UDC 621. 317. 785

FUJI INTEGRATING WATT-HOUR METER (V)

By Toshi Yamaki
Foreign Trade Dep't.

XIV. FUJI THREE PHASE 4 WIRE WATT-HOUR METER, MODEL D-28

1. General

As the three phase 4 wire watt-hour meters, there are two different type : one having two driving elements and the other having three driving elements. The two element type can be used only on balanced circuits, but the three element type can be used on unbalanced circuits as described in the previous edition.

Our three phase 4 wire watt-hour meter has three elements and two discs, and can measure the electric energy exactly regardless of a balance or imbalance on the circuit.

2. Construction

The construction of the driving element, brake magnet, register and bearings are quite same as the three phase 4 wire watt-hour meter, model D–170. The case is made compactly because of the three element, two disc type and both the metal and glass covers are available.

The frame is constructed in such a way as to decrease the mutual electromagnetic interference between each element, and the voltage elements are provided with the mutual interference compensating coil on the main coils similar to model D–27.

3. Compensator

The same compensators as those fitted on the three phase 3 wire watt-hour meter, model D–17, are provided for the overload, voltage and temperature characteristics, etc.

Fig. 101 Three phase 4 wire watt-hour meter, Model D–28G

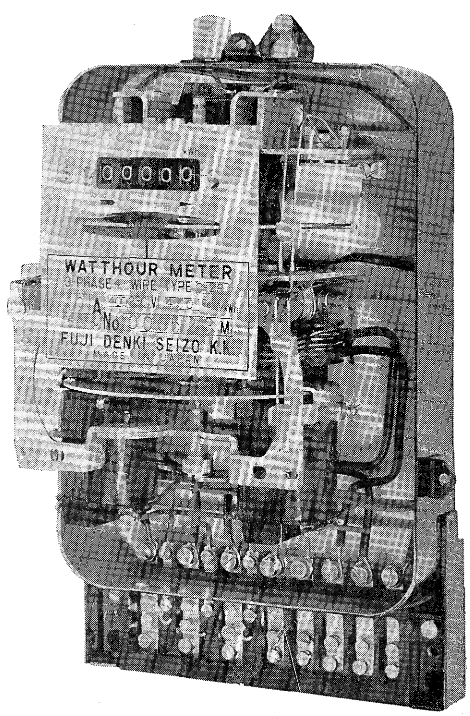


Fig. 102 Internal construction of D–28

4. Adjusting Device

The heavy load, light load, power factor, and torque balance adjusting devices are provided and their construction and adjusting method are the same as those of model D–170.

5. Characteristics

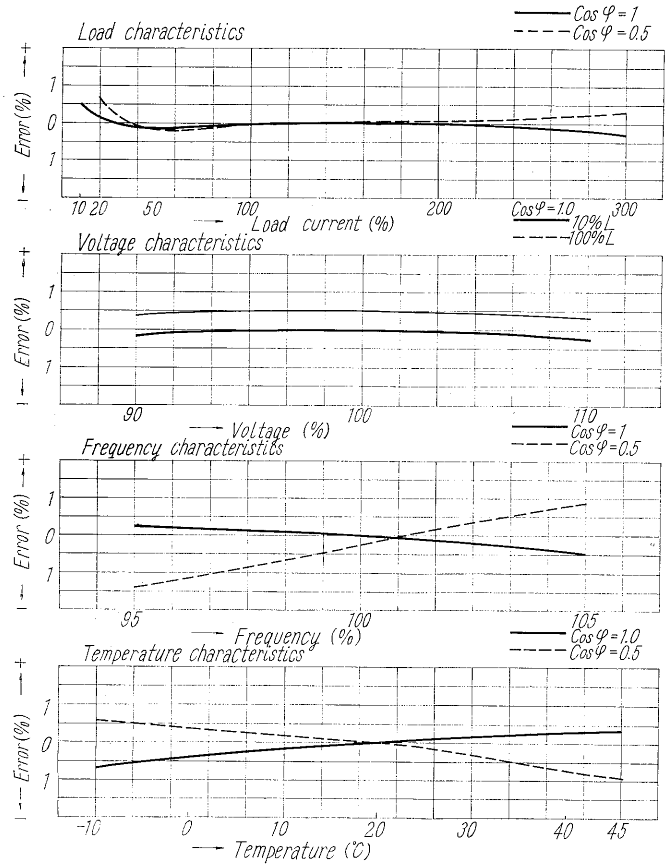


Fig. 103 Characteristic curves of Model D–28G and D–28

6. Technical Data

Rotating speed at full load :
30 amp size, 23 rpm.
50 amp size, 46 rpm.

Driving torque at full load :
30 amp size, about 12.5 g–cm
50 amp size, about 20 g–cm

Rotor weight : 48.5 g.

Self-consumption :
in pressure circuit : about 3× 0.9 w or 3×(3.04∼3.67) va.
in main current coil :
3∼10 amp size : about 3×(0.4∼0.5) w or 3×(0.61∼0.68) va.
20∼30 amp size : about 3× 0.65 w or 3×0.72 va.
50 amp size : about 3×1.25 w
100 amp size : about 3×2.68 w.

Starting current : Under 0.8% of the rated current

Creeping : Does not rotate more than once at 110% of the rated voltage.

Insulation resistance :
Over 10 MΩ when measured by dc 500 v.

Insulation strength :
Withstand for 1 minute when tested by ac 2000 v rms.

XV. FUJI VAR-HOUR METER, MODEL D-16 BWR

Active power at low power factor requires more line current compared with that at high power factor. For the energy supplier, this results in expensive construction and operation of the power station, substation and the equipment of the power transmission and distribution. Therefore, it is not enough to charge the tariff by considering only the consumed energy ; it is more rational to decide the fee by considering both the consumed electric energy and its power factor. Especially for such large consumers who use motors, industrial machines and other similar equipment which requires heavy load at a comparatively low power factor, obviously it is preferable to take the power factor as one element in the tariff system for consumed power in order to maintain the mutual benefit between the energy supplier and the consumer.

