INDUCTION MOTOR LOAD LOSSES

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The question of load losses on induction motors frequently comes up when the various methods of testing are discussed.

It is usually more desirable to measure the losses and thus obtain indirectly the efficiency, than to obtain it from a direct input and output test, because a variation of two or three per cent in the losses will affect the efficiency results only slightly, while on direct measurement the error would be large.

Commercial circuits are, as a rule, more or less unsteady, both voltage and frequency changing, dependent upon the load; as both efficiency and power factor largely depend on the constancy of conditions, it is desirable to eliminate methods which require laboratory conditions to insure accuracy.

On large machines it is almost impossible to take direct measurements, on account of limited power. Therefore, some method of determining the efficiency by losses is imperative.

The losses usually measured are core losses, friction and windage, primary and secondary I^2R losses. See A. I. E. E. Standardization Rules, sections 162-167. Core loss is usually nearly constant, but under certain conditions may increase with the load and materially reduce the efficiency.

The customary method of obtaining the core losses is to run the machine without belt at gradually reduced voltage until it breaks down, reading both watts and amperes; curves of these values are plotted, and the point where the watt curve extended passes through the ordinate at zero voltage is taken as friction.

The I^2R at normal voltage is subtracted and the remainder is taken as core loss.

Primary I^2R is directly obtainable; the secondary, when of a definite phase-wound type, is also directly secured, but when a squirrel cage type, it must be obtained by indirect methods, and is approximately proportional to the slip.

LOAD LOSSES

Under certain conditions the core loss and I^2R are materially increased.

When saturation occurs in the iron, due to the load current, the core loss may be increased on account of a changed flux distribution. This is especially noticeable in motors with completely closed slots, that is, with a thin iron bridge across what would normally be the slot opening.

Such motors do not have a constant reactance or core loss, but both change with load, due to the saturation in the thin iron parts—the core loss increasing and the reactance decreasing. Under these conditions the only correct method of obtaining the efficiency is by an input-output test. The amperes at short circuit, with the rotor blocked, increase more rapidly than the voltage, whereas a motor without saturation will show amperes proportional to the voltage.

Nearly all motors, however, will show some saturation in the blocked condition when several times full load current passes, and a constant core loss should be assumed only through the range of short-circuited current where the amperes are proportional to the voltage.

COPPER LOSSES

The copper losses are also subject to correction. Eddy currents will appear wherever heavy conductors are used. These eddy losses are shown by the wattmeter readings taken with the rotor blocked. Those chargeable to the stator are additional to the primary I^2R from measured resistance; those belonging to the rotor or secondary practically disappear under load conditions, due to the low frequency of slip.

In order to separate these, the rotor can be removed and a stator test made with amperes and watts; if there are no eddies the I^2R and measured watts will agree, but if not, the excess watts will represent additional losses which appear under load, and can be represented by an effective resistance.

Tests have been made which verify the above statements; round wires or rectangular strips of one cm. or less for a maximum dimension, apparently do not show any appreciable loss at

60 ~ or less; this maximum dimension, however, should be further studied, as sufficient tests have not been made to give the maximum limit. Certain deep bar-wound stators, however, have shown losses up to five or six times the losses due to I^2R alone.

Deep bar secondaries show a large eddy loss at standstill, which practically disappears at slip frequency, but the reduction in eddies at slip is partially made up by an increase in reactance and, therefore, a reduction in power factor; there seems no easy way at present to determine this effect, except by an input-output test.

CORE LOSSES

Tests were made on a machine with completely closed stator slots, having a web 0.03 in. (0.76 mm.) thick, and repeated on the same stator having a 1/16-in. (1.58 mm.) and also a $\frac{1}{8}$ -in. (3.17 mm.) opening, the same rotor being used in each case, it having 1/16-in. (1.58 mm.) opening. The primary had 72 slots and the secondary 47 slots. The following are the results:

Completely closed			1/16-in. opening		1/8-in. opening	
Voltage	Watts	Amperes	Watts	Amperes	Watts	Amperes
110	52	3.62	51	3.9	54	4
220 (normal)	224	6.55	202	7.2	208	7.6
300	390	9.25	328	9.85	350	10.5

As there were eight conductors, it will be noticed that the ampere conductors per slot are low.

The full-load current is 25 amperes so that there will be considerable saturation and tufting of flux at load current, and, therefore, increased core loss. The following standstill voltages and currents show the effect of saturation.

Volts	Closed slots Amperes	1/16-in. opening Amperes	1/8-in. opening Amperes
20	4	9.5	10.5
30	6½	14.5	15.8
40	11.6	19.5	21.0
60	22	29.5	31.2
80	32	39	41.5

The curves herewith show more clearly the saturation effect of the completely closed slots.

A method of testing induction motors largely used in Europe measures the input by wattmeters; the core loss, friction, and

primary I^2R are subtracted from the input, and the result is called the primary output. This is multiplied by the per cent of synchronous speed (1 per cent slip) and called the secondary output. While not strictly correct it is as close as is commercially practicable, except in cases of bar-wound stators or non-proportional impedance curves.

