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FUJI INTEGRATING WATT-HOUR METER (II)

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In a recent edition of this journal, we discussed the basic problems of an integrating watt-hour meter ; in this issue, we will describe the construction, special features and electrical characteristics, etc., of the parts actually used in Fuji Integrating Watt-hour Meter.

VI. MODEL NAMES OF FUJI SINGLE PHASE AC INTEGRATING WATT-HOUR METER

At the beginning of our last installment, we explained that every nation has its own specifications for an integrating watt-hour meter. Consequently, meeting all these specifications becomes the first problem to be overcome in watt-hour meters for export. Our company uses as a basic type single phase a-c integrating watt-hour meter E-71 (*Fig. 21* and *22*) which conforms to Japanese Industrial Standards. In order to conform to the various standards of importing countries, not only the electrical characteristics but also the mechanical construction of this basic model E-71 are often changed in many respects for the purpose of exporting watt-hour meters.

We also offer model E-12 or model E-12J to meet B.S.S. and model E-16Z for A.S.A., putting our company in the position of being able to produce watt-hour meters to meet almost all the important standards of the watt-hour meter industry.

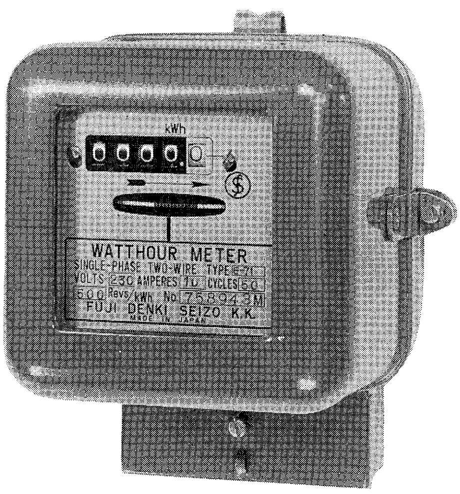


Fig. 21 Single phase 2 wire watt-hour meter, model E-71 (with metal cover)

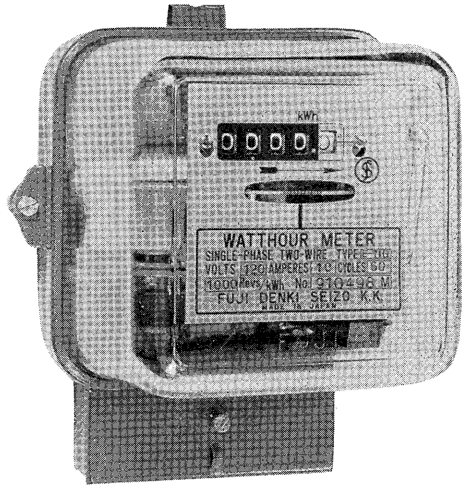


Fig. 22 Single phase 2 wire watt-hour meter, model E-71 G (with glass cover)

VII. FUJI SINGLE PHASE AC INTEGRATING WATT-HOUR METER, MODEL E-71

1. Construction

1) Base (*Fig. 23*)

The base is pressed out of high quality sheet ; the hanger, terminal holder, cover setting pieces and frame, etc., are spot-welded. After rust-proofing both inside and outside, the base interior is coated with silver or gray paint and its exterior is coated, depending on the customer's request, either with black or gray paint.

To increase the weathering characteristic for outdoor use, the rust-proofing and selection of the paint are done with utmost care. Thus Fuji watt-hour meters will last more than one period of official approval of 5∼7 years. This has been proved by actual tests.

For outdoor use in the high temperature and high humidity regions of the tropics, galvanized steel is used for the base and other parts and coated with synthetic resin for protection.

2) Cover

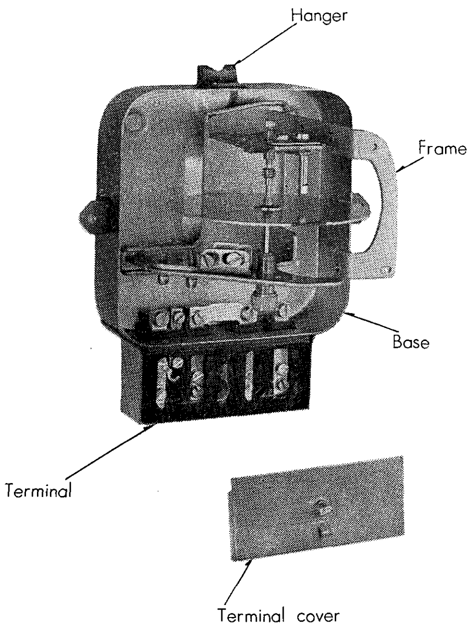


Fig. 23 Construction of meter base and frame

The cover is made from glass or aluminum sheet. The metal cover has a glass window so that the rotation of the disc, name plate, register, etc., can be clearly observed. A neoprene packing between the cover and base maintains air-tightness.

3) Terminal cover

The terminal cover is made also of high quality steel sheet and is given the same treatment as the base. To maintain air-tightness, a neoprene packing is used for the cover interior and to facilitate connection, a connection diagram is pasted on the cover. The terminal cover has a projection for passing through a sealing wire.

