BEE - CODE DEVELOPMENT PROJECT

SECOND
DRAFT CODE

ON

ELECTRIC MOTORS

Prepared by

Devki Energy Consultancy Pvt. Ltd.,
405, Ivory terrace, R.C. Dutt Road,
Vadodara- 390007, Gujarat
Tel: 0265-2330636/2354813
Fax: 0265-2354813
E-mail: devkienergy@sify.com

2004

CONTENTS

1 OBJECTIVE & SCOPE

1.1 Objective

- To determine the efficiency of three phase induction motor, by loss estimation method, under operating conditions in the plant where the motor is installed and running or available as spare,
- To simplify instrumentation so that the test can be conducted with portable instruments and facilities available with plant engineers and energy auditors.
- To provide guidelines to identify energy saving opportunities in motors.

1.2 Scope

- This code deals with Low voltage 3-phase induction motors having output rating up to and including 200 kW.
- These motors and driven equipments account for more than 90% of energy consumption in industrial motor driven systems.
- This code can be used for efficiency testing of squirrel cage and slip ring induction motors.

The following types of electric motors are excluded from the scope in this code

1. DC Motors
2. Synchronous Motors
3. Single phase Motors

1.3 Efficiency Testing of a motor:

Efficiency Testing of a motor defined and described in this code include the following:

Essential Tests:

1. No load test
2. Winding resistance measurement
3. Ambient temperature measurement
4. Electrical input measurements at actual load, if the motor is connected to load
5. Operating speed measurement, if the motor is connected to load

Non-essential Tests:

1. Friction & windage loss measurement

Estimation of total losses:

1. Stator copper losses
2. Rotor copper losses[1]
3. Iron losses
4. Friction and windage losses
5. Stray losses

Estimation of motor efficiency from total losses and output/input power.

---

[1] This term refers to ohmic losses in the rotor windings, either copper or aluminium. Squirrel cage motors of smaller ratings generally have aluminium rotor cage.

1.4 Reference standards:

The following standards are widely used for efficiency testing of motors at manufacturers' test facilities and laboratories.

1. IEC 600 34-2: 1996 Rotating electrical machines- Part-2
2. IEC 600 34-2: Proposed draft document dated August 2003
3. IEEE Standard 112-1996: IEEE Test procedure for poly phase induction motors and generators
4. IS 4889: 1968 (reaffirmed 1996): Methods of determination of efficiency of rotating electrical machines
5. IS 4029: 1967 (Fifth Reprint 1984): Guide for testing Three phase induction motors
6. IS 325: 1996: Three Phase induction motors- Specification

IEC 600 34-2 emphasizes on estimation of motor losses to calculate motor efficiency and has been used as the primary source for developing this code.

2 DEFINITIONS AND DESCRIPTION OF TERMS

2.1 Basic Units and Symbols

The basic units and symbols used in this code are given in Table-2.1.

Table 2-1: Basic Units and Symbols

Symbol	Description	Units
E	Energy	kWh
P	Power	W
t	Time duration	Seconds
T	Temperature	ºC
P_{fe}	Core losses	W
P_{fw}	Friction and windage losses	W
P_k	Constant losses	W
P_{cu-st}	Stator copper loss	W
P_{cu-rot}	Rotor copper loss	W
P_s	Stray losses	W
P_T	Total losses	W
P_{mech}	Mechanical power	W
U	Terminal r.m.s. Voltage	volts
I	Current	Ampere
$\cos \varphi$	Power factor	p.u.
f	Frequency	Hz
p	Number of poles	-
N	Speed	rpm
N_s	Synchronous speed	rpm
s	Slip	p.u.
R	Average D.C. resistance	Ω
η	Efficiency	%

Subscripts used in this code are given in table 2.2

Table 2-2**:** Subscripts

Symbol	**Description**
$_{I}$	At input
$_{o}$	at output
$_{NL}$	At no load
$_{FL}$	At full load
$_{L}$	At operating load
$_{ph}$	Referred to phase
$_{a}$	At ambient temperature
$_{R}$	Referred to R phase
$_{Y}$	Referred to Y phase
$_{B}$	Referred to B phase

2.2 Description of terms

Constant losses: The sum of core, friction and windage losses

Core losses: Losses in active iron and additional no load losses in other metal parts

Friction losses: Losses due to friction in bearings

Windage losses: Power absorbed by rotor rotation and shaft mounted fans

Efficiency: The ratio of output power to the input power expressed in the same units and usually given as a percentage.

Line current: Arithmetic average of r.m.s. line currents

Line to line resistance: Average of the resistances measured across two terminals on all lines

Load losses: Copper losses (I^2R losses) in stator and rotor

No load test: A test in which the machine is run as a motor providing no useful mechanical output from the shaft

Stray losses: Extra losses due to flux pulsations, harmonic fields and other unaccounted losses

Slip: The quotient of (1) the difference between the synchronous speed and the actual speed of the rotor, to (2) the synchronous speed expressed as a ratio or a percent.