In the tariff system considering the power factor, it is necessary to know the average power factor for counting the fee. At present, however, the definition of the average power factor has not been resolved although generally we can determine it by the following formula :

$$\cos\varphi = \frac{\int ei\cos\varphi dt}{\sqrt{(\int ei\cos\varphi dt)^2 + (\int ei\sin\varphi dt)^2}}$$

$\int ei\cos\varphi dt$ can be measured by a watt-hour meter and one which measures $\int ei\sin\varphi dt$ is called a var-hour meter. Thus, if we have both a watt-hour and a var-hour meter, we can arrive at the power factor by the following formula :

$$\cos\varphi = \frac{\text{Registration of watt-hour meter}}{\sqrt{(\text{Registration of watt-hour meter})^2 + (\text{Registration of var-hour meter})^2}}$$

And the reactive power on the three phase system is expressed by the following formula :

$$p = E_{12}I_1\sin(\angle E_{12}I_1) + E_{23}I_3\sin(\angle E_{23}I_3)\ldots\ldots(1)$$

The torque of a var-hour meter which measures reactive power should be in proportion to the reactive power. The torque D of a var-hour meter is expressed as follows :

$$D = K_1\phi_p\phi_c\sin\theta$$

Here, ϕ_p = voltage flux
ϕ_c = current flux
θ = phase angle between voltage flux and current flux

K_1 = proportional constant

Since the driving torque of a var-hour meter must be proportional to the reactive energy,

$$D = K_1 \phi_p \phi_c \sin\theta = K_2 EI \sin\phi$$

K_2 = proportional constant

Thus, assuming that ϕ_p is proportional to E and ϕ_c is proportional to I, the conditions of

$$\theta = \phi \text{ or } \theta = 180° - \phi$$

must be satisfied. That is, to know the reactive power even when the circuit is in any condition it is essential to maintain the phase angle between the voltage effective flux and current effective flux at 180°. (When the phase angle is 0° the armature of the meter rotates to the reverse direction.) Such a meter with the internal phase angle of 180° is called a true meter.

Generally, the voltage flux lags behind the supplied voltage by 90° because of the inductance of the potential coil, and the current flux is almost in-phase for current. Thus it is a serious problem to fix the internal phase angle in-phase for the power factor angle, that is, to make the current flux lag behind the current as much as the voltage flux is lagging behind the supplied voltage because of the decline of characteristics and torque.

In order to solve the above problem, it is possible to use the artificial circuit under such conditions as balanced voltage and designated phase sequence, and such a meter applies this method is called an artificial meter.

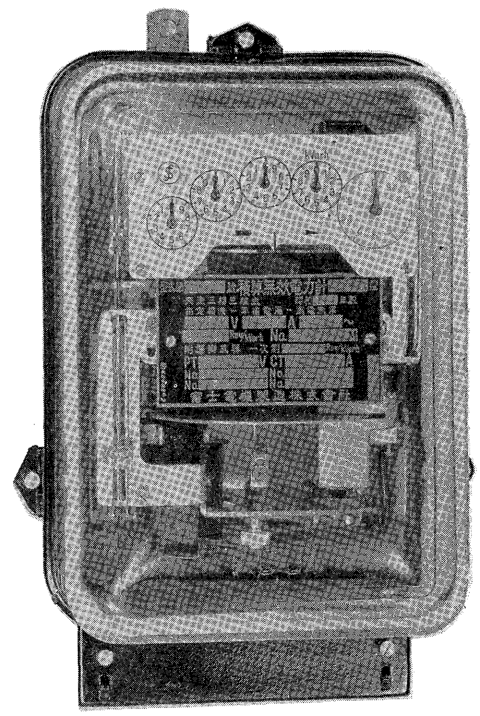


Fig. 105 Three phase 3 wire var-hour meter, Model D-16BWGR

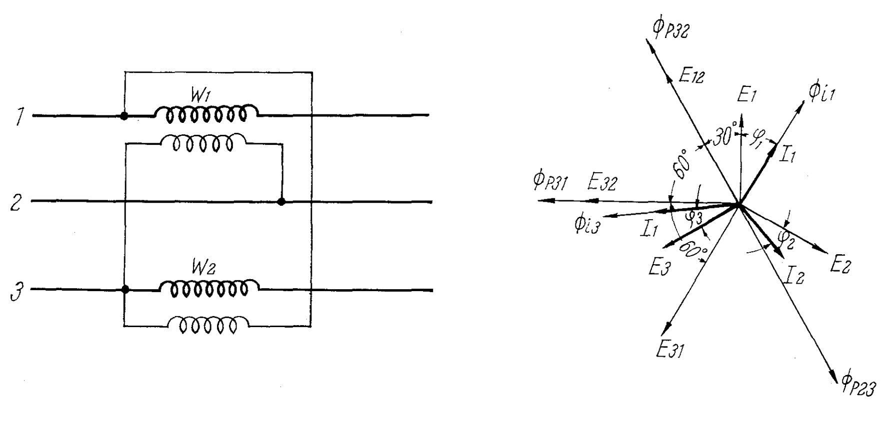


Fig. 104 Connection and vector diagrams of 600 internal phase angle var-hour meter

1. General

Model D-16 BWR is an artificial var-hour meter used for three phase three wire balanced voltage circuits. It is connected as shown in *Fig. 104* with each element adjusted to make the internal phase angle, 0, between the voltage flux and current flux 60° at the unity power factor by inserting the resistance r into the voltage circuits in series and the resistance R into the current coils in parallel. The terminal arrangement of this meter is quite the same as that of the three phase 3 wire watt-hour meter since this connection is performed in the interior of the meter.

When the driving elements are connected as mentioned above, the torque generated by a W_1 element is shown by the following formula:

$$W_1 = K_1 \phi_{p23} \phi_{i1} \sin\{180° - (30° + \varphi_1)\}$$
$$= K_1 \phi_{p23} \phi_{i1} \sin(30° + \varphi_1)$$
$$= K_2 E_{23} I_1 \sin(30° + \varphi_1)$$

The torque due to the W_2 element is as follows:

$$W_2 = K_1 \phi_{p13} \phi_{i3} \sin\{180° + (30° - \varphi_3)\}$$
$$= K_1 \phi_{p13} \phi_{i3} \{-(30° - \varphi_3)\}$$
$$= K_2 E_{13} I_3 \sin\{-(30° - \varphi_3)\}$$

Thus, the synthetic torque is:

$$W_1 + W_2$$
$$= K_2\{E_{23} I_1 \sin(30° + \varphi_1) + E_{13} I_3 \sin\{-(30° - \varphi_3)\} \quad \ldots.(2)$$

In the above formulars, since $(30° + \varphi_1)$ is equal to the angle $\angle E_{12}$, I_1 in formula (1) and $-(30° - \varphi_3)$ is equal to $\angle E_{23} I_3$, the meter can get the torque in proportion to the reactive power when the voltages in each phase are balanced even if the phases are unbalanced.

