SOME FUNDAMENTALS OF ELECTRIC METERS.

BY CARYL D. HASKINS.

In preparing for presentation to the INSTITUTE my third paper on the general subject of recording meters, I have found it somewhat difficult to sift out from the vast mass of details a very few of the most vital considerations in construction and operation, which seem chiefly to merit consideration and discussion at your hands. It is the mass of individually trivial details which to-day constitute the chief field of study and investigation in electric metering.

The broader and more basic characteristics of the art have been widely discussed long since. Like the whole field of electrical engineering, recording meter design has progressed rapidly. A very few years ago our attention was given to such general issues as how to make a meter that would register on a dial, or how to make a meter that would not necessitate the winding of a clock, or how to make a meter that would record with tolerable accuracy through a range somewhat better than 4 to 1. To-day the art has reduced itself to what might be termed "A microscopic study of trivialities" purposed to gain such improvements as a few years since would have been regarded as academic; as, for example, better behavior on variations of wave form, an increase of 1% or less in average accuracy on loads of from 1% to 5% of the meter's rating, the maintenance of straight line accuracy on loads having power factors substantially unheard of commercially a few years ago, and the like.

This last consideration, that of accuracy on inductive loads, is one of the greatest importance, and has probably not received as much attention at the hands of meter engineers as it merits. I have not chosen to deal with it to-day, because it has been my desire in preparing this paper to lay a very few essentials before you in a thoroughly analytical manner.

To properly deal with meter accuracy under inductive loads, a paper should be devoted to this subject alone, and the subject would necessarily confine one to the consideration of alternating current meters only, a limitation which I by no means wish to accept.

Accuracy on inductive loads is unquestionably an absolute essential for all meters destined for use on alternating circuits carrying any other loads than incandescent lamps, but the elaboration of this topic before you to-day belongs more properly to my colleagues than to me.

I have chosen for my theme perhaps the most important of the considerations which are to-day engrossing the attention of meter engineers—namely, the relation between torque, friction, aging of various kinds and local surroundings. These four factors constitute the chief governing conditions in connection with meter accuracy, on loads of less than 20% of the meter's average rating. These considerations are, of course, confined to the typical motor meter. We have, however, long since come to regard the motor type of meter as the only electrical integrating device capable of being manufactured at a cost rendering it a commercial possibility, whilst retaining the degrees of reliability, convenience and accuracy demanded by the American market. It may indeed be fairly said that the considerations I have selected are the dominant ones in the American meter art. Substantially all of the motor meters known to the American market have a straight line law within their limitations, if friction be eliminated from consideration.

The limitations are, I admit, somewhat severe, but I am probably entirely safe in saying that the electricity meter, as the American purchaser receives it, is subject to a straight line law on non-inductive loads of the frequency, wave form and potential for which it has been calibrated.

Unfortunately friction cannot be eliminated, but its effect on accuracy may be minimized to a remarkable degree.

There is relatively little difficulty in producing a recording meter in which the effect of friction on accuracy is negligible,

even to a degree which may defy detection, at the time the meter issues from the laboratory. But friction causes are manifold and elusive, and I doubt if I overstate the mechanical situation when I say that a meter having the least evidence of friction in its initial condition may, at the end of a period of use, show more error due to friction and consequent light load error than other meters which had much more initial friction.

This is the abstract problem which lies before the engineer, and it has been met by numerous alternatives, all more or less effective.

Taking the next step in the analysis of the situation, we note that the motor element of a recording meter does two kinds of work: First, the driving of a dynamo in the form of a foucault current disk, or the equivalent—which is the work contemplated in the meter's theoretic law. The ratio of this work does not vary, provided the permanent magnets are literally permanent, except under physical conditions which can easily be provided for and guarded against. Second, friction work not contemplated in the theoretic law, and therefore tending to distort the accuracy curve.

Friction is relatively unobjectionable so long as it remains a constant value, for as a constant value it can be readily compensated. The meter having X friction can scarcely be regarded as better than the meter having $10X$ friction, provided these values do not change with time or load, a condition which we cannot unfortunately find in practice.

In seeking the alternative remedies for this condition three courses of study present themselves to us: The minimizing of friction as an individual study, means for increasing friction compensation with increase of friction, and finally, the radical increase of foucault current load in relation to possible friction load.

The two latter alternatives have always presented themselves to me as the most promising.