Terminal voltage: Arithmetic average of r.m.s. line voltages

3 GUIDING PRINCIPLES

3.1 Principle

The methods proposed in this code involves estimation of losses in a motor. These losses are:

1. Stator copper losses
2. Rotor copper losses
3. Iron losses
4. Friction and windage losses
5. Stray losses

After estimating the losses, efficiency is calculated by the following relationships.

$$\text{Efficiency at full load} = \frac{\text{Rated Output}}{(\text{Rated Output} + \text{Losses})}$$

$$\text{Efficiency at operating load} = \frac{\text{Motor input power} - \text{Losses}}{\text{Motor input power}}$$

3.2 Planning the Test

There are mainly two situations encountered in the field regarding testing of motors. Choice of the method suitable for each situation shall be done properly.

Method-1:

- ☐ When a motor is not coupled mechanically to any load, but available as spare/newly purchased. In this case, motor efficiency at full load can be estimated.
- ☐ Motor nameplate rating of full load speed and full load output are assumed to be correct.
- ☐ Measurements are done on the motor at no load conditions.

Method-2:

- ☐ When a motor is installed and coupled to driven equipment, say a pump, compressor etc. In this case, motor efficiency at operating load and full load can be estimated.
- ☐ In addition to the measurements at no load, measurements are also required to be done at the actual operation of the motor on load.
- ☐ In this method, actual speed and power input is measured at load condition and output is estimated from power input and measured losses.

Details of calculations in both methodologies are given in section 5.4 & 5.5

3.3 Pre Test Requirements

1. Ensure that the motors to be tested are in working condition.

2. Nameplate information of the motor is required for the tests. Ensure that the nameplate information is clearly visible. If nameplate is not available, obtain the details from the manufacturer’s specification sheets/purchase department etc., if the source of the information is reliable.

3. Any Variable Frequency drive, voltage controller or soft starter installed at the motor need to be disconnected from the line during measurements.

4. While conducting the tests at site, a qualified person-one who is familiar with the installation and operation of the motor- should be present to energize, de-energize the equipment in accordance with established safety practices.

5. While conducting no load test, ensure that the motor is completely decoupled from the load.

6. If the motor has been in operation prior to no load test, stop the motor, decouple the load and keep the motor idle condition till the motor cools to ambient temperature. Usually, it may take about 2 hours.

7. When efficiency test is done on a motor, which is not bolted to the foundation (as in maintenance workshops), beware of injuries due to jerky motor starting.

8. While measurements are being taken when motor is operating, as required in method-2, ensure that the shaft load on the motor is steady and constant. If the motor is driving a pump, the pressure and flow need to be maintained same through out the test. Similarly, if the motor is driving an air compressor, the air pressure should be maintained constant throughout the test.

3.4 Precautions during test

1. Use appropriate safety precautions while taking measurements on live cables.

2. Make sure the clamp-on jaws of CTs are completely closed. The jaws do not always close tightly, especially in tight locations. Even a small gap in the jaws can create a large error. To ensure the jaws are fully closed, wiggle the probe a bit, making sure it moves freely and is not bound by adjacent wires or other obstructions.

3. Measure and average the currents on all 3 phases, if possible.

4. Use properly sized CT's. Using over or under-sized CTs (current transformers--the clamp on "jaws") can result in large inaccuracies. For example, using a 2,000-amp CT with 0.5% of full span accuracy (which is good) to measure a 20-amp current may result in a 50% measurement error.

5. Average the current on fluctuating loads. Motor load, and thus current may fluctuate on some processes. Some meters have an automatic "min/max/average" function that can be used for this.

6. Make sure you are measuring the actual motor current. Some motors and/or motor controllers are equipped with power-factor correction capacitors. Refer fig 3.1. Make sure you are measuring downstream from the power factor correction equipment and reading the actual motor input. Measuring upstream from the power-factor correction equipment can result in large errors--up to a 25% or greater difference in current. In fig 3.1, if the current is measured upstream of capacitor bank, the indicated current would be 102 Amp, instead of actual motor current of 124.9 amp. It is recommended to disconnect the capacitors if connected at the motor.

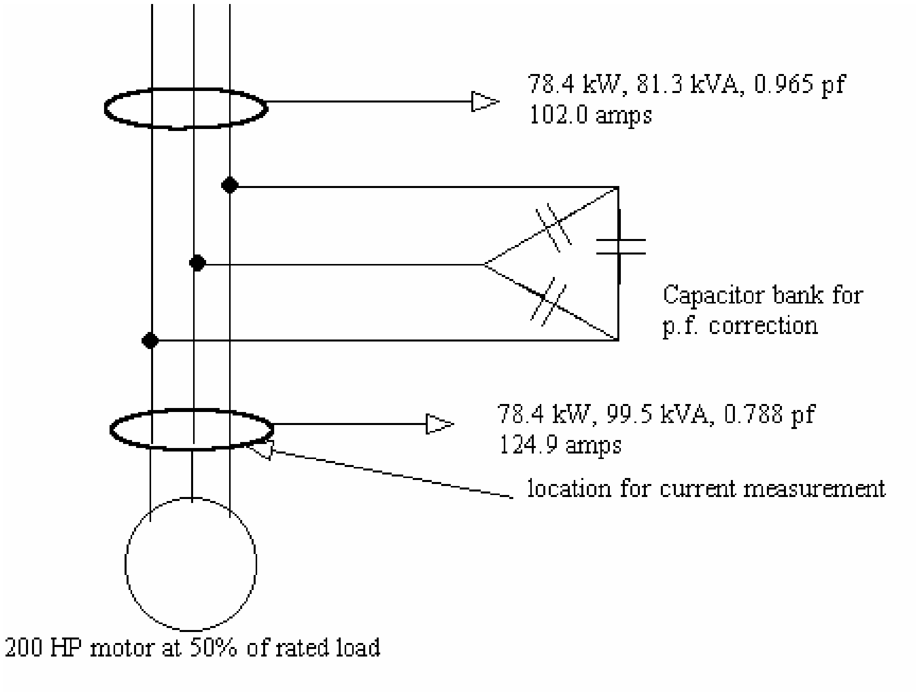


Figure 3-1: Location of current measurement

4 INSTRUMENTS AND METHODS OF MEASUREMENTS

4.1 Measurement/estimation of parameters

The measurement of following parameters is required for efficiency testing of motor

