The calibration constants of an elctromechanical watthour meter

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ABSTRACT

The classical analog AC watthour meter involves a special type of AC motor with an aluminum disk rotor. Its rotational speed is proportional to the amount of power flowing through the meter. The revolutions of the disk are totted up by an elaborate set of gears driving a number of decimal dials, the overall indication of which represents the net number of kilowatthours passing through the meter since its birth.

The relationship between revolutions of the disk and the energy flow that represents is described by two numerical “calibration constants”, Rr and Kh, which are almost always stated on the meter nameplate. They usually have what seem to be very curious values. Those two constants are directly related.

If we know how to interpret those, we can determine the power now being consumed by timing the rotation of the disk with a stopwatch.

This article describes the meaning of those two constants and their relationship.

1 THAT PESKY HYPHEN

The reader may note that I spell the energy units “watthour” and “kilowatthour” without a hyphen. Often we see them written as “watt-hour” and “kilowatt-hour”, which is fine. Or sometimes as “kilowatt hour” and “watt hour”.

As the watthour is not a formal SI unit of energy, it follows that there is not really an “official” spelling (although many technical publications prescribe one for their authors).

2 THE CLASSICAL ELECTROMECHANICAL AC WATTHOUR METER

2.1 Introduction

The classical electromechanical AC watthour meter is familiar to most of us. Most of us have (or have had) one on the side of our house or one for us among a bank of them on the side of our apartment house (although often today they may well have been replace by digital, electronic watthour meters). Figure 1 shows a popular type.

Figure 1. GE watthour meter

2.2 The motor

This type of watthour meters is based on a special type of AC induction motor. One set of field windings is energized by the current through the meter (these have a very low resistance). A second set is energized by the voltage across the line (these have a high resistance). The rotor of this motor is a thin aluminum disk (we see it edge-on just below the marking "KILOWATTHOURS").

The structure is such that the torque on the disk is proportional to the product of the RMS current through the current windings, the RMS voltage on the voltage windings, and the cosine of the phase angle between the current and voltage waves. This product is of course the average power passing through the meter.

The disk is also in the gap of a powerful permanent magnet. If the disk turns, a voltage is induced in it from its motion through the magnetic field of that magnet. The voltage causes a current in the disk. That current causes a magnetic field to be generated in the disk. Its direction is such that its interaction with the stationary magnetic field exhibits a torque on the disk counter to its direction of motion and proportional to its rotational speed.

The interaction of (a) the "forward" torque on the disk proportional to the power flow through the meter and (b) the "counter" torque proportional to the rotational speed of the disk makes the disk stabilize in dynamic equilibrium at a rotational speed proportional to the power through the meter.

It then follows that the total amount of rotation of the disk over some time period is proportional to the total electrical energy passing through the meter during that period.

Now all we have to do is to provide for some type of display of the total rotation of the disk and arrange all the innards so that display will read in kilowatthours.

2.3 The register

That is the job of the module called the *register*. The most common type is as we see at the top of figure 1, although sometimes a register is used that looks like an auto odometer.

The register is driven through a fairly complicated and somewhat delicate gear train from the disk shaft. We see a typical one, in somewhat schematic form, in Figure 2.

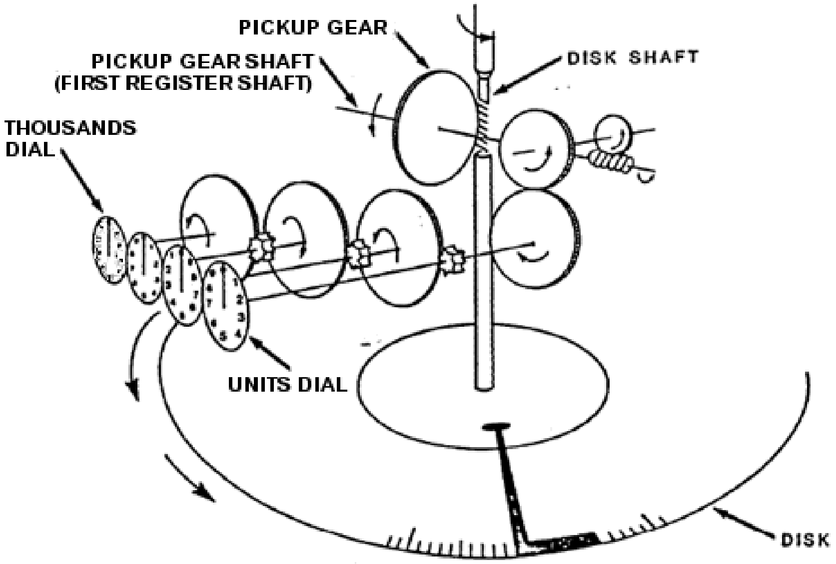

Figure 2. Register gearing

Unlike the “drums” in an odometer, here the successive dials are just simply geared together with a 10:1 ratio in each stage. That brings about these two “curiosities”:

- Alternate dials turn in alternating directions (as we can see from the direction of increase of the number value labels on the various dials in Figure 1).
- If, for example, the “units” dial is at 5, then on the “tens” dial, the pointer will not be on a number but halfway between two numbers. If the last two digits of the present “reading” of the register are 29, the “units” dial pointer will point to 9, and the “tens” dial pointer will be very near the “3” (just a little on the “2” side).

These facts of course make reading the register a little tricky, but if one has to do that regularly, it soon becomes second nature.

I will talk shortly about the various gear ratios involved.

3 THE CONSTANTS

3.1 Introduction

Of interest for several reasons is the matter of how much energy is represented by one revolution of the disk shaft. Three reasons that is of interest are:

- As an electric energy consumer, we might want to know, for example, at a certain time of day, how much power is being consumed by our dwelling unit. For the description above, we realize that we could ascertain that by timing the rotation of the meter disk with a stopwatch (and in fact normally the disk has a nice black blob at one point on its periphery for use in just such a project. But we of course need to know the relationship between disk rotation and energy though the meter.

- At a calibration facility (perhaps in the power utility’s “meter shop”), we may verify the calibration of a meter by connecting it to a setup that applies a standard load and seeing how rapidly it ticks off the watt hours. Of course, we can’t take the time to do this by waiting until the register advances some substantial amount, so we must do it by timing the disk (just as in the process above).

- In a typical “line” of watthour meters, the same “motor” assembly might be used in model variants with different kinds of registers. The relationship between disk rotation and register indication must be consistent between modules being coupled to form a complete meter.

3.2 Notation

Because several of the factors involved in the equations below have two characters (not one and a subscript), if the usual convention for multiplication were followed (the factors just shown one after the other) there might be some confusion. To avoid that, in all cases I will use the centered dot to indicate multiplication.

3.3 The two constants

3.3.1 *Introduction*

Describing the relationship between the rotation of the rotor disk and the amount of energy recorded for a given mete is the role of two meter calibration constants, Kh and Rr. We see both of those stated on the nameplate(s) of the meter in figure 1.

3.3.2 *Some interesting facts*

I call attention to some interesting facts about these constants:

a. The values seen on that meter (Kh=7.2, Rr=13-8/9, a common set for residential meters) seem a bit curious (especially the latter).

b. The product of the two constants is exactly 100, and this is true for most (but not all) watthour meters encountered in a residential application setting.

As to (a), this comes about for historical reasons that are beyond the scope of this article.

As to (b), this comes about from the relationship between the two constants, although the product might be different depending on the value of another constant (important not so often mentioned). This will be further discussed at length shortly.

3.3.3 *Kh*

The constant Kh has the simplest definition. It is the number of watthours corresponding to one revolution of the disk. We can write that as an equation thus:

$$e_d = Kh \bullet N_d \qquad (1)$$

where e_d is the energy, in watthours (I use lower case *e* when the unit is the watthour), indicated by N_d revolutions of the disk.

And that is all we need to know if we want to determine the power consumption at a particular time by timing the rotation of the disk. The relationship is:

$$P = \frac{3600\ Kh}{t} \qquad (2)$$

where *P* is the power through the meter, in watts (W), and *t* is the time for the disk to make one revolution, in seconds. The factor 3600 (the number of seconds in an hour) comes into play since *t* is in terms of seconds and *Kh* is in terms of watthours.

3.3.4 *Rr*

Constant Rr (the register ratio) is the number of revolutions of the first gear on the register assembly, turned by a worm on the disk shaft, (often called the “pickup” gear”) needed to cause one revolution of the “units” dial pointer of the register (see Figure 2). Note that one revolution of the units dial pointer represents the indication of 10 kilowatthours of energy.

Because that gear is part of the register assembly, then if this constant is to be a property of the register assembly, the ratio must start there (rather than, for example, with the disk shaft).

