 3 has wound thereon an input voltage coil 4 consisting of seven hundred turns of SWG 35 enamelled copper wire. An input current coil 5 consisting of twenty turns of SWG 35 enamelled copper wire is wound longitudinally about the middle arm of the first core 1, the free end of the middle arm being notched to receive this coil.

The first output coil 6 consisting of twenty turns of SWG 44 enamelled copper wire is wound in two slots in the second core 2, the first slot being located centrally of the free end of the middle arm of the first core 1, and the second slot being located substantially midway between the middle arm and one end arm (the left-hand end in Figure 1) of the first core 1. A second output coil 7 identical to the coil 6 is wound in the mentioned first slot in the second core 2, and in a third slot in the second core located substantially midway between the middle arm and the other end arm (right-hand end in Figure 1) of the first core 1.

Although the cores 1 and 2 described above are of soft ferrite material, other core materials can otherwise be used, for example silicon steel laminations, mumetal (a Registered Trade Mark), or even non-magnetic materials such as plastics material, glass, wood or ceramic, the use of such other core materials necessitating, however, changes in the electromagnetic circuits of the transducer.

Referring now to Figure 4, this shows that the input voltage coil 4 having terminals V^1 and V^2 is wound in a plane perpendicular to that of the input current coil 5 having terminals I^1 and I^2 to ensure a minimum of mutual flux-linkage between these two coils 4 and 5. Coil 4 will in use carry a current I_v which is proportional to the impressed voltage. The MMf of coil 4 will circulate two equal and parallel fluxes ϕ_v around the cores 1 and 2, as indicated. Each flux ϕ_v will link magnetically with an output coil 6

or 7. The coil 6 has terminals E^{L1} and E^{L2} , while the coil 7 has terminals E^{R1} and E^{R2} . The input current coil 5 will carry a load current I_1 , which may be out-of-phase with respect to V_1 by an angle of $+\alpha$ or $-\alpha$ electrical degrees. The MMF of coil 5 will circulate to flux ϕ , which will link with both the output coils 6 and 7. It can thus be seen from Figure 2 that ϕ_V and ϕ_I are aiding in one of the output coils and opposing in the other coil. Coil 5 also circulates a flux ϕ_1 in the end arms of the core, but this flux will be small in magnitude compared with ϕ_1 and since it does not link with any other coil it has no significance in the transducing function of the transducer. It will contribute to the self-inductance of coil 5 and thus introduce phase-defects in the current-circuit, but these defects will be negligible in view of the small number of turns in the coil 5.

Referring now to Figures 5 and 6 also, the transducer is designed to work within the linear part of the B—H curve of the magnetic circuit. Figure 4 shows the relationships between the flux components ϕ_V and ϕ_I . Within the planes of the two output coils 6 and 7, ϕ_V and ϕ_I are combined vectorially to produce resultant fluxes ϕ_L and ϕ_R respectively. The vector diagrams of these flux components for the two sides are shown in Figure 5.

We have:—

$$\phi_R = \phi_V - \phi_I \quad (1)$$

$$\phi_L = \phi_V + \phi_I \quad (2)$$

By trigonometric consideration we have:—

$$\phi_R^2 = \phi_V^2 + \phi_I^2 - 2\phi_V\phi_I \cos \alpha \quad (3)$$

$$\phi_L^2 = \phi_V^2 + \phi_I^2 + 2\phi_V\phi_I \cos \alpha \quad (4)$$

Equation (4) — (3) gives:—

$$\phi_L^2 - \phi_R^2 = 4\phi_V\phi_I \cos \alpha \quad (5)$$

$$\phi_V\phi_I \cos \alpha = \frac{\phi_L^2 - \phi_R^2}{4} \quad (6)$$

But

$$V = k_V \phi_V \quad (7)$$

And

$$I_1 = k_I \phi_I \quad (8)$$

Further

$$E_R = k_o \phi_R \quad (9)$$

and

$$E_L = k_o \phi_L \quad (10)$$

Substituting equations (7) to (10) into (6) we have:—

Real Power $P = VI_1 \cos \alpha$

$$= k_V k_I k_o^2 \left\{ \frac{E_L^2 - E_R^2}{4} \right\}$$

$$= K \left\{ E_L^2 - E_R^2 \right\} \quad (11)$$

where

$$K = \frac{k_V k_I k_o^2}{4} \quad (12)$$

The transducer could also be used to indicate the power-factor $\cos \alpha$ since from equation (11) we have

$$\cos \alpha = \frac{K}{V I_1} \left\{ E_L^2 - E_R^2 \right\} \quad (13)$$

It should be noted that in order to make the transducer operate in the wattmetric mode, I_V must be in phase with the supply voltage V . Since the input voltage coil 4 is predominantly inductive, this coil must be tuned to resonance by a series capacitor, and this will be described later with reference to Figure 8.