1. Power/energy input
2. Current
3. Voltage
4. Frequency
5. Speed
6. Stator resistance
7. Ambient temperature

4.2 Calibration of instruments

- ☐ Portable power analyzer, which can measure voltage, current, frequency, power, energy are suitable for electrical measurements at site.
- ☐ Calibration of power analysers/energy meters shall be done at NABL accredited laboratories. Period of calibration is 1 year. A sample calibration data for a power analyser is given in Annexure-2. A list of NABL accredited laboratories is given in Annexure-3.
- ☐ The error of the instrument shall be known at various load conditions and power factor. A calibration curve shall be plotted for each of the parameter indicating error. This curve is useful for uncertainty analysis of test results, as explained in Section 7.
- ☐ The calibration curve can be plotted with meter reading on x-axis and % error on y-axis. % Error for any other measured value within the range can be noted from the calibration curve. Estimation of error at measurement value is required for uncertainty analysis.
- ☐ It is desired that calibration may be done at more number of points. For example, since % error in power measurement at low power factor is likely to be significant during no load measurements in a motor, calibration may be done at p.f varying from from 0.1 to 1.0 with an interval of 0.1 for different loads.
- ☐ Power analysers are generally calibrated with CTs which are used with the instrument at site. Hence the errors are sum of instrument and CT error. Separate calibration of CTs is not required in this case.

4.3 Power input

For no load power measurements, a low power factor corrected energy meter/power analyser having full-scale error of 0.5% is recommended. It should be noted that energy meters, which are used usually in measurements above 0.7 pf might indicate errors of 5 to 10% when used in low p.f. (0.1 to 0.3) load conditions. Hence it is important to have power analysers and CT's calibrated for various load currents and p.f ranging from 0.1 to 1.0.

Measurement of energy consumed during a known period can be done using a power analyser and power can be estimated from energy measurement and time duration. This averages out fluctuations seen in instantaneous power measurements.

The CT ratios should also be selected to read preferably above 50% or above of the input current. For example, for measurement of 100 A current, a 200/5 A CT is more desirable than using a 500/5 A CT.

4.4 Voltage

Measure voltages on all the three phases and compute average voltage. Voltage shall be measured using a power analyzer or a voltmeter with an error of not more than 0.5%. If at the time of measurement, voltage is nearly but not absolutely balanced, the arithmetical average of the line voltages shall be used.

Line to line r.m.s. voltages across R-Y, R-B and Y-B are measured and average of line to line r.m.s voltage is calculated as follows.

In motors, where stator winding is connected in Δ (delta),
Phase Voltage, U_{ph} = Line voltage

In motors, where stator winding is connected in Y (star),
Phase Voltage, U_{ph} = Line voltage ÷ √3

4.5 Current

The line current in each phase of the motor shall be measured using an ammeter or a power analyzer with error not exceeding 0.5%. If current is not equal in all phases, the arithmetic average of the currents shall be used.

Current measurements are done in the R,Y & B incoming line at the motor starter. From the average of line currents measured, phase current is calculated as follows.

In motors, where stator winding is connected in Δ (delta),
Phase current = Line current ÷ √3

In motors, where stator winding is connected in Y (star),
Phase current = Line current

4.6 Frequency

Frequency shall be measured by using a power analyser or a frequency meter having error not more than 0.1 Hz. For synchronous speed estimation to calculate slip, frequency measurement shall be done simultaneously with speed measurement.

4.7 Speed

Operating slip is measured from synchronous speed and operating speed measurements as given below.

Slip at operating speed,

$$S_L = \frac{Ns - N_L}{Ns}$$

Where, N_L = operating speed
Ns = Synchronous speed
$= \frac{120 \times f}{p}$

Where, f = operating frequency
p = number of poles

Note: The frequency of power supply should be measured simultaneously with the speed measurements.

Full load slip is estimated from name plate full load speed and synchronous speed at name plate frequency.

$$S_{FL} = \frac{Ns - N_{FL}}{Ns}$$

Where,
N_{FL} = operating speed

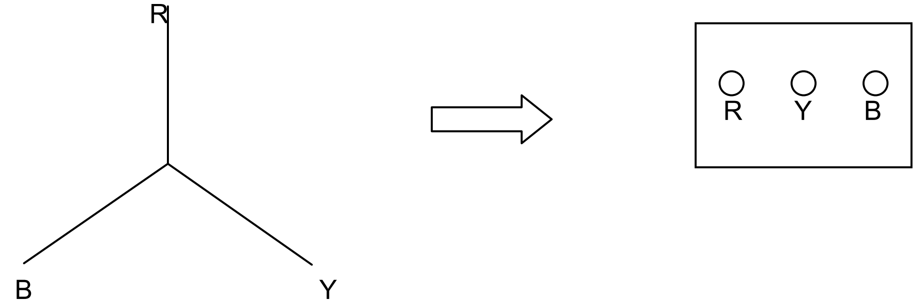
$$N_s = \text{Synchronous speed} = \frac{120 \times f}{p}$$

Where, f = rated frequency
p = number of poles

Speed of motor can be measured using a non-contact tachometer having error of not more than 1 rpm.