2. Construction

a) External dimension

The external dimension of the var-hour meter,

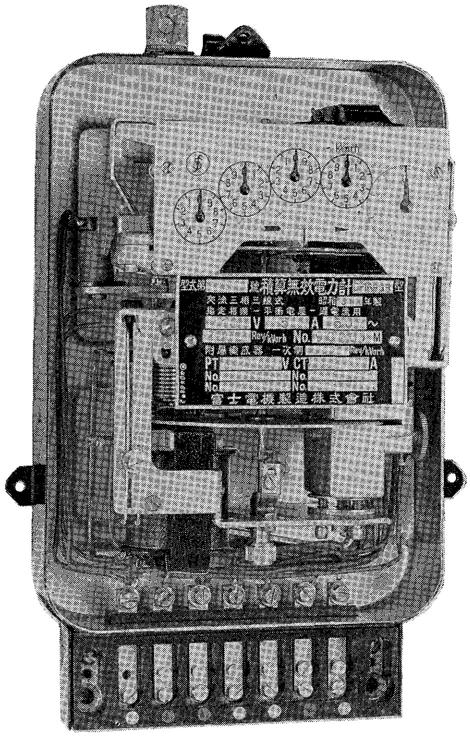


Fig. 106 Internal construction of D–16BWGR and D–16BWR

model D–16 BWR is the same as that of our meter, model D–16 PW.

b) Rotor

The rotor is exactly the same as that of model D–16 PW and there are different types, such as D–16 BWR having a reverse rotation preventing device, and D–16 BW not having it.

c) Voltage element

The voltage element involves special construction to increase the torque and fix the internal phase angle at 60°, and is designed to compensate the internal phase angle by inserting the series resistance into it as shown in *Fig. 107.* The upper part of the potential core is provided with the phase angle adjusting coil in order to perform the phase adjustment effectively.

d) Current element

The current core is provided with the magnetic

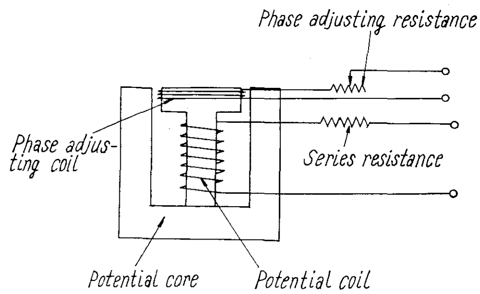


Fig. 107 Construction of voltage elements

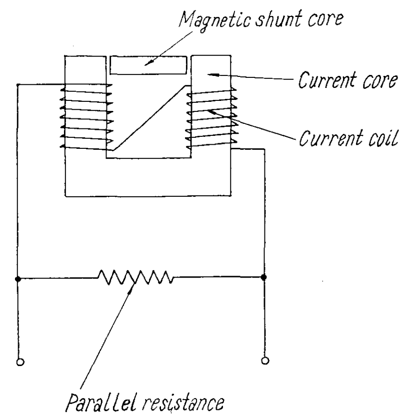


Fig. 108 Construction of current elements

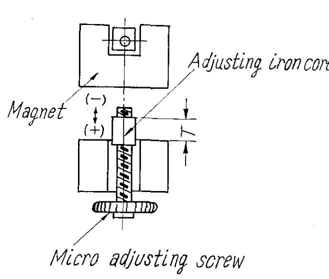
shunt core to compensate for the overload characteristic. The parallel resistance wire is inserted into the current coil, as shown in *Fig. 108,* to compensate the internal phase angle and the frequency characteristic.

e) Other parts

The meter base, frame, register and other parts are similar to those of model D–16 PW.

3. Adjusting Devices

The construction, adjusting method and adjusting range of the heavy load adjusting device and the light load adjusting device are similar to those of D–16 PW. The power factor adjusting device fixed on the upper part of the voltage core is connected in series to the phase adjusting coil. The internal



Number of turn of micro adjusting screw	Error (%)
0	+ 7.0
4	+ 2.6
8	− 1.5
12	− 4.2
16	− 6.3
20	− 7.8

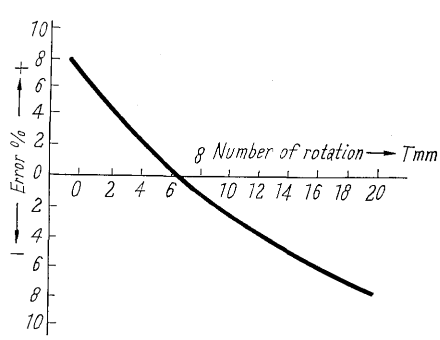
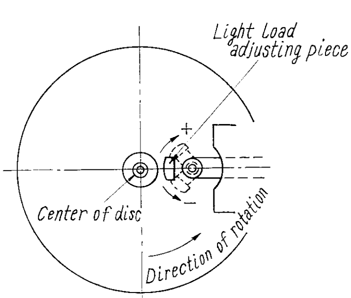


Fig. 109 Heavy load adjuster



Removal angle(deg)	Error(%)
10	0.8
20	1.8
30	2.9
40	4.0
50	5.0
60	6.3
70	7.6
80	9.3

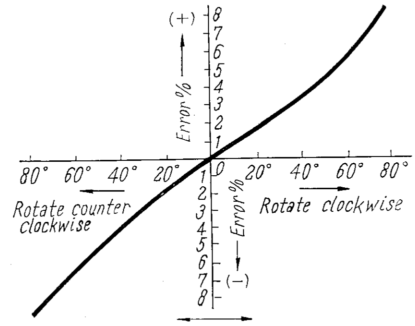
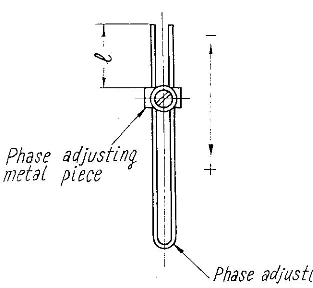


Fig. 110 Light load adjuster



l mm	Error(%)
0	−2.5
10	−0.6
20	+0.4
30	+1.2
40	+1.6
50	+2.0
60	+2.3
70	+2.5
80	+2.6

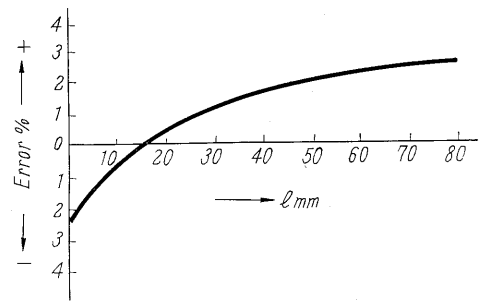


Fig. 111 Phase adjuster

phase angle is adjusted by the adjusting resistance wire and the adjusting range is shown in *Fig. 109～111*.