We can write that thus:

$$N_u = \frac{N_p}{Rr} \qquad (3)$$

where N_u is the number of revolutions of the units pointer resulting from N_p revolutions of the pickup gear.

3.3.5 *The relationship between Kh and Rr*

If we want to determine the relationship between Kh and Rr, we must recognize that there is another gear ratio involved in the train: the number of revolutions of the disk shaft to produce one revolution of the pickup gear. This ratio is often called the *shaft reduction*, Rs.[1] We can write that thus:

$$N_p = \frac{N_d}{Rs} \qquad (4)$$

where N_p is the number of revolutions of the pickup gear from N_d revolutions of the disk shaft.

We can combine to give:

$$N_u = \frac{N_d}{Rs \bullet Rr} \qquad (5)$$

Substituting for N_r we get:

$$N_u = \frac{e_d}{Rs \bullet Rr \bullet Kh} \qquad (6)$$

where N_u is the number of revolutions of the units pointer for e_d watthours of energy through the meter.

But one revolution of the units pointer indicates 10 kilowatthours, or:

$$E_u = 10 \bullet N_u \qquad (7)$$

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[1] Note that in most watthour meters, especially of the class seen in residential service, Rs is 100. I will assume that later. However, there are watthour meters of this general type in which Rs is 50. And sadly, Rs is almost never stated on the meter nameplate.

so:

$$E_u = \frac{10 \bullet e_d}{Rs \bullet Rr \bullet Kh} \qquad (8)$$

where E_u is the indicated energy for the units dial, in kilowatthours, for e_d watt hours recognized by the disk (that is, passing through the meter).

Which we can write as:

$$E_u = \frac{10{,}000 \bullet e_d}{Rs \bullet Rr \bullet Kh} \qquad (9)$$

But we expect that the amount of energy indicated will be identical to the amount of energy passing through the meter; that is:

$$E_u = e_d \qquad (10)$$

and so, substituting for e_d and rearranging, we get:

$$Kh \bullet Rr = \frac{10{,}000}{Rs} \qquad (11)$$

But I noted that in most of the meters that we encounter, Rs=100. If so, substituting for Rs, we get:

$$Kh \bullet Rr = \frac{10{,}000}{100} \qquad (12)$$

which we can of course simplify to

$$Kh \bullet Rr = 100 \qquad (13)$$

which was just as we had observed.

4 LOCATION OF THE CONSTANTS ON THE NAMEPLATES

If we look at various meters, from different manufacturers, we would often find that Rr is on the upper part of the nameplate and Kh on the lower part, rather than both being in a set of values listed nearby on the nameplate.

We note that (as for example on the meter shown in figure 1) the nameplate might well be in two pieces, the lower piece on the "motor" and the upper piece on the register. In any case, the value of Kh is a property of the motor part of the meter, and the value of Rr is a property of the register part. So it is natural that each might be put on the part of the nameplate that corresponds to (or in some cases is actually a part of) the pertinent portion of the meter.

5 DISK SPEED IN RPM

Sometimes the power flow through the meter is described as related to the disk speed in RPM. To see how that works, we start with this equation, which works on the time (in seconds) for one revolution of the disk:

$$P = \frac{3600\,Kh}{t} \qquad (14)$$

where P is the power through the meter, in watts (W), and t is the time for the disk to make one revolution, in seconds.

But the rotational speed of the disk in RPM, S, is given by:

$$S = \frac{60}{t} \qquad (15)$$

So substituting, we find that:

$$P = 60 \bullet Kh \bullet S \qquad (16)$$

6 IN DIGITAL WATTHOUR METERS

The announced scope of this article is analog (electromechanical) watthour meters. And indeed the constants spoken of here, Kh and Rr, really only pertain to such meters.

Yet on the modern digital, electronic meters (with a digital readout), we often see a value of Kh stated. What can that mean? There is no turning disk for which we would like to know how much energy is represented by one revolution.

But in fact many digital, electronic watthour meters have a visual proxy for the disk, typically a set of marching dots or the like on the display panel. (One manufacturer of such meters calls this the “annunciator”.)

One “step” of the marching dots corresponds to a certain amount of energy having passed through the meter, And now our familiar friend, the calibration constant Kh, appears on the nameplate, now telling us how many watthours one step of the marching dots represents.

In many digital wattmeters of the class used for residential service, Kh = 1; one step of the marching dots represents one watthour of energy.

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