It can also be shown theoretically that the transducer will operate in the varmetric mode, as well as being used to indicate reactive power-factor. To do this, I_V must be made to lag V by 90° . In practice this is not possible since the resistance in the input voltage coil 4 cannot be eliminated. The varmetric transducer will always operate with some phase-defects, although these can be made negligible by using an input voltage coil 4 with a high inductance and a small resistance. Figure 6 shows the vector relationships between ϕ_V and ϕ_I for the transducer when operating in the varmetric mode.

We have:—

$$\phi_L^2 = \phi_V^2 + \phi_I^2 + 2\phi_V\phi_I \cos(\pi/2 - \alpha) = \phi_V^2 + \phi_I^2 + 2\phi_V\phi_I \sin \alpha \quad (14)$$

$$\phi_R^2 = \phi_V^2 + \phi_I^2 - 2\phi_V\phi_I \cos(\pi/2 - \alpha) = \phi_V^2 + \phi_I^2 - 2\phi_V\phi_I \sin \alpha \quad (15)$$

By similar reasoning to that given for the set of Equations (5) to (13), we can show that—

$$\text{Reactive Volt-Ampere } Q = K(E_L^2 - E_R^2) \quad (16)$$

and

$$\text{Reactive Power-Factor } \sin \alpha = \frac{K(E_L^2 - E_R^2)}{V I_1} \quad (17)$$

Figure 7 illustrates the cores 1 and 2 of the transducer described above, and shows the dimensions thereof, these dimensions being as follows:—

A=20.46 mm

B=5.46 mm

C=20.42 mm

a=4.9 mm

b=4.8 mm

c=3.7 mm

d=4.8 mm

e (thickness)=9.72 mm

=0.4 mm

f=2.23 mm

w=3 mm

h=2.12 mm

$\theta=45^\circ$

The transducer will operate linearly and accurately only if the input voltage coil 4 is tuned to resonance so that the I_V becomes in-phase with V . The input voltage coil 4 then becomes purely resistive. Voltage range changing is effected simply by adding series resistance to the input voltage coil 4 without affecting the resonance setting. Current range changing can be effected by adding various values of shunt resistance across the terminals I^c to I^c of the input current coil 5.

Figure 8 of the drawings shows the transducer connected for operation in the wattmetric mode, between an input power supply of 230 Volts A.C. at 50 Hz, and a load Z_L . Connected in series in the input voltage coil 4 is a variable resistor R_s variable between 6.86 kohms and 114.36 kohms, and inductance L_s of 2.6 H, and a capacitor C_s of $1.09 \mu F$. For changing the load current range a variable resistor R_{sh} is connected across the input current coil 5. The output coils 6 and 7 are connected to a signal processor-10 operating in accordance with the above set of equations, which gives an output P in watts.

The transducer was tested at 50Hz using the circuit shown in Figure 8, the arrangement being as set out below:—

Rated Frequency:

50Hz

Rated Voltage:

230V r.m.s. max.

Rated Currents:

Input Voltage Coil: 0—2mA

Input Current Coil: 0—50mA

Coil Parameters:

Input Voltage Coil: $R_v=38.83\Omega$

$L_v=865\text{mH}$

Turns=700

Wire Gauge: SWG 35

Input Current Coil: $R_i=1.654\Omega$

$L_i=930\mu\text{H}$

Turns=20

Wire Gauge: SWG 35

Output Coils:

Two identical coils

Max. Output Voltage $>35\text{mV}$

Avg. Resistance/Coil $=3.7\Omega$

Avg. Inductance/Coil $=830\mu\text{H}$

Turns/Coil=20

Wire Gauge=SWG 44

Power Consumption:

Input Voltage Coil $>0.16\text{mW}$

Input Current Coil $>5\text{mW}$

Copper+Core Loss $>0.05\text{W}$

Core Material:

Soft Ferrite (Grade A₃)

Core Dimensions:

See Figure 7

Rated Accuracy and Range:

Wattmetric Mode.

I) Basic transducer, used without the resistor R_{sh} :—

II) When used with the resistor R_{sh} :—

Lagging p.f. load

$R_{sh} R$

1Ω

0.5Ω

0.25Ω

Range

(0—30W)

(0—45W)

(0—80W)

Accuracy

$\pm 2.7\%$ F.S.O.

$\pm 3.7\%$ F.S.O.

$\pm 2.5\%$ F.S.O.

Leading p.f. load

R_{sh}

1Ω

0.5Ω

0.25Ω

Range

(0—30W)

(0—45W)

(0—80W)

Accuracy

$\pm 4.7\%$ F.S.O.

$\pm 4.7\%$ F.S.O.

$\pm 2.5\%$ F.S.O.

Output scale:— Linear after signal processing.