4) Terminal box

The terminal box is molded out of bakelite of high insulation characteristic. Terminal pieces are square brass rods with ample sectional areas corresponding to current capacity to prevent heat generation when current passes. The terminal box interior is provided with terminals for testing: both voltage and current circuits can be connected to these terminals.

A weather-proof synthetic rubber packing is placed between the base and terminal box to maintain air-tightness.

To prevent wrong wiring connection, each terminal is plainly marked with a terminal symbol.

5) Frame

The frame is made of stamped out high quality steel sheet bent into a ⊐ shape. To give it great mechanical strength, the frame is caulked on a frame base plate, spot welded and vibration proofed to eliminate the effect of external shocks and impacts upon the drive parts of the meter interior. On this frame, the meter's principal components such as the current and voltage elements, braking magnets, upper and lower bearings and registering device, etc., are mounted closely and accurately so that there will be no deviation in their relative positions.

6) Current core (*Fig. 24*)

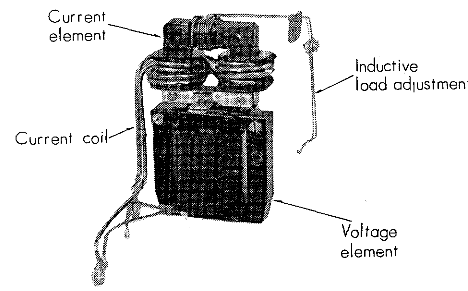


Fig. 24 Measuring element

The current core is made of laminated silicon steel plates of superior magnetic characteristic. The laminated core is given a rust-proofing treatment. It is provided with an electromagnetic shunt (described in last installment) for load characteristic compensation. A phase adjusting coil is also provided.

7) Current coil

The current coil is wound on a highly heat resisting bakelite bobbin with polyvinyl covered copper wire of excellent insulation and moisture-proofing characteristics. The values for the coil sectional area and turns are the values properly designed according to the value of the passing current.

8) Voltage core

Like the current core, the voltage core is made of laminated high quality silicon steel sheet. The voltage core is provided with a shading coil and magnetic field adjusting steel piece for temperature compensation. The shading coil is for a secondary temperature compensation: this principle was also adequately described in the last installment.

9) Voltage coil

The voltage coil is wound with enameled copper wire on a synthetic resin bobbin. To prevent wire from breaking, an especially designed terminal plate is used.

10) Rotating disc

The rotating disc is of high purity aluminum sheet for uniform quality and increased torque. The rotating disc shaft is provided with worm; the upper end of the shaft has a cap bearing with an oil chamber to decrease upper bearing friction, to increase stability and durability.

On periphery of disc, for testing by master meter method, 100 equally divided scale is provided and on side surface of periphery, 250 equally divided slits are cut for testing by storoboscopic testing method.

11) Bearings

The upper and lower bearings perform important functions, so quality and life of these bearings directly affect the life of the meter itself. Utmost care is

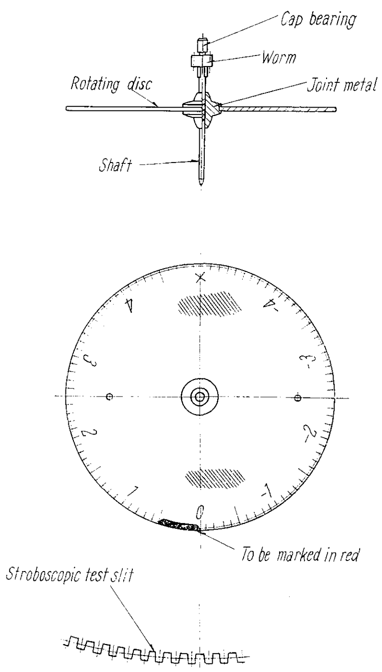


Fig. 25 Complete rotor

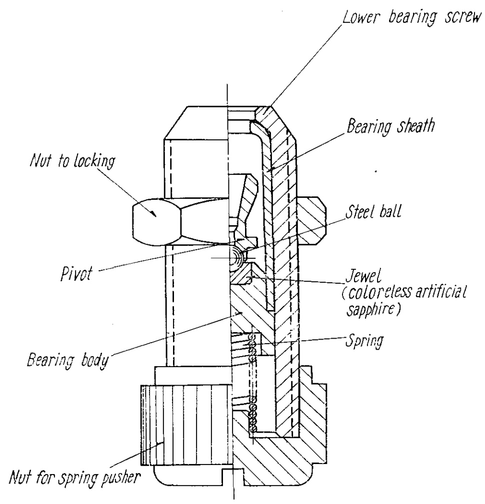


Fig. 27 Lower bearing (single jewel)

given to the design and manufacture of these bearings. The upper bearing, as shown in *Fig. 26*, is a needle bearing, with single sheath support. The thinner the steel needle the smaller the frictional moment; however, the stability against stress in a lateral direction becomes less. With Fuji single phase meters, experiments have shown that a steel wire with a diameter of approximately 0.4 mm can withstand the stress which the rotating disc gives in the radius direction. Its friction torque of 1∼3 mg-cm is stable, also.