4.8 Resistance

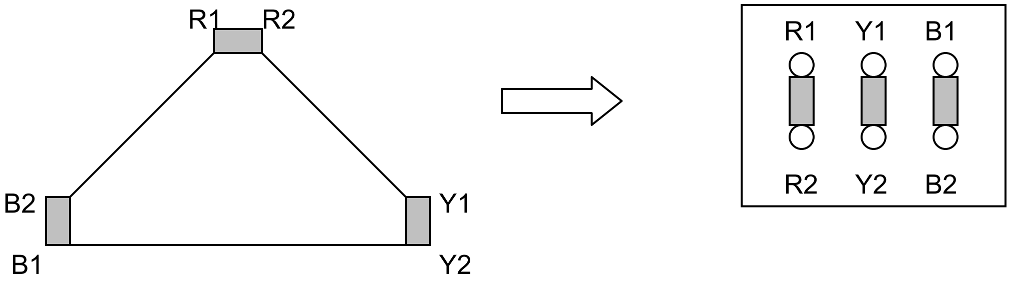
The stator winding may be in 'Star' connection in a motor as shown below in figure 4.1



Star connected winding **Connection at motor terminal box**

Figure 4-1: STAR connected winding

'Delta' connected winding in a motor is shown below in figure 4.2.



Delta connected winding **Connection at motor terminal box**

Figure 4-2: DELTA connected winding

Note:

- ❑ The shaded bar is a metal strip, which is used to connect R1 & R2, Y1 & Y2 and B1 & B2 as shown in the schematic o motor terminal box.
- ❑ Measurement of winding resistance should be done at the winding leads available at motor terminal box.

Measurement of winding resistance is done across line to line. I.e. R-phase & Y phase, Y & B and R & B phases. The average value of line-to-line resistance obtained is designated as R_{ll}

To convert the measured value of line-to-line resistance to phase resistance, the following relationships are used.

In 'Star' connection, phase resistance, $R_{ph} = 0.5 \times R_{ll}$
In Delta connection, phase resistance, $R_{ph} = 1.5 \times R_{ll}$

The resistance must be corrected to the operating/full load temperature by using following relationship

$$\frac{R_2}{R_1} = \left(\frac{235 + T_2}{235 + T_1}\right)$$

where, R_2 = unknown resistance at temperature T_2
R_1 = resistance measured at temperature T_1

While estimating full load efficiency of motor, winding resistance at full load is calculated by using the temperature given for each class of insulation. The values are given in table 4.1.

Table 4-1**:** Reference temperature for insulation classes

Thermal class of insulation	Reference temperature, ºC
A	75
B	95
F	115
H	130

While estimating motor efficiency at actual load, the winding resistance is measured immediately measured after stopping the motor. Hence temperature correction is not required in this case.

Any of the following 2 methods can be used for measurement of winding resistance.

1. Bridge method: the unknown resistance is compared with a known resistance by use of a suitable bridge.
2. Digital resistance meters with accuracy of 1 milli ohms.

Use of digital ohm meters is recommended. It is sufficient to measure winding resistance with an accuracy of 0.001 ohms.

4.9 Ambient Air Temperature

The air temperature shall be measured by any of the following instruments:

a) Calibrated mercury in glass thermometer
b) Thermocouple
c) Resistance thermometer

The temperature device shall be so chosen that it can be read with an accuracy of 1% percent of the absolute temperature. Absolute value of Full-scale error shall not exceed 1°C.

Use of Calibrated mercury in glass thermometer, which can measure temperature with an accuracy of 1°C, is preferred.

4.10 Summary of instrument accuracies

The table given below summarises accuracy requirements of various instruments.

For calibrating various instruments, visit www.nabl-india.org for a detailed list of accredited laboratories. Calibration interval suggested for instruments is 6 months.

Instrument and range	**Accuracy**
Temperature	1.0%. Precision of 0.1 C
No load power	0.5%
Voltage	0.5%
Current	0.5%
Resistance	0.001 ohms
Speed	1 rpm
Frequency	0.1 Hz

5 COMPUTATION OF RESULTS

5.1 Determination of efficiency

The efficiency can be calculated from the total losses, which are assumed to be the summation of the following losses.

1. Constant losses (Core losses, P_{fe} + Friction and windage losses, P_{fw})
2. Stator copper losses ($P_{cu\text{-}st}$)
3. Rotor copper losses ($P_{cu\text{-}rot}$)
4. Stray losses (P_s)

5.2 No load test for Constant loss estimation

The motor is run at rated voltage and frequency without any shaft load until thermal steady state is attained. Input power, current, frequency and voltage are noted. Alternatively, by noting the input energy consumption and time duration, input power can be estimated.

From the input power, stator I^2R losses under no load is subtracted to give the constant losses, which is the sum of friction, windage and core losses. The test instrumentation set up is given in figure 5.1.