The dissipation of a relatively very large amount of energy in the foucault current disk renders wide variations of friction substantially negligible. In other words, if we can make the work contemplated in the law of the meter a large value, then the variations of work not contemplated in the law become insignificant in relation to the whole work. This means that we must dissipate in the foucault current disk the largest possible

amount of energy consistent with economy. This statement, translated into practical terms, means permanent magnets of the greatest possible strength and a foucault current disk of the greatest possible conductivity consistent with the physical limitations.

The whole essence of success in a motor meter necessarily lies in literally permanent magnets. Since it is vastly easier to make a weak permanent magnet than a strong one, the temptation to get along without the dissipation of a maximum amount of energy in the disk is very great.

If one could make only very weak damping magnets, and therefore dissipate in the foucault disk a very small amount of energy, it would naturally become necessary to get initial friction very low to secure initial accuracy, and in doing this there is always grave danger of sacrificing a permanent minimum of friction to a temporary minimum of friction.

At this point the meter engineer must, if he is to follow the right path, become a physicist, a metallurgist, and, in some measure, a chemist; for he must make a deep and consistent study of strong permanent magnets, which involves a careful investigation of the chemical and physical properties of steel, and of the best means for introducing the initial magnetism, and of reducing this initial magnetism to the largest permanent residue that the magnet can be relied upon to retain. The shaping of the permanent magnets is also of the very greatest importance. How important you probably realize, for this subject has already been carefully dealt with in a most able essay by Dr. Kennelly.

Certain recording meters use a copper foucault disk in place of the more common aluminium disk. With a copper disk of a given thickness, moving at a given speed, more work can be expended in the generation of foucault currents with a magnet of given strength than with any other metal commercially possible. To substitute an aluminium disk having the same peripheral speed and the same thickness, means either to decrease the total work in the disk or to increase the strength of the permanent magnets. The latter is a desirable alternative which can possibly be achieved. The former is a highly undesirable alternative, for reasons which I have stated.

On the other hand, to substitute an aluminium disk of the same conductivity and purposed to rotate at the same speed as

the copper disk, it is necessary to increase the thickness of the disk. This means that the jaws of the magnets must be further separated, if the clearances have already been reduced to a minimum. This, in its turn, means less density in the permanent magnets and less drag or load.

I have mentioned these tributary considerations to show the conditions which surround the work of the engineer whose purpose is to design a meter which shall expend a maximum proportion of total work in the foucault disk, and to show the chief danger in this direction of effort—namely, that of resorting to a magnet which may not be permanent.

Having achieved a meter mechanism in which the work expended in rotating the foucault disk is relatively high, and having constructed a mechanism in which the *changes* of friction are a minimum, rather than a mechanism in which *initial* friction is a minimum, it is next necessary to provide means for immediately offsetting external conditions, which exert a modifying effect upon the friction value.

In the earlier days of meter operation it was regarded as desirable to reduce friction periodically to as nearly its initial value as possible by cleaning and the like.

It may be regarded as an axiom that friction will increase with use. This increase may be large or small in relation to the whole friction dependent upon design, and it may be large or small in relation to the total work of the meter, dependent largely upon the amount of work expended in the foucault disk.

All friction, however, as well as friction increases, is tributary to and governed by the conditions surrounding installation, and the chief of these external influences is vibration, though the literal results of time, consequent corrosion, etc., as well as changes of temperature, play their part.

The effect of vibration on the work value of friction is great, for perfectly obvious physical reasons, and this effect of vibration on friction becomes more prominent as the friction value increases in relation to total work.

It is, therefore, not sufficient that friction should be neutralized by compensation at an average point of calibration. It is important that ready means for variation of friction compensation should be provided, which can be instantly adjusted to meet the actual conditions surrounding the meter at its point of use. Such means for local adjustment have been provided in numerous

forms, and are, I venture to think, highly necessary to the ideal electric meter.

Granting that the variations of friction load due to local surroundings can be accurately and quickly compensated by adjustment of the strength of friction compensation, every meter can be made substantially perfect for the point where it is actually to be used, without in any way affecting its total calibration.

It is well established that such friction increases as occur—due to use and surroundings—occur relatively early in the meter's life, the whole tendency being for the friction load to reach a substantially permanent condition after a comparatively brief period of service.

Instead of restoring the meter to its initial condition periodically by cleaning and the like, it becomes possible, where an adjustable compensation is available, to recompensate at the appropriate time for the permanent friction load, and thus restore the meter to a stable condition of equilibrium.

I have now laid before you the considerations which have led me to the conclusion that the two essentials meriting the most careful study in meter design are :

First, the expenditure of the maximum permissible amount of work in the foucault disk ; and

Second, the provision of the best means for instantly compensating for friction variation at the point of use, without affecting total calibration.