Actually, contributing factors to the long life of this meter are this upper bearing and the good quality oil in the oil chamber of the cap bearing of the upper end of the disc.

For the lower bearing, either a single jewel bearing or double jewel bearing is generally used. A single jewel bearing (*Fig. 28*) is composed of steel balls held fixed on the rotating disc shaft which turn with the disc and a fixed bearer jewel. A double jewel bearing (*Fig. 29*) has freely moving steel balls between a bearer jewel fixed on the rotating disc shaft and an unmovable bearer jewel. Compared to the former, the double jewel bearing has smaller friction factor; but in addition to its more complicated construction, it is easily affected by tilting. Its handling generally requires great caution. An explanation of the single jewel bearing follows:

The pivot and sapphire bearer deform slightly depending on the rotating disc weight. Because of that the contacting condition becomes a circular contact. The radius of this contacting surface is given by the following formula:

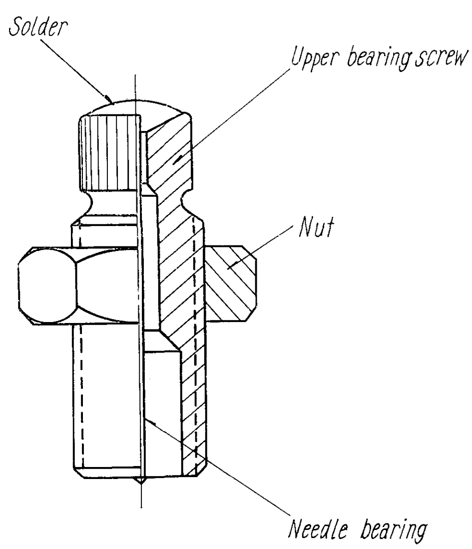


Fig. 26 Upper bearing

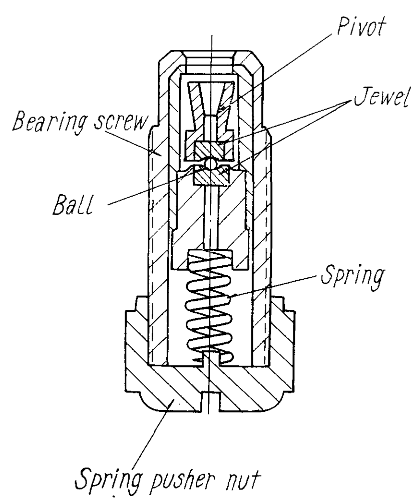


Fig. 28 Lower bearing (lower jewel)

$$a=\sqrt{0.68\,P\frac{\frac{1}{E_1}+\frac{1}{E_2}}{\frac{1}{r_1}-\frac{1}{r_2}}}$$

where a = contacting surface radius
P = rotating disc weight
E_1 = pivot elasticity E_2 = bearer elasticity
r_1 = pivot radius of curvature
r_2 = bearer radius of curvature

A special surface pressure which the material must withstand is created on the contacting surface. This surface pressure is not distributed equally over the surface but increases 1.5 times the mean suface pressure at the center. Thus, the maximum surface pressure

$$\delta_{\max}=\frac{1.5\,P}{\pi a^2}=\sqrt{0.235\,P\frac{\left(\frac{1}{r_1}-\frac{1}{r_2}\right)^2}{\left(\frac{1}{E_1}+\frac{1}{E_2}\right)^2}}$$

Fig. 29 indicates a maximum surface pressure by the rotating disc weight when $r_1=0.6$ mm and $r_2=1.2$ mm.

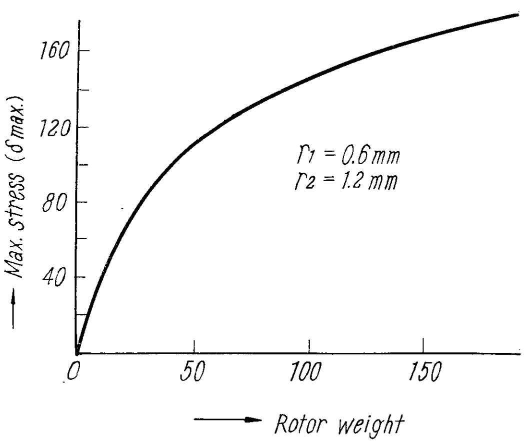


Fig. 29 Relation between max. stress and rotor weight

The friction moment of the lower bearing:

$$Mr=\frac{2}{3}\mu a p$$

where Mr = friction moment
a = contacting surface radius
μ = friction coefficient
p = rotating disc weight

if Mr is expressed with $Mr=f(\delta_{\max})$,

$$Mr=0.462\frac{1.5\,P}{\sqrt{\delta_{\max}}}$$

This formula shows when rotating disc weight is given, Mr decreases as $\delta_{\max}$ increases. When rotating disc weight is given, $\delta_{\max}$ can be varied over a wide range by changing the pivot radius r_1 and bearer radius r_2. However, it is clear that if $\delta_{\max}$ is made large, the life of the meter becomes short. *Fig. 30* shows the friction moment when the rotating disc weight is changed. *Fig. 31* shows the friction moment actually measured when a good quality watch