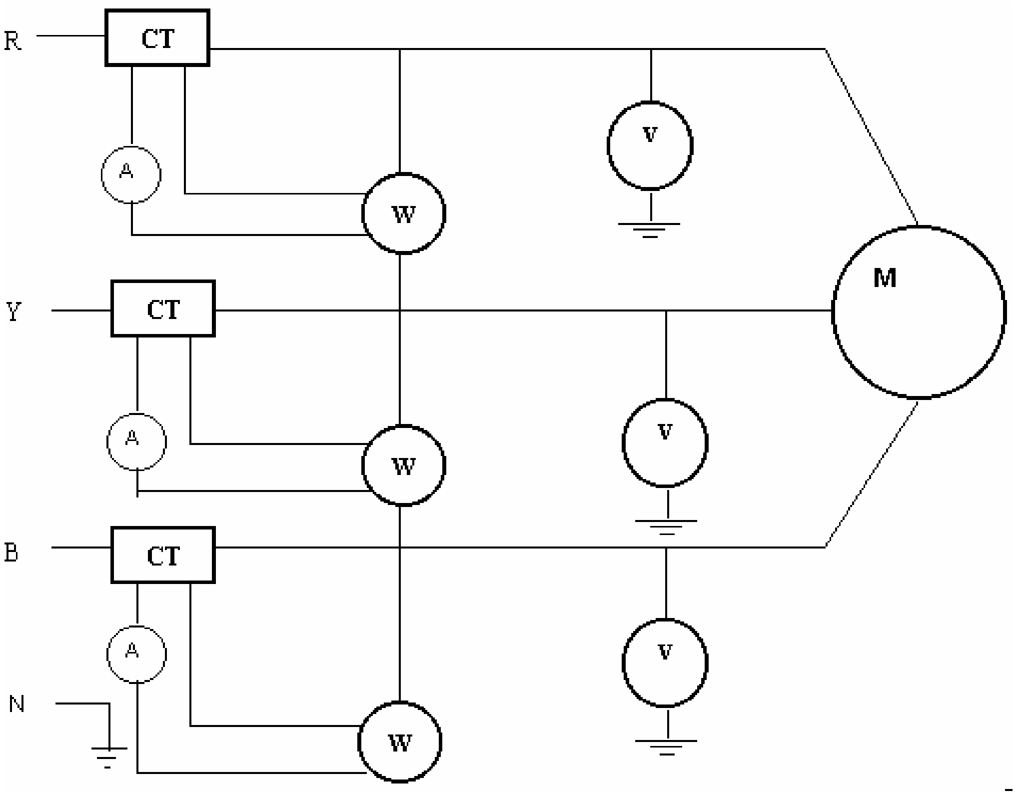


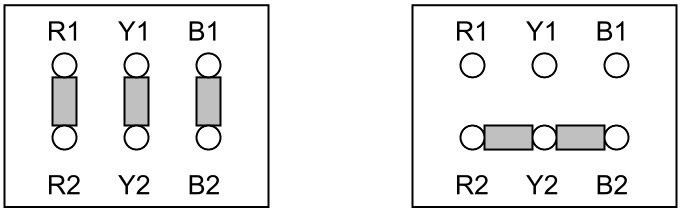
Figure 5-1: No load test schematic diagram

5.2.1 Estimation of friction & windage losses (Non essential test)

It is not necessary to separate core losses and friction & windage losses from constant losses to estimate motor efficiency.

However, If it is required to know how much is the friction and windage losses, the no load test is repeated at variable voltages. In case variable voltage source is not available, for delta connected motors, two readings can be taken; one with stator in ‘delta’ and the other with stator in ‘star’.

When stator is in delta connected by manipulating terminals externally, the phase voltage = line voltage. The connection to be made at the motor terminal box is as given below in fig 5.2



Delta connection **Star connection**

Figure 5-2: Conversion of delta connected motor into star connection externally

When stator is connected in ‘star’ externally as shown above,
Phase voltage = Line voltage ÷ √3.

Values of power vs. voltage^2 is plotted, with voltage^2 on x-axis and power on y-axis.

This is graph approximately a straight line and which if extended to touch the y-axis gives the friction & windage loss as the y intercept. Alternatively, a plot of voltage vs. kW may also be constructed. This curve is extended to zero voltage to find out friction and windage losses as core losses will be zero at zero voltages.

Fig 5.3 shows a sample plot. of power vs. voltage^2 & voltage

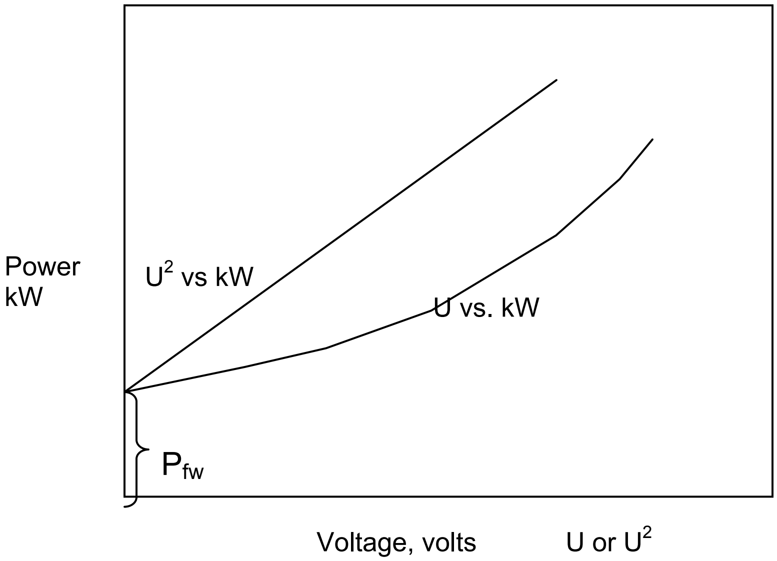


Figure 5-3: Determination of friction & windage losses

Alternatively, if variable voltage testing is not possible, assuming friction & windage losses as follows is also reasonably correct,

