SOME QUESTIONS OF INDUCTION-TYPE METERS

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Up-to-date electrical measuring instruments have to fulfil the following requirements

1. safety
2. high accuracy (low relative errors)
3. low costs of manufacturing
4. stability
5. quickness of operation
6. low internal consumption
7. insensibility against variations of internal parameters of the measurement and against overload
8. insensibility against variations of external parameters
9. beauty

From these the fifth may be neglected in the case of the meters ; and the third contradicts the rest, so a reasonable compromise is inevitable.

According to the above requirements, meters should be judged by their metering-equation. As it is generally known the driving torque $M_{i,u}$ of an induction-type meter is proportional to the electric power ($P = IU \cos \varphi$) flowing through the meter into the consumer's electric circle ; the braking torque M_b generated by the permanent magnet works in opposite direction and is proportional to the meter's Ω angular velocity and to the square of the braking flux Φ_b.

That is why the electric power flowing through it is measured by the angular velocity of the meter, whereas the electric energy flown through it during the same time by its returns made in a time-interval :

$$\int_{t_1}^{t_2} p \, dt = k \int_{t_1}^{t_2} \Omega \, dt \quad \text{and} \quad W_2 - W_1 = (\nu_2 - \nu_1) K$$

All circumstances that may cause any variation in the values of the above-mentioned torques and those exciting further torques change the measuring equation of the meter, i. e. its constant which had been found correct.

The said measuring equation may be deduced in different ways without, however, ignoring some simplifying assumptions. It does not seem to be correct to use analogies of a rotating magnetic field (there is no magnetic flux rotating around the axis of the meter's disc) so in the case of a meter we had better discard such expressions as "number of poles" or "synchronous angular velocity".

The driving elements of a meter are the current coil and magnet and the voltage coil and magnet, on the one hand, and the rotating disc, on the other. These magnets are independently excited but their fluxes develop in each other's immediate neighbourhood, in narrow intimacy. Each of them excited alone develops a flux passing through the disc with lines, in general, perpendicular to the disc, varying with the frequency of the net inducing eddy currents of the same frequency (Figs. 1 and 2).

The orbit and strength of the eddy currents are subject to continuous changes and so is the resultant, penetrating the disc, of the flux derived from the two fluxes excited in the two magnet-cores.

The resulting magnetic flux together with the eddy currents generates a force which acts in the plane of the disc (though may from time to time act even outside of it). With varying direction and value this force makes a fan-like (oscillatory) movement in the disc:

$$F = f(t)$$

is a periodical function of time, its frequency being the double of that of the supplying voltage. Because of the inertia of the disc, the average resultant of the force should be calculated for one period of the voltage. If it is zero or if it passes through the axis of the disc, the medium driving torque is zero, in all other cases there exists a — positiv or negativ — driving torque. Even "shaking forces" leaving the plane of the disc are likely to act.

An alternating magnetic flux generates zero medium-torque with the eddy currents induced if the average orbits of the eddy currents are symmetrical to the straight line connecting the average centre of the flux with the centre of the disc. By disturbing this symmetry a driving torque can be generated; this is the task of the cooperation of current coil and voltage coil (the simplest example: compensation of friction by the aid of a small asymmetry in the air gape of the voltage magnet).

In the first years of development, the safety of continous operation was the only requirement that could be fulfilled. The first specimens (Fig. 3a, 3b) had an error limit of $\pm 5\%$ in case the intensity of the current was between 10% and 120% of the basic current and the power factor cos φ not less than 0,5. Their weight was surprisingly great (12 to 14 kgs). Bláthy, of course, was aware of the principles governing the operation of the meter, but when manufacturing was started there was no possibility of taking into account all the parameters of the measurement.