4. Compensating Devices

The compensating devices for load and temperature characteristics are the same as those of D–16 PW, and the frequency characteristic is compensated by connecting the fixed resistance wire in parallel for the current coil.

The theory of the frequency characteristic compensation by means of a parallel resistance wire for the current coil can be summarized as follows:

The voltage coil of the meter having the 60° internal phase angle (hereafter called a 60° meter) is connected with a non-inductive resistance wire R_e to maintain the 60° internal phase angle as shown in *Fig. 112*.

When there are, E_0 = applied voltage
i_p = exciting current
ϕ_{p0} = main voltage flux

As shown in the vector diagram, *Fig. 112*, i_p is lagging behind E_0 about 60°. When the load current I is in-phase for the supplied voltage E_0, the resistance R_e should be adjusted so that the effective flux ϕ_p lags just 60° behind the current flux ϕ_c. If the strength of both ϕ_p and ϕ_c, and the phase difference between them are kept constant for the change of frequency, the error due to the variation of frequency does not arise; however, the internal phase angle $\angle\phi_p\phi_c$ is changed remarkably and the frequency characteristic becomes incorrect.

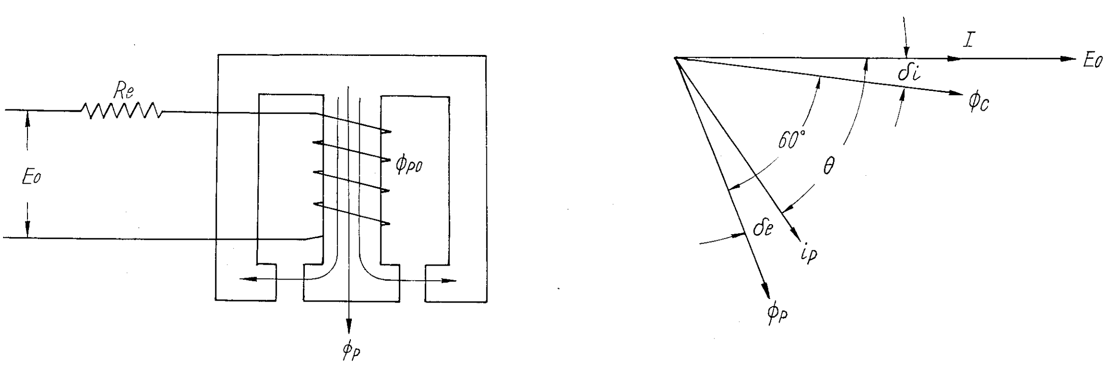


Fig. 112 Connection and vector diagrams of voltage element

When the inductance of the potential coil is L_e and the resistance is r_e,

$$\tan\theta=\frac{\omega L_e}{R_e+r_e} \quad \cdots\cdots\cdots\cdots(3)$$

$$i_p=\frac{E_0}{\sqrt{(R_e+r_e)^2+(\omega L_e)^2}} \quad \cdots\cdots\cdots(4)$$

that is, $\tan\theta$ changes in proportion to ω and i_p is changed slightly by ω.

Formula (3) expresses the change of the internal phase angle $\angle\phi_p\phi_c$ and illustrates that the phase characteristic is greatly affected by the variation of frequency.

Formula (4) expresses the effect due to the change of the exciting current.

Generally, the driving torque D of the meter is expressed as follows:

$$D=K_f\phi_p\phi_c\sin\theta$$

When ϕ_c is constant the torque can be maintained constant if ϕ_p is decreased inversely proportion to θ since the more frequency increases, the more θ increases. It is understood by the formula (4) that i_p is not inversely proportional to ω because the resistance R_e is not small, and the torque D increases gradually with the increase of ω if $\angle\phi_p\phi_c$ is nearly 90°. When $\angle\phi_p\phi_c$ is 30° or becomes less, that is, when the phase angle $\angle E_0I$ becomes less than 30°, the torque is greatly influenced by a small change of θ.

In order to compensate for the increase of θ by reason of that of ω a method of providing the current coil with shunt resistance its presented as shown in *Fig. 113*. When the current I is on the main current circuit and the current I_c flows through the current coil,

$$I_c(r+j\omega L)=i_cR$$

$$I_c+i_c=I$$

So, $\tan\delta_{i1}=\dfrac{\omega L}{R+r}$ $\quad I_c=\dfrac{R}{\sqrt{(R+r)^2+(\omega L)^2}}I\ ..(5)$

This fact means that the current I_c through the current coil lags by δ_{i1} behind the main load current I and the magnitude of I_c decreases slightly as shown in formula (5). If the internal phase angle θ decreases as a result of the increase in frequency, the above mentioned angle δ_{i1} becomes smaller, and then $\delta_{i1}+\delta_{i0}$ is affected in order to decrease the change of the internal phase angle θ.

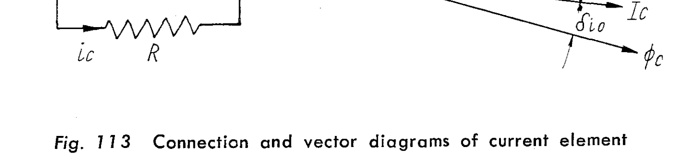


Fig. 113 Connection and vector diagrams of current element

Thus by determining the shunt resistance R effectively, the error due to the change of the internal phase angle can be compensated. Also, the magnitude of I_c is as expressed in formula (5) and it affect so that the increase of torque may be compensated.

When the parallel resistance is connected to the current coil, many influences are exerted on the other characteristics as will be mentioned below.

1) Voltage characteristic

In such a case as the attached shunt resistance, it is necessary to make the voltage flux lag behind the applied voltage as much as the phase angle of the current flux ϕ_c lags behind the load current I. Not much influence is exerted by the effect of the shunt resistance to the voltage characteristic except that ϕ_p increases slightly as a result of having the series resistance R_e inserted into the potential coil decrease.

2) Load characteristic

As shown in formula (5), the current I_c of the current coil is proportional to the load current I, and there is little influence if the changes of r and L of each are very slight.

3) Frequency characteristic at unity reactive factor

The characteristics are hardly influenced by the change of δ_{i1} except by the change of I_c. As shown in formula (5), I_c decreases because of the increase of ω and there are such characteristics that the changing range of I_c becomes less because of r.