For Drip proof motors, friction & windage losses ≈ 0.8 to 1.0% of motor rated output
For TEFC motors, friction & windage losses ≈ 1 to 1.5% of motor rated output

5.2.2 Voltage correction factor to core losses

To estimate full load efficiency, voltage correction factor should be applied to core losses to correct it to the rated voltage. Core losses vary with square of the voltage applied. Hence, core loss corrected to rated voltage $P_{fe\text{-Rated}} = P_{fe} \times (U_R/U)^2$

Where U = Applied terminal voltage during test
U_R = Rated voltage

5.3 Stray loss

Stray losses are very difficult to measure with any accuracy under field conditions or even in a laboratory.

IEC standard 34-2 suggests a fixed value for stray losses as given in figure 5.3

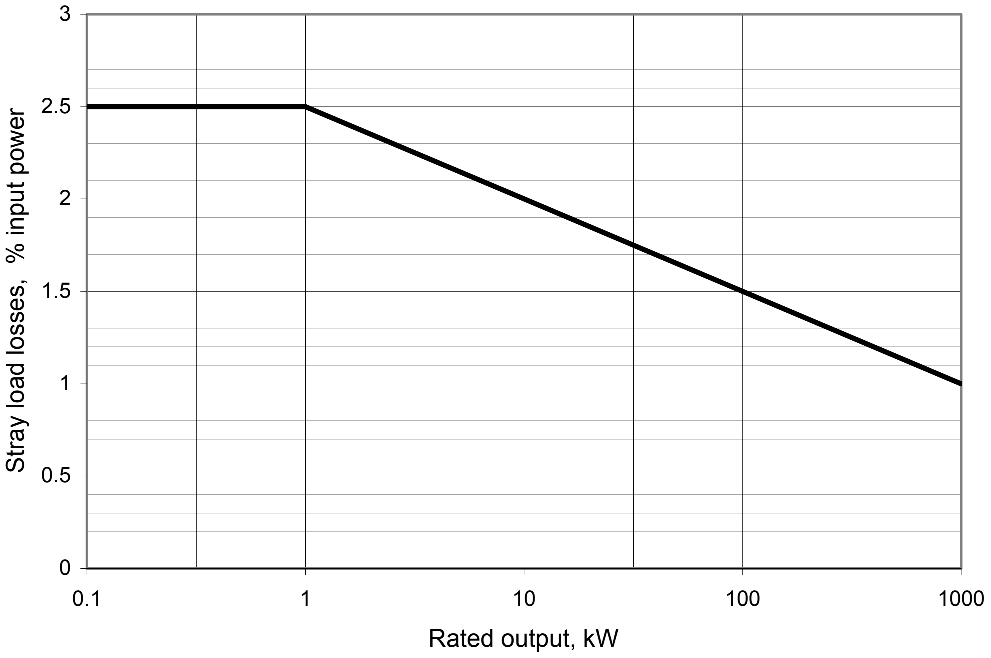


Figure 5-4: Stray load estimation

Note that stray losses are given as a percentage of input power in the above figure.

In method-1, to estimate the stray losses, an iterative solution must be attempted because of not knowing the full load input power or efficiency beforehand. In section 6, a spreadsheet format is given in Table 6.1 which has been programmed to incorporate iteration.

In the iterative method, first guess a value of stray loss and estimate full load efficiency. From this, calculate full load input power = rated output/efficiency. From the estimated full load input power and known values of constant losses, copper losses and rated output, calculate stray losses. Repeat the above steps till stray loss value converges.

In method-2, the stray losses can be taken directly as percentage of actual input power when motor is on operating load.

IEEE Std 112-1996 gives values for stray losses as given in table 5.1 below.

Table 5.1: Assumed values for stray losses

Machine rating	Stray loss, % of rated output
1 – 90 kW	1.8%
91 – 375 kW	1.5%
376 to 1850 kW	1.2%
1851 kW and greater	0.9%

Use of stray loss values from IEC 34-2, as given in Figure 5.4, is recommended.

5.4 Method-1: Estimation of motor efficiency at full load

Full load efficiency of the motor is estimated in this method.

Chronological order of measurements is as follows.

1. If the motor has been in operation prior to this test, stop the motor, decouple the load from the motor and keep the motor idle till the it cools down to ambient temperature. Usually, it may take about 2 hours.

2. Measure winding resistance R_{ph-a} at cold conditions. Record the ambient temperature T_a

3. Apply voltage across the motor at no load and start the motor.

4. Measure line voltage (U), line current (I_{nl}), frequency (f), energy (E_{nl}) and time duration (t). From measured energy (E_{nl}), estimate power consumption (Pi_{nl}) by dividing E_{nl} by time duration.