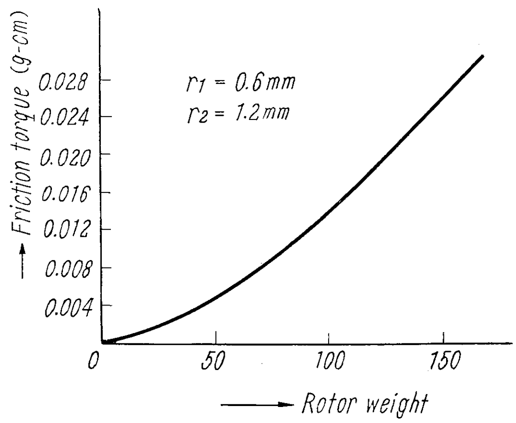


Fig. 30 Relation between friction torque and rotor weight

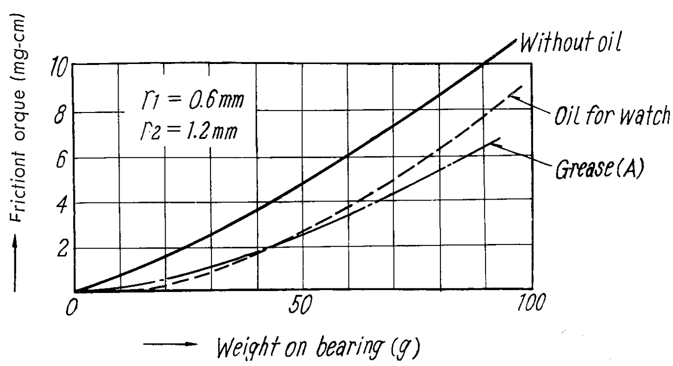


Fig. 31 Change of friction torque by lubricating oil

oil is used as the lubricant. As is clear from this, with a well polished pivot, the friction moment is not very large at first even if no lubricant is used. However, as can be seen from meters no longer used, the increase of friction of the lower bearing to 20～30 times the normal value was of course due to lack of oil and presence of dirt. Even though the pivot surface was almost entirely corroded, rust-proofing was a saving factor in retarding friction.

12) Registering mechanism (*Fig. 32*)

Previously, among the trouble of watt-hour meters, the register had been one of the most important factors and one cause of secular change. Improvement in the register has become a great factor in improved meter quality.

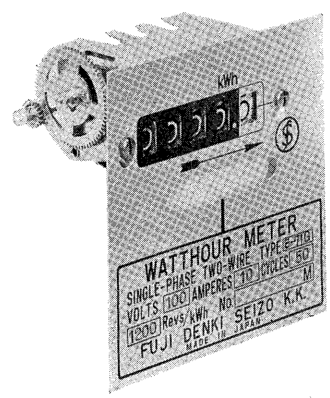


Fig. 32 Cyclometer register

Our company, in its experiments to improve the cyclometer register, was successful in the manufacture of a new number wheel out of aluminum sheet by a drawing process which was quickly put into practical application in the integrating watt-hour meter.

The special features of the aluminum sheet drawn out number wheel:

Extremely light weight (only about 1/6 of die-cast type)
Small register friction torque.
Small friction torque due to moving up.
Small error and variation at time of light load
Easy reading of the numbers because of surface printing.

Compared to the conventional die-cast type cyclometer counter, the register friction torque and the error at the time of moving up are much smaller.

Fig. 33 compares the construction of these two number wheels; their weight comparison is shown in *Table 2*. *Fig. 34* shows a comparison between each shaft friction torque and the friction torque at the time of moving up; it fully exhibits the superior advantages of the aluminum sheet drawn out number wheel.

The problem of lubricating of register bearings, like the lower bearing, requires consideration. Special care should be exercised to prevent creep vaporization of the lubricant and dust invasion.

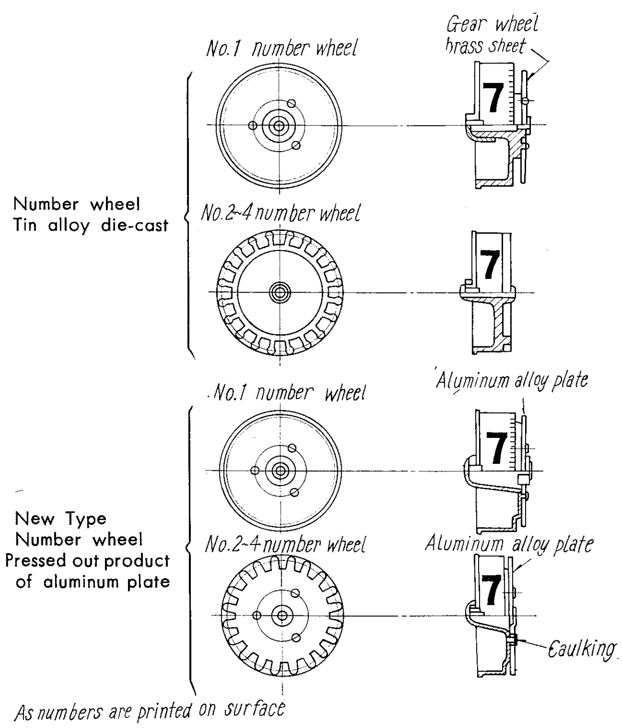


Fig. 33 Comparison of die-cast number wheel aluminum wheel

In practice, there are instances in which old registers used until expiration of official approval terms were made to operate like new registers by disassembling, washing and lubricating. The inoperation