4) Temperature characteristic

When the current coil is provided with shunt resistance, the temperature characteristic is influenced greatly by the substance of shunt. The current coil is made of copper wire and its temperature coefficient is about +0.04/10°C. If the resistance of the shunt is made of maganin, constantan, etc., the coil current I_c decreases for the constant current according to the temperature rise and negative error is generated. This is to compensate for the plus error because of the temperature co-efficient of the brake magnet. That is, by using the parallel resistance made of a reasonable substance we can compensate the temperature characteristics.

5) Torque

The coil current I_c decreases because of the shunt, but on the otherhand, since it is needed to decrease the resistance of the voltage circuit, ϕ_p increases and and the torque is not changed remarkably.

5. Characteristics

In the var-hour meter, especially the characteristics at low power factor are most important, and considering its use much care is taken for the various compensators, the design and materials. Thus, D-16 BWR has superior characteristics corresponding to JIS-C 1212 (Japanese Industrial Standard for the precision watt-hour meter.)

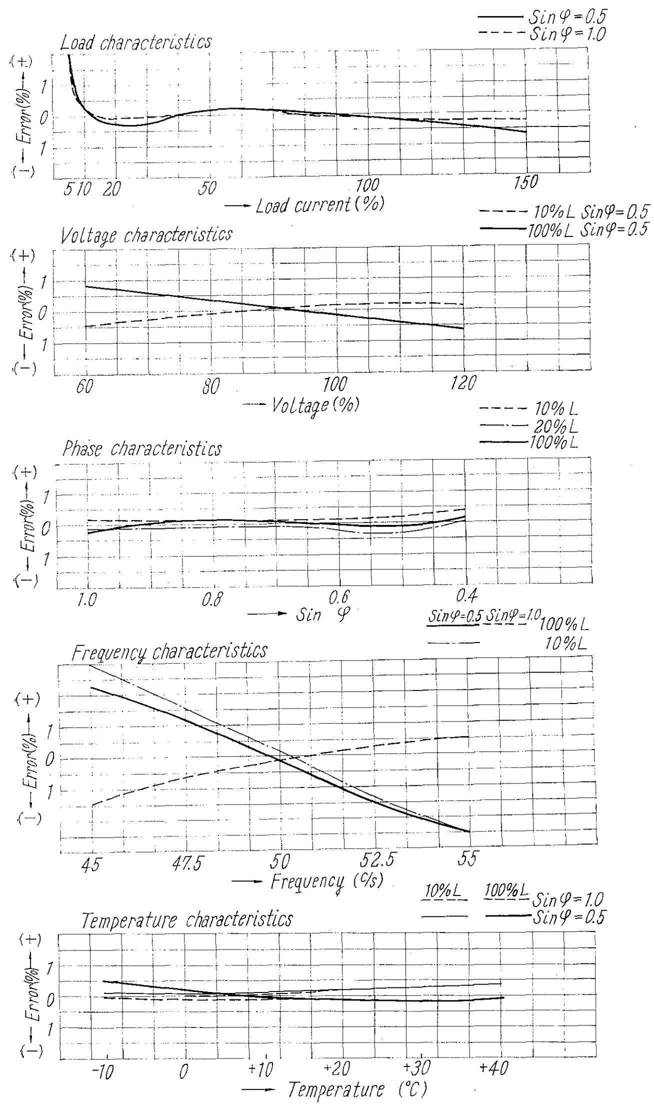


Fig. 114 Characteristic curves of D-16BWR & D-16BWGR

6. Technical Data

Meter constant	2000 Rev/kvar-hour at 110 v 5 amp		
Rotating speed in full load	31.746 rpm.		
Driving torque in full load	15.5 g-cm		
Rotor weight	44 g		
Driving torque/rotor weight	0.35		
	Voltage element		Current element
Rated value	110 v	110 v	5 amp
	50 c/s	60 c/s	
Apparent power (va)	3.08	2.82	4.7
Watt loss (w)	1.69	1.54	2.1
Exciting current (ma)	28	25.6	—
Voltage drop (v)	—	—	0.92
Starting current	Under 0.25% of the rated current		
Creeping	Does not rotate more than once at 110% of the rated voltage		
Insulation resistance :	Over 10 MΩ when measured by dc 500 v		
Insulation strength :	Withstand for 1 minute when tested by ac 2000 v rms.		

XVI. VAR-HOUR METER, MODEL D-24 BWR

1. General

As described previously, model D–16 BWR is an artificial meter having the internal phase angle of 60° and it accurately measures the reactive energy only under such conditions as the appointed phase sequence and the balanced voltage. Therefore, if the applied voltage is unbalanced logical error will naturally occur and care must be taken in regard to the phase sequence when installing the meter.

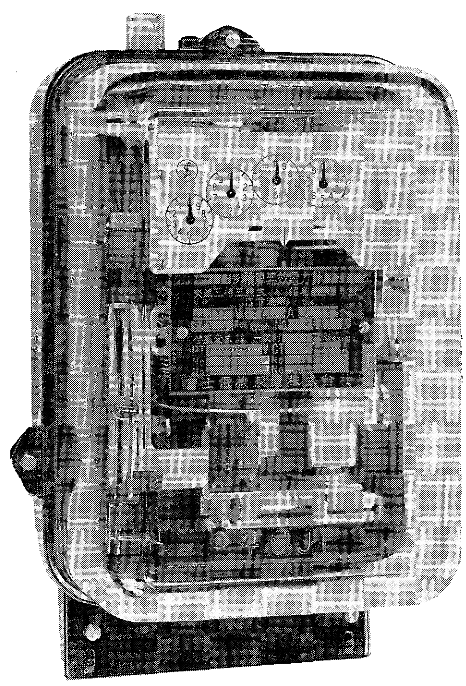


Fig. 115 Three phase 3 wire var-hour meter, Model D–24BWGR

But a var-hour meter having an internal phase angle of 180° can exactly measure the reactive energy even under an unbalanced load and this is called the true meter.

We at Fuji Electric have manufactured model D–24 BWR having the 180° internal phase angle in order to measure the average power factor exactly and to improve the quality of the meter.

The features of this meter are as follows:

1) Since the internal phase angle is 180°, there is no logical error like that of the watt-hour meter even though it is used under the unbalanced load.

2) It is possible to measure the reactive energy on the single phase since each element itself measures the reactive energy respectively.
3) No logical error is considered at all even if the connection is bad for the phase sequence because it is unnecessary to define the phase sequence. This point is quite different from the meter having a 60° or 90° internal phase angle.
4) Since this meter utilizes a new adjusting method which can be accomplished readily and exactly, it has many conveniences and the adjusting curve is nearly straight.
5) This meter conforms well in all respects to JIS–C 1212. The frequency characteristic is especially superior.
6) This meter is particularly designed in order to obtain the maximum efficiency for a meter utilizing such a principle.