Claims

1. A wattmetric transducer comprising a first, E-shaped core; a second, I-shaped core secured across the free ends of the arms of the first core; a bobbin mounted on the middle arm of the first core; an input voltage coil of insulated wire wound on the bobbin; an input current coil of insulated wire wound longitudinally about the middle arm of the first core; a first output coil of insulated wire wound in two slots in the second core the first slot being located centrally of the free end of the middle arm of the first core and the second slot being located substantially midway between the middle arm and one end arm of the first core; and a second output coil of insulated wire wound in said first slot in the second core and a third slot in the second core located substantially midway between the middle arm and the other end arm of the first core.

2. A wattmetric transducer comprising a first, E-shaped core; a second, I-shaped core secured across the free ends of the arms of the first core; a bobbin mounted on the middle arm of the first core; an input voltage coil of insulated wire wound on the bobbin; an input current coil of insulated wire wound longitudinally about the middle arm of the first core; two identical output coils of insulated wire wound in three slots in the second core the first slot being located centrally of the free end of the middle arm of the first core and shared by the coil sides of the two identical output coils and the remaining two slots being located substantially midway between the middle arm and the two outer end arms of the first core and occupied solely by the other coil sides of the output coils.

3. A transducer as claimed in Claim 1 or 2, in which the first and second cores are of soft ferrite material.

(M)



	Coil Parameters:	Input Voltage Coil: $R_v=38.83\Omega$ $L_v=865\text{mH}$ Turns=700 Wire Gauge: SWG 35													
5		Input Current Coil: $R_i=1.654\Omega$ $L_i=930\mu\text{H}$ Turns=20 Wire Gauge: SWG 35	5												
10		Output Coils: Two identical coils Max. Output Voltage $>35\text{mV}$ Avg. Resistance/Coil $=3.7\Omega$ Avg. Inductance/Coil $=830\mu\text{H}$ Turns/Coil=20 Wire Gauge=SWG 44	10												
15	Power Consumption:	Input Voltage Coil $>0.16\text{mW}$ Input Current Coil: $>5\text{mW}$ Copper+Core Loss: $>0.05\text{W}$	15												
20	Core Material: Core Dimensions:	Soft Ferrite (Grade A ₂) See Figure 7	20												
	Rated Accuracy and Range: Wattmetric Mode. I) Basic transducer, used without the resistor R _{sh} :— II) When used with the resistor R _{sh} :—														
25	Lagging p.f. load	<table><tr><th>R_{sh} R</th><th>Range</th><th>Accuracy</th></tr><tr><td>1Ω</td><td>(0—30W)</td><td>$\pm 2.7\%$ F.S.O.</td></tr><tr><td>0.5Ω</td><td>(0—45W)</td><td>$\pm 3.7\%$ F.S.O.</td></tr><tr><td>0.25Ω</td><td>(0—80W)</td><td>$\pm 2.5\%$ F.S.O.</td></tr></table>	R _{sh} R	Range	Accuracy	1 Ω	(0—30W)	$\pm 2.7\%$ F.S.O.	0.5 Ω	(0—45W)	$\pm 3.7\%$ F.S.O.	0.25 Ω	(0—80W)	$\pm 2.5\%$ F.S.O.	25
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Claims

1. A wattmetric transducer comprising a first, E-shaped core; a second, I-shaped core secured across the free ends of the arms of the first core; a bobbin mounted on the middle arm of the first core; an input voltage coil of insulated wire wound on the bobbin; an input current coil of insulated wire wound longitudinally about the middle arm of the first core; a first output coil of insulated wire wound in two slots in the second core the first slot being located centrally of the free end of the middle arm of the first core and the second slot being located substantially midway between the middle arm and one end arm of the first core; and a second output coil of insulated wire wound in said first slot in the second core and a third slot in the second core located substantially midway between the middle arm and the other end arm of the first core.
2. A wattmetric transducer comprising a first, E-shaped core; a second, I-shaped core secured across the free ends of the arms of the first core; a bobbin mounted on the middle arm of the first core; an input voltage coil of insulated wire wound on the bobbin; an input current coil of insulated wire wound longitudinally about the middle arm of the first core; two identical output coils of insulated wire wound in three slots in the second core the first slot being located centrally of the free end of the middle arm of the first core and shared by the coil sides of the two identical output coils and the remaining two slots being located substantially midway between the middle arm and the two outer end arms of the first core and occupied solely by the other coil sides of the output coils.
3. A transducer as claimed in Claim 1 or 2, in which the first and second cores are of soft ferrite material.



4. A transducer as claimed in Claim 1 or 2 or 3, in which the free end of the middle arm of the first core is notched to receive the input current coil.

5. A transducer constructed and arranged to operate substantially as hereinbefore described with reference to Figures 1 to 6 of the drawings.

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