Table 2 Weight comparison of die-cast number wheel and aluminum wheel

	No. 1 number wheel	No. 2, No. 3, No. 4 wheel (intermediate)	No. 5 wheel (left-end wheel)	Total
Die-cast wheel	6.7 g	4.8 g×3	4.7 g	25.8 g
Aluminum plate wheel	1.0 g	0.9 g×3	0.9 g	4.6 g
Comparison ratio	14.9 %	18.7%	19.1%	17.8%

of these registers was due to dust and lack of lubricant and not to any damaged bearing.

As stated above, Fuji standard register is composed of a five digit cyclometer counter and a series of gear mechanisms, all installed on a frame.

A total gear ratio is indicated on the register frame which shows the rotations required of the disc to rotate the lowest positioned number wheel in one complete revolution. Since the total gear ratio differs according to the rated value of a meter, gears of all ratios are available so that by replacing one set of

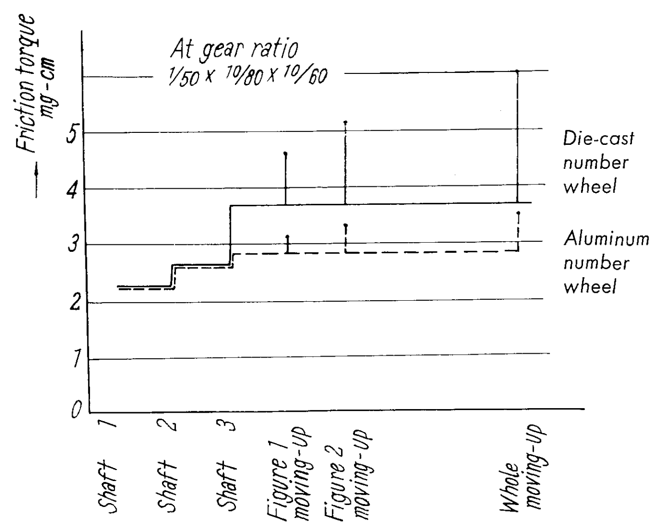


Fig. 34 Friction torque comparison curves at each shaft of die-cast number wheel and aluminum number wheel

gears in the gear row, all the rated values are matched.

13) Braking magnet (*Fig. 35*)

For the braking magnet, we used double pole MK precipitation hardening processed magnet made by diecasting with aluminum alloy. This magnet, as will be explained later, has practically no demagnetization due to heat, shocks and external clutter magnetic fields, etc. Its stabilized characteristics increase its durability greatly, remaining accurate even after many years' use.

In the following paragraghs, we will touch on the basic problems of braking magnet design. The braking torque of a braking magnet is proportional to the square of the flux of the braking magnet: when it is necessary to reduce the disc rotations to 1/2, the flux of the braking magnet can be $\sqrt{2}$ times= 1.41 times the first.

To fulfill the above, using two magnets of an equal strength is effective to bring the magnetic poles of the two magnets in proper conjunction.

In this case, however, the required magnetic flux is approximately 1.7 times that of one magnet. Of course, with a method in which two magnets are positioned at a distance, the required flux is 2 times that of one magnet. This relationship is shown in *Figs. 36* and *37*.

Thus, in order to obtain an equal braking force, with a double magnet, the material of the magnet increases by 70% ; with a single magnet, the material increases by approximately 40%. With these conditions, a meter constant equal to 1/2 of conventional meters can be obtained. However, since the double magnet requires mounting of the magnet on the frame front, the frame is required to possess a greater mechanical strength and the weight is increased because of an increase in material. In the case of a single magnet, the object is realized with a lighter magnet and consequently, the magnet and meter frame

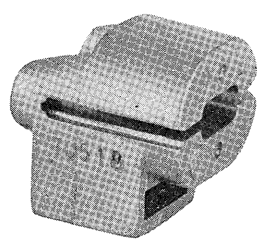


Fig. 35 Brake magnet

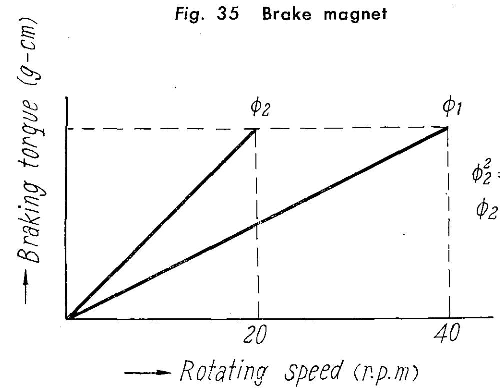


Fig. 36 Explanatory diagram for single magnet

become relatively stronger. That the double pole types of double or single magnets are the most advantageous against the vibration of the disc, etc., goes without saying. Strengthening of a braking magnet can be accomplished most effectively by making a single magnet into a double pole magnet.