The procedure for obtaining the 180° internal phase angle is troublesome because the phase angle between the potential effective flux and current effective flux in a watt-hour meter is generally about 90° even without the compensators and adjustors.

However, the following methods are suggested:

a. To connect L. R. C. into the voltage coil in series or in series-parallel.
b. To insert a large value resistance into the voltage coil in series so that the voltage effective flux becomes in-phase for the supplied voltage.
c. To make the current flux lag by 90°.
d. To both make the voltage flux lead and the current flux lag for the current.

However, methods a., b. & c. entail many technical difficulties, for example, method a. entails construction difficulties; in method b., the voltage flux and driving torque decrease as the exciting current of the voltage element decreases thus making this method impractical; in method c., the number of turns of current coil must increase very much thus making this method also impractical.

We have adopted method d. in our model D–24 BWR. In this meter the lagging angle of the voltage flux behind the supplied voltage is decreased by using the specially formed iron core and connecting the resistance to the potential coil in series, and the current flux is made lag for the current by means of connecting the resistance to the current coil in parallel.

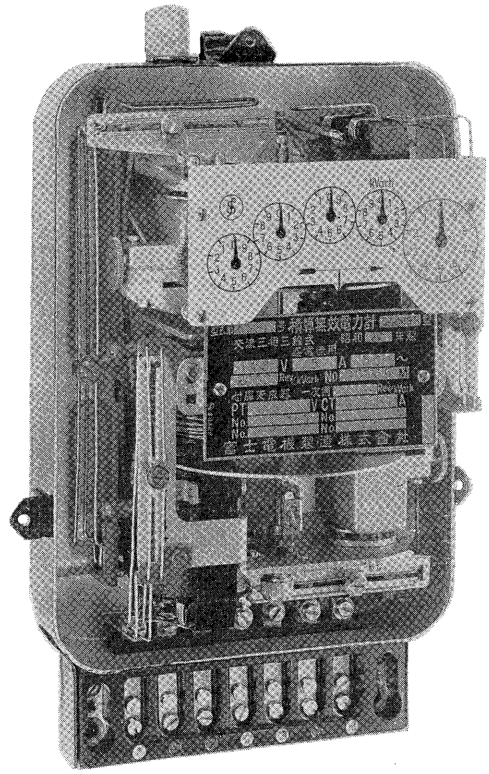


Fig. 116 Internal construction of Model D–24BWGR & D–24BWR

After making the current flux and the voltage flux in-phase according to this method, the phase difference between them is fixed at 180° by exchanging the polarity of the voltage coil. In this way the most important point is how to make the voltage flux lead and the current flux lag to get in-phase. Each approaching angle of the voltage and current flux is decided so that the logical torque becomes the maximum one and the frequency characteristic is highly accurate.

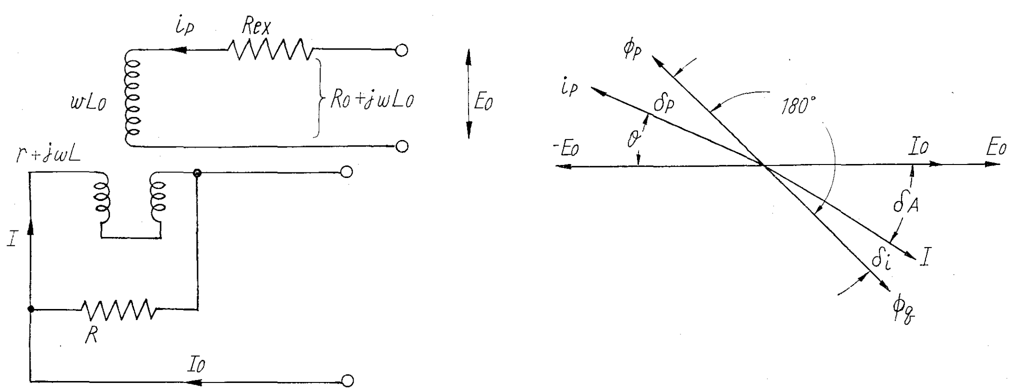


Fig. 117 Connection and vector diagrams of driving element

2. Construction

1) External dimensions

The external dimensions of this meter are the same as our precision watt-honr meter, D-16 PW. Both the surface mounting and flush mounting type are acceptable.

2) Voltage element

The voltage element of this meter is particularly constructed in order to increase the torque and compensate the internal phase angle by connecting the resistance in series.

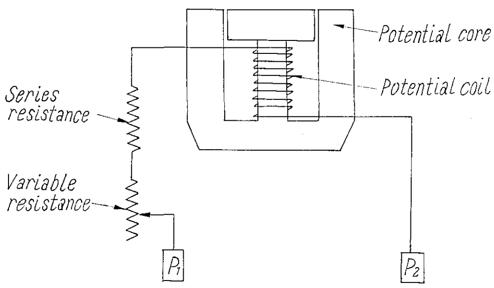


Fig. 118 Construction of voltage elements

3) Current element

The current core and coil are specially adjusted to increase the torque as shown in *Fig. 119.* The resistance wire is inserted into the current coil in order to compensate the internal phase angle, and the current flux is made lag for the current and adjusted to be in-phase for the voltage flux. Moreover, the connection of the resistance wire is especially considered so as not to change the phase angle of the current flux on account of the adjustment of this resistance.

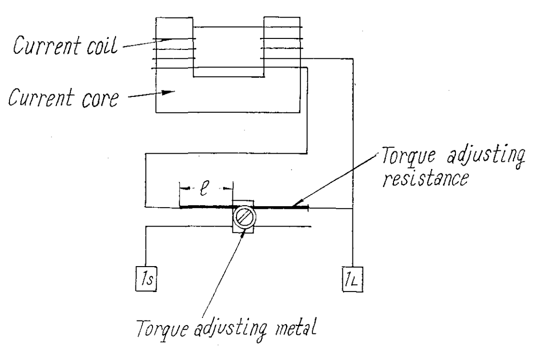


Fig. 119 Construction of current elements

4) Other parts

The construction of the upper and lower bearing, register, meter base, cover and other parts are the same as our watt-hour meter, D-16PW, and the rotor is such that it is provided with the reverse rotation preventing device similar to that of model D-16PW.

3. Adjusting Devices

1) Heavy load adjusting device

The construction and adjusting method are the same as model D-16 PW.

2) Light load adjusting device

As shown in *Fig. 120,* the adjustment is accomplished by changing the magnetic flux distribution between both poles of the voltage iron core by means of shifting the light load adjusting metal attached on the light load adjusting resistance wire which is connected to the coils wound at the bottom of both poles. This adjusting device has many conveniences for adjustment, such as the adjusting range is very wide and its adjusting curve is nearly straight.