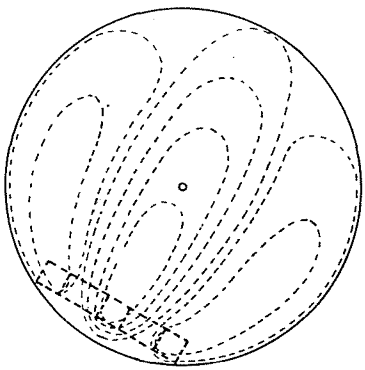

Fig. 1. Eddy currents induced by the voltage coil alone

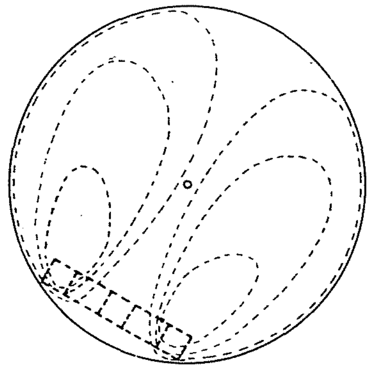

Fig. 2. Eddy currents induced by the current coil alone

The first attempt was aimed at decreasing the error-limits; having recognised the influence of friction Bláthy wished to decrease weight and angular velocity of the rotating system. Soon he solved the first problem but as to the angular velocity he could not find the necessary braking magnet, so there was a delay in the solution. A further step was the compensation of friction (by the mentioned small asymmetry) and together with it the reliable elimination of rotation at no load (braking filament).

The power of the driving eddy currents has a braking effect. This recognition led to further development: special forming (magnetically shunting) applied in the core of the current coil compensates the braking effect of the eddy currents induced by the flux of the current coil.

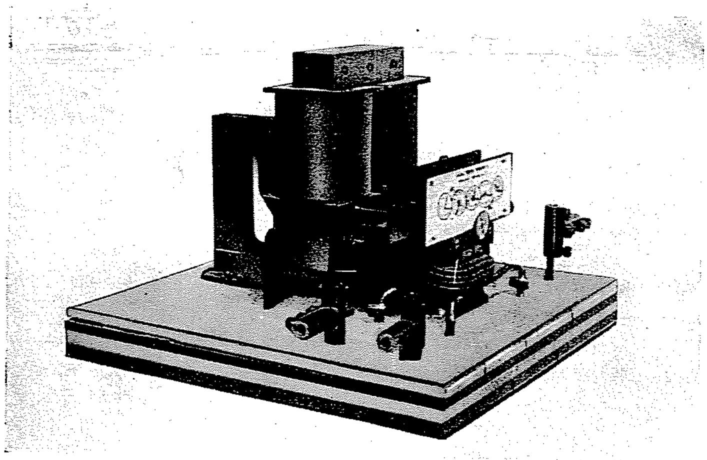

Fig. 3a. Bláthy's first induction-type meter, left: braking magnet, centre: voltage coil, right: current coil

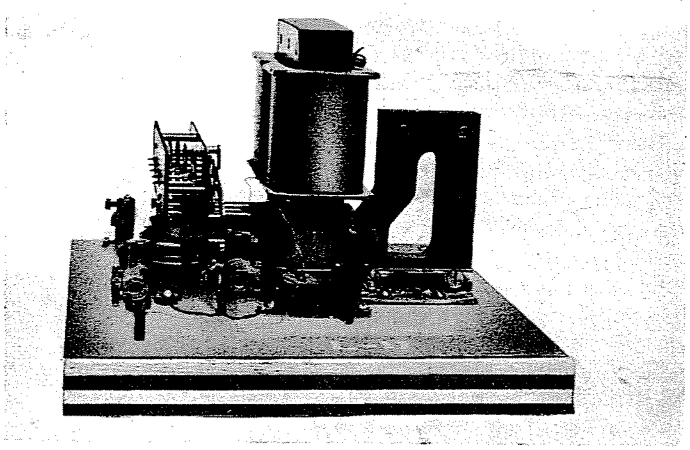

Fig. 3b. Bláthy's first induction-type meter, left: current coil, centre: voltage coil, right: braking magnet