   Direct power input measurement (Pi_{nl}) can also be done using power meter instead of energy and time measurements.

5. Calculate phase current (I_{ph-nl}) from line current (I_{nl}) as given below.

   For Delta connected windings, phase current, $I_{ph-nl} = \frac{I_{nl}}{\sqrt{3}}$

   For Star connected windings, phase current, I_{ph-nl} = line current

6. Calculate stator copper loss at no load and subtract this from no load power to get constant losses

   No load stator Copper loss, $P_{cu-st-nl} = 3 \times I_{ph-nl}^2 \times R_{ph-nl}$

   Constant loss, $P_k = Pi_{nl} - P_{cu-st}$

7. Estimate friction & windage losses, P_{fw} ,of the motor as explained in section 5.2.1. Generally it is sufficient to assume the friction and windage losses as follows.

For Drip proof motors, friction & windage losses ≈ 0.8 to 1.0% of motor rated output
For TEFC motors, friction & windage losses ≈ 1 to 1.5% of motor rated output

8. Estimate core losses

Core losses, $P_{fe}' = P_k - P_{fw}$

Correct core losses to the rated voltage, U_r, by multiplying with the factor $\left(\frac{U_r}{U}\right)^2$

$$P_{fe} = P_{fe}' \times \left(\frac{U_r}{U}\right)^2$$

9. Calculate stator winding resistance at full load. i.e. at temperature as defined in the class of insulation as given in Table 5.1.

$$R_T = R_{ph\text{-}a} \times \frac{(235 + T_T)}{(235 + T_a)}$$

Table 5-1: Reference temperature for insulation classes

Thermal class of insulation	Reference temperature, ºC
A	75
B	95
F	115
H	130

10. Estimate Stator copper losses at full load, assuming nameplate full load current and corrected stator resistance at full load.

$$P_{cu\text{-}st\text{-}FL} = 3 \times I_{ph\text{-}FL}^2 \times R_T$$

11. Obtain stray losses, as a % of input power from fig.5.4 corresponding to rated output as explained in section 5.3 and calculate stray loss, P_s by iterative procedure.

12. Calculate full load slip (s_{FL}) from the rated speed (N_{FL}) and synchronous speed (Ns) at the rated frequency.

$$s_{FL} = \frac{N_s - N_{FL}}{N_s}$$

13. Calculate rotor input power from rotor output at full load.

$$\text{Power input to rotor, } Pi_{rot} = \frac{\text{Rotor output}}{(1 - s_{FL})}$$

$$= \frac{P_{mech}}{(1 - s_{FL})}$$

Rotor output at full load is the nameplate output kW rating of the motor.

14. Calculate rotor copper losses from full load slip and rotor input

Rotor copper loss, $P_{cu\text{-}rot} = s_{FL} \times Pi_{rot}$

15. Total losses at full load is sum of all the above losses

Total losses, $P_T = P_{fw} + P_{fe} + P_{cu\text{-}st\text{-}FL} + P_s + P_{cu\text{-}rot}$

16. Efficiency at full load is obtained from rated output and estimated total losses as

Efficiency at full load, $\eta_{FL} = \dfrac{P_{mech} \times 100}{(P_{mech} + P_T)} \%$

A sample calculation is shown in Table 6.1 with MS Excel™ programmable equations.

5.5 Method –2: Estimation of motor efficiency at operating load

Chronological order of measurements is as follows.

1. If the motor has been in operation prior to this test for more than one hour, it can be considered to be close to steady operating conditions. In this case, while testing, operation of the motor for 10 to 15 minutes is sufficient to attain steady operation.
2. If the motor and load were idle before the test, continuous operation of the motor on load for at least 30 minutes is recommended to attain steady state conditions.
3. Start the motor with load and bring it up to desired steady operating conditions.
4. Measure r.m.s. line voltage (U), r.m.s. line current (I_L), frequency (f), energy (E_L) and time duration (t) for energy measurements. From measured energy (E_L), estimate power consumption (Pi_L) by dividing E_L by time duration (t).

   Direct power input measurement (Pi_L) can also be done using power meter instead of energy and time measurements.

5. Measure operating speed of motor, N_L

6. Switch off the motor. Disconnect power supply. Measure D.C. resistance of the stator (R_{ph-L}) winding immediately after switching off the motor.

7. Decouple motor from the load and allow the motor to cool for at least 2 hours.

8. Measure winding phase resistance (R_{ph-a}) at cold conditions. Note the ambient temperature, T_a

9. Apply voltage across the motor at no load and start the motor.

10. Measure line voltage (U), line current (I_{nl}), frequency (f), energy (E_{nl}) and time duration (t). From measured energy (E_{nl}), estimate power consumption (Pi_{nl}) by dividing E_{nl} by time duration. Direct power input measurement (Pi_{nl}) can also be done using power meter instead of energy and time measurements.