The losses method does not show correct results when the standstill ampere curve is bent as shown above.

RESULTS OF TESTS: LOAD TESTS

A number of tests on wire-wound machines with partly open and straight slots have been made, checking efficiency and power factor by input-output method with the method of losses (A. I. E. E. method.) These cover machines from fractional to 150 h.p. From 29 tests ten showed lowest efficiency by loss method, and the remaining 19 showed lowest by brake test. The average is about three-fourths of one per cent lower by brake than by losses.

Two bar-wound stator machines showed 1.4 per cent and 3 per cent, respectively, lower by load test than by losses method. Unfortunately, tests were not made on the stator alone to determine eddy losses. As these were tested commercially no great accuracy should be expected, but they show a general agreement of the two methods.

The following are the results from a certain induction motor which has completely closed slots in both stator and rotor: the

efficiency from method of losses was 0.881, while from an input-output test 0.774 was obtained; the power factor by losses method was 0.901, and from input-output tests 0.903.

This result is rather startling, but the tests have been made carefully, and while not conclusive, show that the question of load losses on completely closed slot motors may become serious. As both stator and rotor are wire-wound with small wire, and the I^2R total checks very closely with the watts at stand-still, it would seem the extra losses are due to saturation of the

Horse power	Rev. per min.	Efficiency by losses method	Efficiency by brake method	Difference per cent
10	1800	85.85	84.2	1.65
7½	1500	81.2	79.7	1.5
5	900	85.7	85.2	0.5
3	1200	80.4	80.5	—0.1
2	1000	80.2	79.3	0.9
1	1200	80.9	82.6	—1.5
1.5	1000	75.5	74.85	0.65
½	1200	70.1	72.2	—2.1
1	800	56.2	53.5	2.7
1½	900	36.2	34.8	1.4
½	1200	68	70.3	—2.3
1	450	51.6	50.2	1.4
½	600	46.3	43.8	2.5
5	1800	85.9	84.6	1.3
7½	1800	85.5	87.4	—1.9
2	1800	82.6	84.2	—1.6
10	1800	89.8	90.3	—0.5
9	1200	84.8	86.5	—1.7
2	1800	86.6	86.3	0.3
20	1800	87.2	89.4	—2.2
1	1800	81.2	78	3.2
7½	1800	87	86.9	0.1
150	600	93.2	91.8	1.4 bar-wound
36	360	88.1	85.1	3 " "
50	600	89.4	89	0.4
20	800	88.2	88.6	0.4
30	800	90.5	91	—0.5
10	1200	87.5	86	1.5
10	1200	85.6	87	1.4

teeth. The core loss running light is 6 per cent of the rated output.

A further test has been made on a motor with partly closed primary slots and completely closed rotor slots, the thickness of the web being one mm.: the core loss running light was 2.3 per cent (approximately ½ of what would be obtained if one member were of the usual straight slot construction).

At one-half load the difference in efficiency between the loss method and input-output was 1.7 per cent, at three-quarter load 2.2 per cent, at full load 2.8 per cent, at one-half load 3.4 per

cent. The corresponding differences in power factor were 1 per cent, $\frac{1}{2}$ per cent, 0.2 per cent, and 0.2 per cent.

The load test was taken by a friction brake and is the average of a number of readings, it being necessary to take a number on account of scattering points.

The motor was designed to have a large core loss and small copper loss, therefore, the load losses, due to saturation of the thin overhang, are not as large as would be the case in a motor of more ampere-turns per slot, such as a standard type.

The results, however, show a decided load loss, increasing approximately proportionally to the load.

The results of these two load tests are in agreement, and seem to indicate that load losses of considerable magnitude may be expected when the iron paths are saturated, due to load current.

In connection with the above, to show the effect of tufted flux, certain tests were made on machines with and without magnetic wedges; the magnetic wedge approaches the condition of a nearly closed slot. Where the wedge was properly made and insulated the core loss was one-half to one-third of the corresponding straight slot; with a poorly insulated wedge, however, the losses increased from two to three times, showing that magnetic wedges require very careful design and handling. Due to the structure of the wedges more or less of an air path was included by the wedges and the short-circuited current was directly proportional to the voltage.

The effect of filing and turning on the cores is shown as an excess core loss during the excitation or running light test; it is constant for a given machine, but is largely the cause of the different core loss measurements on duplicate machines.

Designing engineers are aware of the above conditions and the general practise at present is to build motors with an air path somewhere in the magnetic circuit of each slot.

Present experience seems to indicate that where there is no saturation or bend in the standstill or impedance curve, there are no appreciable load losses; where wire winding is used no allowances are necessary for copper losses; where bar-wound machines are used it is necessary to test the stator without the rotor to determine the stator copper losses; bar-wound rotors show a greater loss and a lower inductance at standstill than when running. Half or quarter frequency tests will largely determine the eddy losses which modify secondary slip and reactance. The slip is a direct measure of the secondary loss.