For this purpose, the conventional chrome steel or low cobalt steel with low coercive force cannot be used. The use of a high quality magnet made of material with high coercive force becomes an absolute necessity.

As early as 1953 our company adopted the use of MK steel. This steel contains 20~30% of nickel and 10~15% of aluminum, its coercive force reaching as high as 400~600 oersteds.

The advantages of this MK steel when used as the braking magnet of an integrating watt-hour meter are as follows :

(1) High magnetic stability because of its high coercive force.

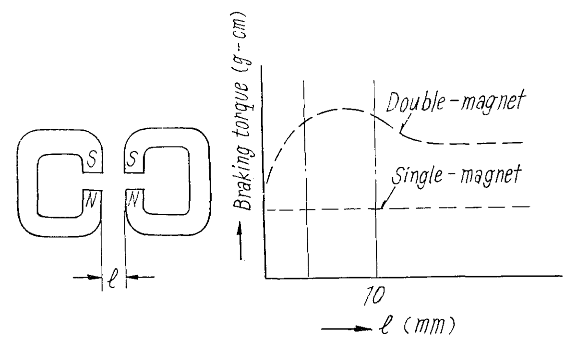


Fig. 37 Explanatory diagram for double magnet

(2) Extremely small demagnetization due to heat, vibration and impact because of large magnetic energy.

(3) Compact size and light weight decreases troubles such as magnet displacement due to frame deformation, mechanical shocks and other mechnical troubles.

A comparison curve of the magnetic lines and curve of demagnetization of different types of magnets are shown in *Figs. 38* and *39*.

From these curves it can be seen that MK steel has a coercive force approximately 4 times that of chrome steel; residual magnetism response is 0.7 times greater and magnetic energy 4 times greater. A comparison between the weight and magnetic energy of the magnets in actual use is shown in *Table 3*. From this table, it can be seen that by using a high quality steel, the size of a magnet can be decreased greatly at the same time improving its magnetic stability.

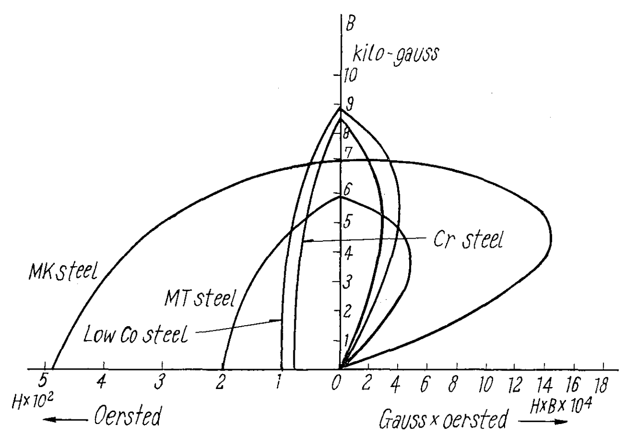


Fig. 38 Magnetic characteristics comparative curves

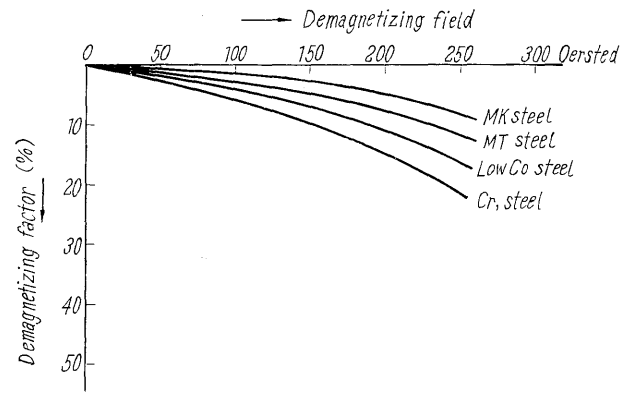


Fig. 39 Demagnetizing curves

2. Adjusting Devices

The adjusting device for each load has an individual construction, using a micrometer which is easy to adjust and yet contains small mutual interference.