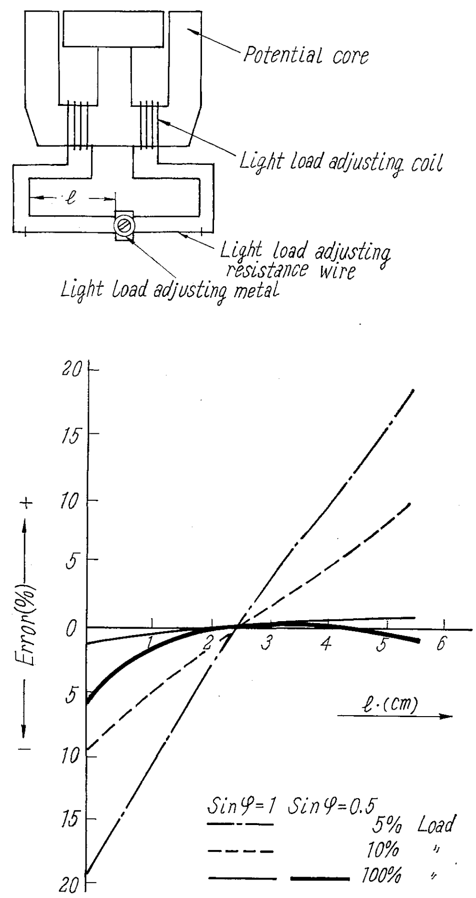


Fig. 120 Light load adjuster

3) Phase adjusting device

This adjustment is accomplished by changing the variable resistance connected to the phase adjusting coil fixed at the top of the voltage core in series. The adjustment curve is nearly straight and the adjustment is done easily and exactly.

4) Adjustment of torque balance

This adjustment is accomplished by changing the resistance ratio between the current coil and the shunt resistance wire, and changing the current running on the current coil. This device is designed so as not

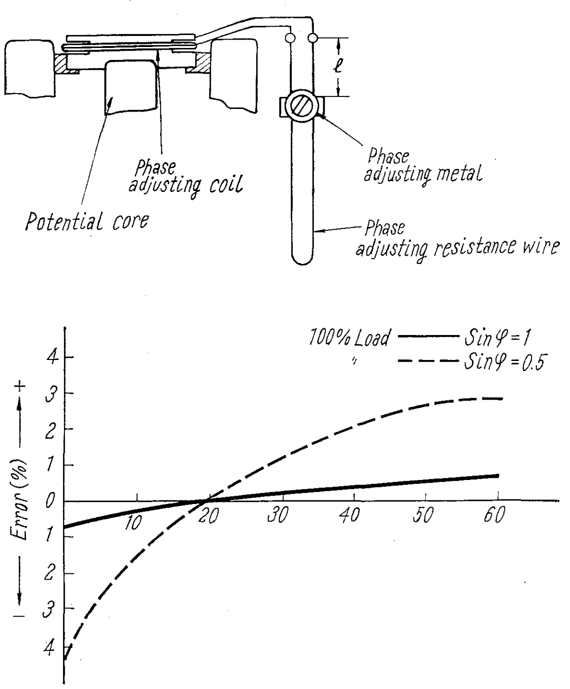


Fig. 121 Phase adjuster

to change the phase angle of the current flux if the parallel resistance is changed by adjustment.

If the equivalent circuit of the current element is as shown in *Fig. 122,* the current I_c running on the current coil is as follows:

$$I_c = I\frac{r_2}{r_1 + r_2 + r + j\omega L} \qquad r_1 + r_2 = \text{constant}$$

Here, r = resistance of current coil
ωL = reactance of current coil
r_1, r_2 = each value of parallel resistance
I = load current

Therefore, if each value of the parallel resistance, r_1 and r_2, changes by adjustment, the phase angle of the current flux is not changed because of $r_1 + r_2$ being constant and only its magnitude is changed. Therefore, the torque adjustment can be done and the range of adjustment is shown in *Fig. 123.*

4. Compensating Devices

1) Load characteristics

The meter is provided with the load characteristic compensating magnetic shunt core to maintain high accuracy at a low power factor.

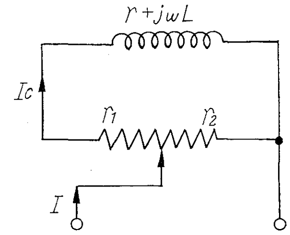


Fig. 122 Equivalent circuit of current element

2) Frequency characteristics

As described in D–16 BWR, high accuracy in frequency characteristic is maintained by connecting the resistance wire to the current coil in parallel.

3) Temperature characteristics

Since the circuit constant of the meter is designed to cancel each resistance temperature co-efficient of the voltage and current circuit mutually, the temperature characteristic is highly accurate. The theory of compensation is as follows:

Magnitude error—this is the error having no relation with the power factor and is generated mainly by the change of the permanent magnet as well as that of the watt-hour meter. The current of the coil decreases with the increase in temperature of the current coil because of the shunt resistance and thus the error caused by the permanent magnet is compensated. Further, if there is the resistance having a positive temperature coefficient in the voltage circuit, the exciting current of the voltage element decreases and the current element affected so as to cancel the error due to the temperature co-efficient of the permanent magnet.

Assuming that the error due to the change of current I in the current coil is εt_c, the error due to the change of the exciting current i_p of the voltage element is ε_{tp}:

$$\varepsilon_{tc} = \frac{I - I_0}{I_0} \qquad \varepsilon_{tp} = \frac{i_p - i_{p0}}{i_{pa}}$$