Attention was soon turned to the internal and external parameters of the measurement: variations of voltage frequency and ambient temperature influence in different ways the working of the meter. Clear knowledge of the principles governing the operation of the meter has been gained thanks to the diligent work of many investigators — with prominent cooperation of Rogowsky and his collaborators. Based on the vector-diagramm of the meter (Fig. 4) they deduced the equation of its driving torque, calculating with component fluxes (flux Φ_u and Φ_i of voltage coil and current coil resp.) and with component eddy currents (j_u and j_i). So the instantaneous value of the tangential force being

$$F_{i,u} = c_i \Phi_i j_u + c_u \Phi_u j_i = c_i \Phi_i c_u' f \Phi u + + c_u \Phi_u c_i' f \Phi_i,$$

Rogowsky has shown that, in the above equation,

$$c_i' = c_i \quad \text{and} \quad c_u' = c_u$$

and therefore the instantaneous value of the torque is

$$M_{i,u} = c_1 \Phi_i \Phi_u f = c_2\, i\, u$$

and the medium value with rms. voltage and current

$$M = K\, I U \sin \psi$$

where ψ is the phase-angle of the two fluxes. If by the aid of construction this angle and the phase angle φ of the load can be made complementary, i. e., $\varphi + \psi = 90°$, the medium torque is

$$M = K\, I U \cos \varphi$$

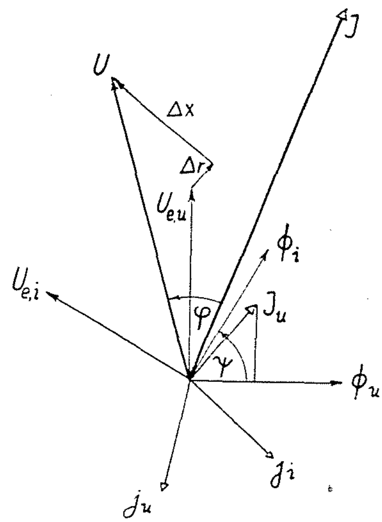

Fig. 4. Vector-diagramm of an induction-type meter

This deduction is shorter than to observe the eddy currents and the force connected with them, but, taking into account tangential forces only, fails to remind us that the forces may leave the disc, periodically causing undesirable "shaking" effects.

The influence of the variation of voltage, frequency and power factor and the changes in the temperature can be read from the vector-diagramm of the meter.

The influence of the variation of voltage and frequency is clearly shown in the transformer equation: the induced voltage U_e is

$$U_e = 4\, k_f f N B_m A$$

where only U_e f and B_m (voltage, frequency and maximum induction) are variable; the first two being parameters of the load's circle, their variation causes a variation of the flux density B. This, in turn, changes strength and phase angle of the exciting current I_u; this again, alters the flux Φ_u in the voltage coil and its phase angle to the load's current I. The error so caused is expected to be considerable if the power factor cos φ is small.

Thus the influence of the changes in temperature can be traced. The resistance of the disc might vary nearly without any further result since it alters driving and braking torque — even the braking losses of the driving eddy currents at the same ratio. Altering of temperature and resistance of the voltage coil will have a considerable effect upon the internal phase angle of the meter (upon the one between voltage flux and current flux). Alteration of the internal temperature of the meter involves changes in the parameters of ferromagnetic materials too (in first line the flux of the brake magnet which will decrease with rising temperature and so will the braking torque, by the square). The latter change might be compensated by applying a magnetic shunt of proper qualities at the poles of the brake magnet.

Such requirements as durability and stability of the meter have set new and difficult tasks to construction and manufacture. Competition in reducing costs caused further difficulties. The problem became a pure technological one. All artifices of mass production were applied, new and better materials used in searching for best solution.

The distribution of electrical energy all over the whole earth has brought forth two further requirements: transportability of the meters and their resistance to aggressive climates. Correct working in overloads is the third, raised by the average consumer.