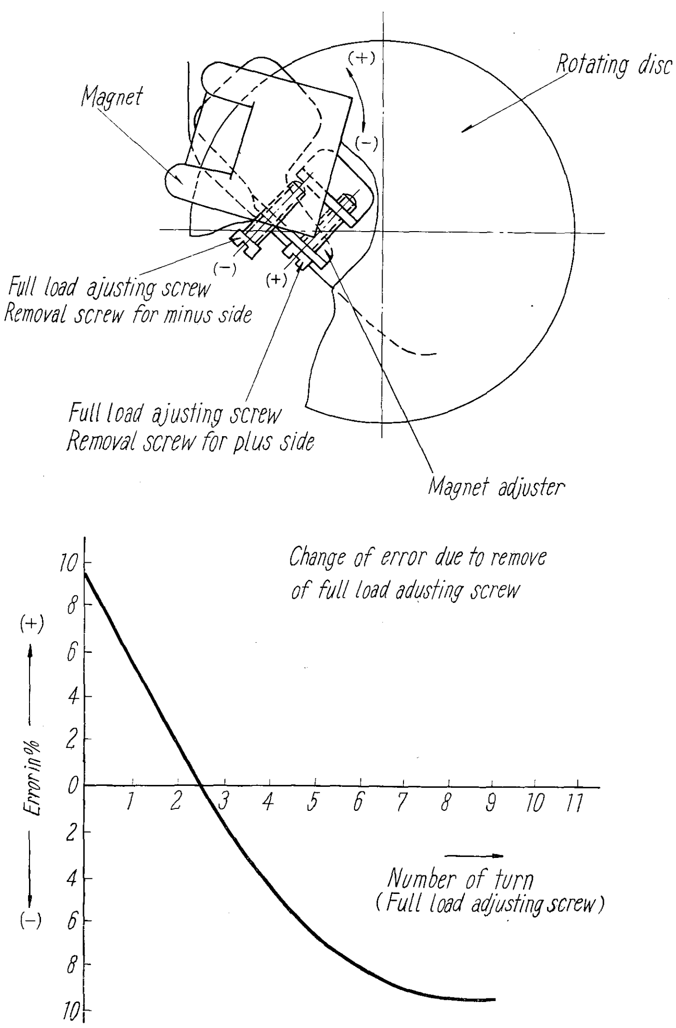


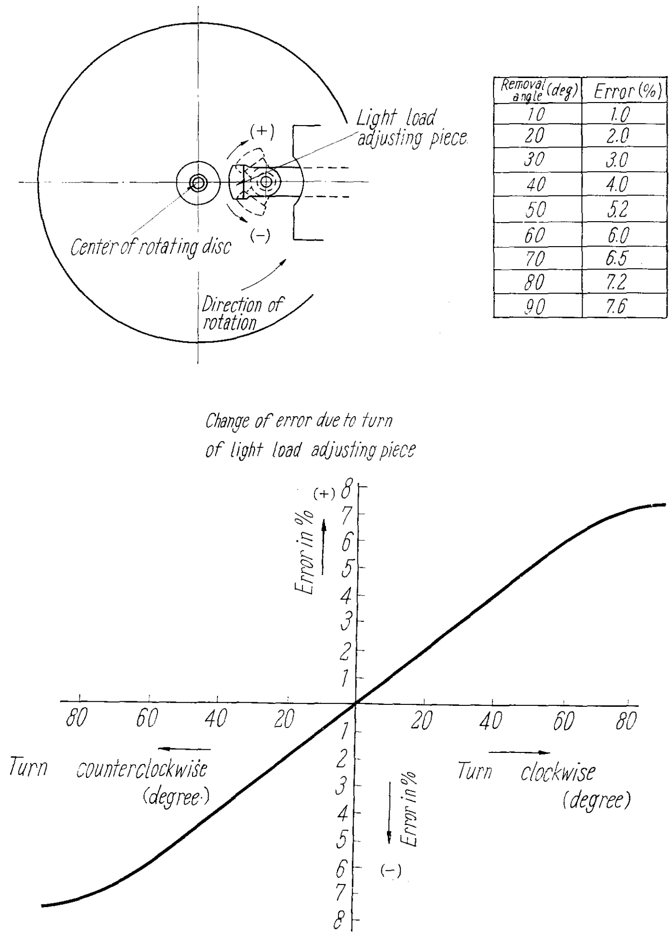
Fig. 40 Range of full load adjustment

Table 3 Comparison table of weight and magnetic energy

Magnet	Radio of weight (%)	Ratio of weight neccesary to produce same magnetic energy
MK steel	100	1
MT steel	660	6.6
Low Co steel	636	6.3
Cr steel	825	8.25

(1) Fine adjusting for heavy load is done by turning the two screws located on the lower side of the braking magnet either to the right or left. These two screws are of a mutually interlocking type; the deviation of error due to the screw rotation is shown in *Fig. 40*.

(2) Adjusting at the time of light load is done by turning the adjusting piece attached to the voltage element by means of the light load stud coupled to the adjusting piece. The deviation of error due to the stud rotation angle is as shown in *Fig. 41*.

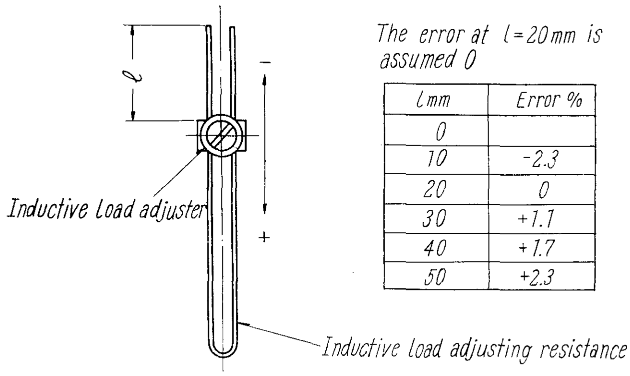


Removal angle (deg)	Error (%)
10	1.0
20	2.0
30	3.0
40	4.0
50	5.2
60	6.0
70	6.5
80	7.2
90	7.6

Fig. 41 Range of light load adjustment

(3) Phase adjusting is done by varying the resistance value of the resistor connected in series with the shorting coil located at the center of the current core by means of a shorting piece.