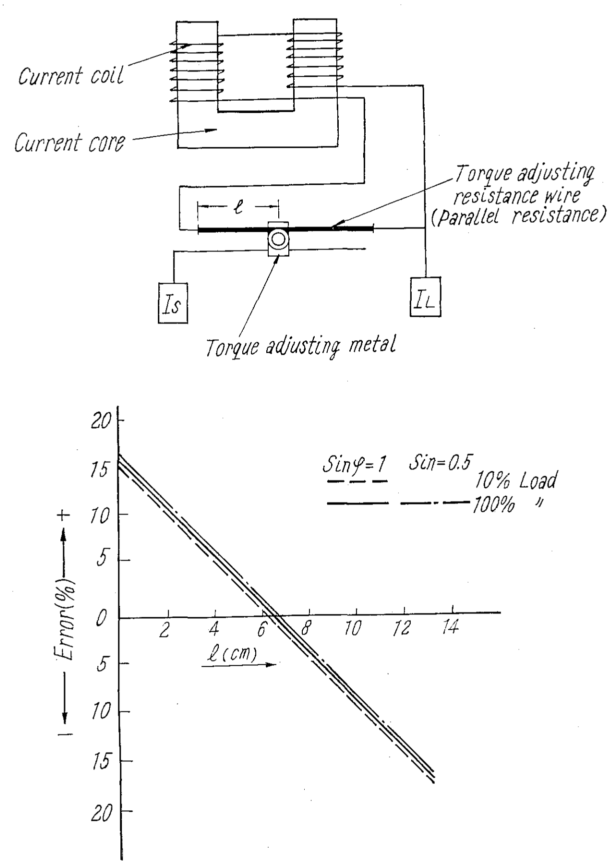


Fig. 123 Torque balancer

Here, I_0, i_{p0}—current in standard temperature.

$$I=I_0\frac{R}{\sqrt{(R+r)^2+\omega^2L^2}}-j\delta_A$$

$$\therefore\quad \varepsilon t_c\doteqdot\frac{[R+r\sec\delta_A]_0}{R+r\sec\delta_A}-1$$

$$\dot{i}_p=\frac{\varepsilon^0}{\sqrt{(R_{ex}+r_p+r_{es})^2+(\omega L\theta)^2}}-j\theta$$

$$\therefore\quad \varepsilon_{tp}\doteqdot\frac{[R_0\sec\theta]_0}{R_0\sec\theta}-1$$

If the value of $\varepsilon_{tc}+\varepsilon_{tp}$ compensates for the temperature error due to the brake magnet the error becomes zero. Actually the resistance wire having a small temperature co-efficient is used for the shunt resistance R and the voltage series resistance R_{ex}, so that no resistance changes because of temperature except the coil resistance r and r_p, and it is believed that r_{e0}, which is loss resistance, does not change either.

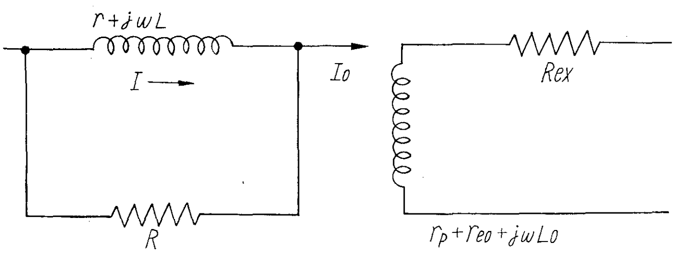


Fig. 124 Circuit diagrams of current and potential circuits

The error due to the change of phase angle:

$$\tan\delta_A=\frac{\omega L}{R+r}\qquad \tan\theta=\frac{\omega L_0}{R_0}$$

$$R_0=r_0+r_{e0}+R_{ex}\qquad \delta_A\doteqdot\theta$$

In the above formulas, assuming that ωL and ωL_o do not change even if the temperature changes, and if the variations of δ_A and θ, depending on the changes of the temperature coefficient of $(R+r)$ and R, are equal the error due to the change of the phase angle will be zero. Though the external resistance, R_{ex}, having high resistivity, is connected to the voltage coil resistance R_o in series, it is easy to fix the equivalent temperature co-efficient of the voltage circuit at a reasonable value. And it is possible to make the change of phase angle $\Delta\delta_A$ and $\Delta\theta$ the same.

5. Characteristics

Since great care is taken in the designation and selection of meterials and since the meter is provided with the many compensators as described avove, it is maintained in high accuracy. (See *Fig. 125*)

6. Technical Data

Meter constant	2000 rev/kvarh at 110 v 5 amp
Rotating speed in full load	31.746 rpm

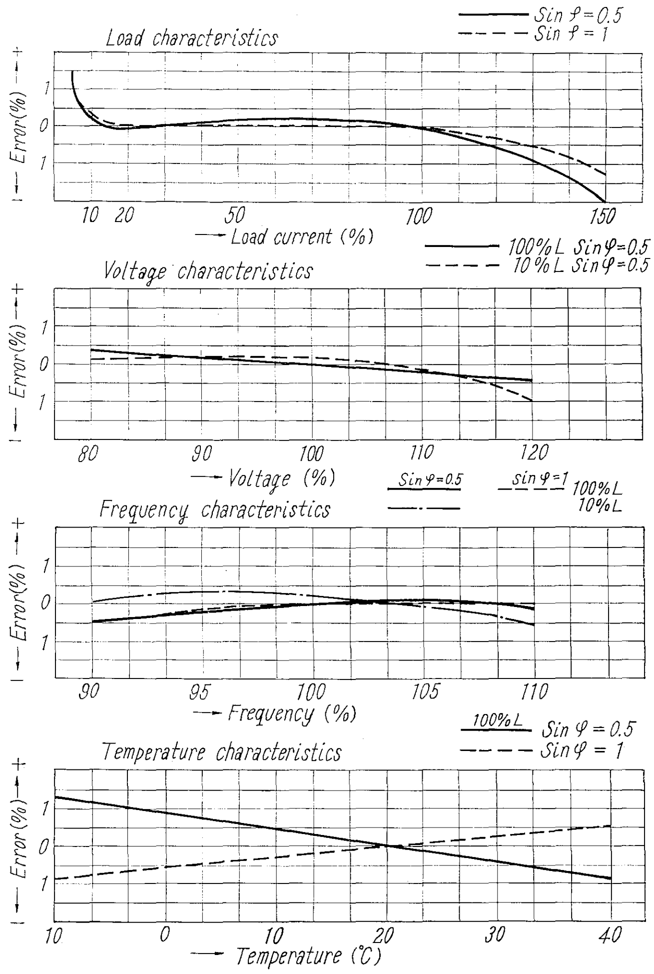


Fig. 125 Characteristic curves of Model D-24BWGR & D-24BWR

Driving torque in full load	11.5 g-cm		
Rotor weight	44 g		
Driving torque/Rotor weight	0.262		

	Voltage element		Current element
	110 v 50 c/s	110 v 60 c/s	5 amp
Apparent power (va):	3.69	3.47	2.8
Watt loss (w):	3.2	3.1	2.7
Voltage drop (v):	—	—	0.56
Exciting current (ma):	33.5	31.5	—

Starting current:	Under 0.25% of the rated current
Creeping:	Does not rotate more than once at 110% of the rated voltage
Insulation resistance:	Over 10 MΩ when measured by dc 500 v
Insulation strength:	Withstand for 1 minute when tested by ac 2000 v rms.