Transportability determines the mechanical properties of the meter: resistance against acceleration, shaking and shocks within reasonable limits without any deformation, tear and wear or breaking of the moving parts. The solution is a mere technological one by utilizing the best construction materials (pivots, gears, shaft etc). The dynamically correct construction of the moving parts is of no less importance (possibly small masses and inertiae); and at last the properly solid and stiff internal holding construction and a strong and stiff case are equally important.

Resistance to aggressive climate and other harmful effects (dust, insects, fungi, bacteria etc.) may be also obtained by technological procedures. General interest is focused now on this question but experiments and experience are insufficient as yet to form definite opinion as to the methods to be applied in construction and manufacturing. The use of extraordinarily resistant basic materials, protecting and covering materials, excellent fillings is inevitable. It is also obvious that a meter cannot preserve its correct measuring abilities unless its insulation, its mechanical and electromagnetical properties remain unaltered.

A meter has to bear overloads thermically and mechanically, without its measuring abilities decreasing under a given (narrow) limit. Overload can be caused by increasing voltage and current. Only a small rise of voltage is permitted (e. g. 10 per cent above nominal). In everyday practice overload is a current increase above the nominal (basic) value; so we speak of meters "built for fourfold load" (for $I = 4\,I_b$).

The thermical effect of an overload ascertains itself first in the temperature rise of the overloaded coils. Its influence upon the voltage coil has partly been discussed. However, the rise of voltage is connected with an increase of the field density and of the exciting current and so with a further change of the internal phase angle of the meter. — The alteration of the resistance of the current coil has no consequence in the phase position of the (forced-on) current, though owing to the increase of field-density, the magnetical shunting in the core of the current coil (at high overloads) might change in an undesirable direction. This circumstance may be corrected e. g. if the magnetic shunt of the current-core is made of two different iron-materials (one saturated at lower densities and the other at high ones only).

The overloadability of the meter can be increased by diminishing the local temperature-rise of the coils, provided the thermical transductivity of the case does not simultaneously change. This can be achieved e. g. by doubling the driving system (by a diametral action of a couple of forces, without friction. At present this leads to an expensive solution because of the friction of the gearing but it will obviously be practicable as soon as the mass-production of precision gears at moderate costs will be solved.

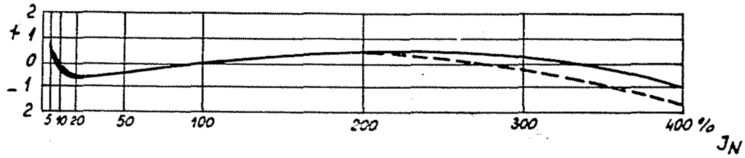

Fig. 5a. Diagramm of the relativ errors of an overloadable meter

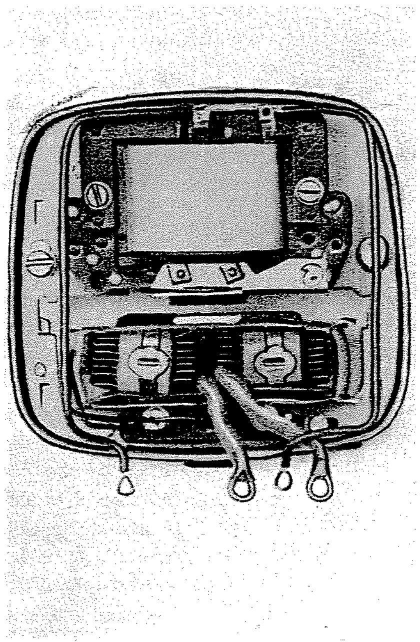

Fig. 5b. Up-to-date overloadable meter

an increase of the torque) increasing thereby the cooling surfaces.

The simultaneous decrease of the internal dimensions may also be taken into consideration (i. e. decreasing the driving forces without diminishing the braking ones) if, we succeed in proportionally decreasing

This solution must ensure the curve of relative errors to remain within the limits recommended by the I. E. C. as shown in the curve of errors (Fig. 5a) of a meter made in Hungary. The considerations exposed above may lead to more simple constructions at moderate costs.