The deviation of error due to the movement of the shorting piece is as shown in *Fig. 42.*



The error at l=20mm is assumed 0

l mm	Error %
0	
10	-2.3
20	0
30	+1.1
40	+1.7
50	+2.3

Change of error due to removal of inductive load adjuster

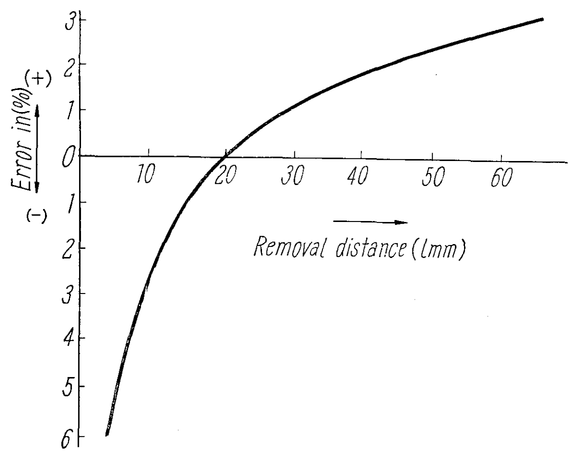


Fig. 42 Range of inductive load adjustment

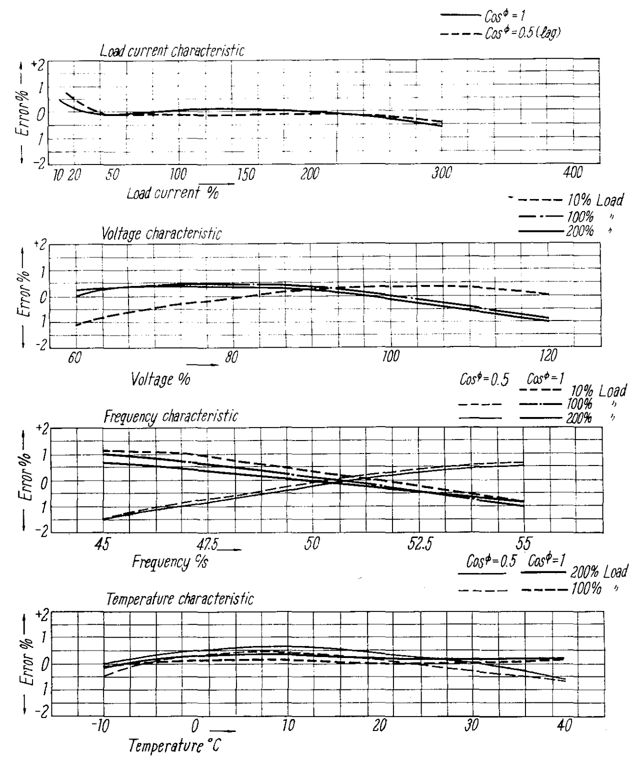


Fig. 43 Characteristics curves

3. Electrical Characteristics

The improvement of the electrical characteristics is as described in the first installment. The use of standardized materials, improvement in design and manufacturing techniques and thorough quality control have contributed greatly toward making Fuji Integrating Watt-hour Meters electrical characteristics vastly superior to any other. *Fig. 43* shows these characteristics.

The technical data of Model E-71 is given below:

(1) Starting current:
below 0.8% of rated full load.

(2) Self-consumption
- in pressure circuit: about 1×0.7∼0.9 w or 1×3.04∼3.67 va
- in main current coils 3∼10 amp. sizes: about 0.4∼0.5 w or 0.61∼0.68 va
- in main current coils 20∼30 amp. sizes: about 0.65 w or 0.7∼0.72 va
- in main current coils 50 amp sizes: about 1.25 w or 1.44 va
- in main current coils 100 amp sizes: about 2.68 w or 3.54 va
- 5 amp sizes for transformer connection: about 0.41 w or 0.61 va

(3) Average torque at rated full load
- 3∼30 amp sizes: about 3.75 g-cm
- 50∼100 amp size: about 6.25 g-cm

(4) Effect of temperature at power factor 1.0: within 0.5% for each 10°C

(5) Weight of rotor about 18.8 g

(6) Speed at rated full load
- 3∼30 amp sizes: within 20 rpm
- 50∼100 amp sizes: within 25 rpm

(7) Net weight of meter
- 3∼30 amp sizes: approx. 1.42 kg
- 50∼100 amp sizes: approx. 2.19 kg

(8) Overload capacity
- 3∼10 amp sizes: 300% continuously
- 20 amp sizes: 200% continuously
- 30∼50 amp sizes: 150% continuously
- 100 amp size: 130% continuously