11. Stop the motor. Immediately measure D.C. resistance of the stator winding (R_{ph-nl}).

12. Calculate phase current (I_{ph-nl}) from line current (I_{nl}) as given below.

    For Delta connected windings, phase current, $I_{ph-nl} = \dfrac{I_{nl}}{\sqrt{3}}$

    For Star connected windings, phase current = line current

13. Calculate stator copper loss at no load and subtract this from no load power to get constant losses

    No load stator Copper loss, $P_{cu-st-nl} = 3 \times I_{ph-nl}^2 \times R_{ph-nl}$

    Constant loss, $P_k = Pi_{nl} - P_{cu-st-nl}$

14. Calculate stator copper loss at operating load

    Stator Copper loss, $P_{cu-st-L} = 3 \times I_{ph-L}^2 \times R_{ph-L}$

15. Calculate stray losses, $P_{s-L,}$ from fig.5.4 as explained in section 5.3.

16. Calculate rotor input power from motor input power, constant losses, stator copper losses and stray loss.

    Power input to rotor, $Pi_{rot} = Pi - P_{cu-st-L} - P_k - P_{s-L}$

17. Calculate slip (s_L) from the operating speed (N_L) and synchronous speed (N_s) at the measured frequency

    $$s_L = \frac{N_s - N_L}{N_s}$$

18. Calculate rotor copper losses from slip and rotor input

    Rotor copper loss, $P_{cu-rot} = s_L \times Pi_{rot}$

19. Total losses at full load is sum of all the above losses

    Total losses, $P_T = P_k + P_{cu-st-FL} + P_s + P_{cu-rot}$

19. Output power (P_{mech-L}) is estimated from input and total losses measurements

    $P_{mech-L} = Pi_L - P_T$

20. Efficiency is estimated from estimated output and measured input input.

    Efficiency at operating load, $\eta_L = \dfrac{P_{mech-L} \times 100}{Pi_L} \%$

21. Efficiency at full load can also be estimated from steps 8 to 15 and following the procedure of calculating losses at full load as explained in **Method-1**.

A sample calculation is shown in Table 6.2 with MS Excel™ programmable equations.

6 FORMAT OF TEST RESULTS

6.1 Method-1: Estimation of Motor Efficiency at Full Load

Format of data collection, measurements and calculation of test results used in Method-1 is given in Table 6.1 below. The table also contains sample calculation of test results. The equations used in both tables 6.1 and 6.2 can be copied into **MS Excel™** spreadsheet.

Table 6-1: Format of test results & Sample calculation

1	A	B	C	D
2	**Motor specifications**	**Equation to be used in column C**	**Value**	**Unit**
3	No of poles		4	-
4	Winding connection		DELTA	
5	Type		TEFC	
6	Output		30	kW
7	Voltage		415	Volts
8	Full load current, I_{FL}		53	Amp
9	Phase current at Full load, I_{FL-ph}	IF(C4="delta",C8/SQRT(3),C8)	30.60	Amp
10	Speed		1465	rpm
11	Frequency		50	Hz
12	Full load Slip	(120*(C11/C3)-C10)/(120*(C11/C3))	0.023	p.u
13	Efficiency		88	%
14	Insulation		Class F	-
15	Full load winding temperature	**Function-1**	115	Deg. C
16	**No load test**			
17	Line Voltage, U		418.1	Volts
18	Line Current, I_{nl}		26.9	Amp
19	Phase current, I_{NL-ph}	IF(C4="delta",C18/SQRT(3),C18)	15.5	Amp
20	No load power input, P_{i-nl}		1875.7	Watts
21	Stator phase resistance at cold conditions		0.36	Ohms
22	Stator phase resistance after no load test		0.38	Ohms
23	Ambient Temperature, T_a		35	Deg.C
24	Frequency, f		50.1	Hz
25	Winding resistance at full load R_{ph-FL}	C20*(235+C15)/(235+C23)	0.467	Ohms
26	**Calculation of losses**			
27	Stator Copper loss- no load	3*C19^2*C22	274.97	Watts
28	Constant loss	C20-C27	1600.73	Watts
29	Friction & windage loss as % of full load output	IF(C5="TEFC",0.012,0.01)	1.2%	%
30	Friction & windage loss	C29*C6*1000	360	Watts
31	Core loss at rated voltage	(C28-C30)*(C7/C17)^2	1222.4	Watts
32	Stator Copper loss at full load	3*C9^2*C25	1310.87	Watts
33	Rotor input at full load	C6*1000/(1-C12)	30716.72	Watts
34	Rotor Copper loss	C33*C12	716.72	Watts
35	Stray Loss as per % of input power	Take value from figure 5.3	1.75	%
36	Stray loss	((C6/C39)*C35*1000)/100	598.65	Watts
37	Total losses at full load	C28+C29+C30+C32+C33	4208.64	Watts
38				
39	**Efficiency**	C6*1000/(C6*1000+C37)	87.7%	%
40	**Function-1 = IF(B14="class F",115,IF(B14="class A",75,IF(B14="class B",95,IF(B14="class H",130))))**			

6.2 Method-2: Estimation of Motor Efficiency at Operating Load

Format of data collection, measurements and calculation of test results used in Method-1 is given in Table 6.2 below. The table also contains sample calculation of test results.

Table 6.2: Format of test results & Sample calculation

1	A	B	C	D
2	**Motor specification**	**Equation to be used in column C**	**Value**	**Unit**
3	No of poles		4	-
4	Winding connection		DELTA	
5	Type		TEFC	
6	Output		30	kW
7	Voltage		415	Volts
8	Full load current, I_{FL}		53	Amp
9	Phase current at Full load, I_{FL-ph}	IF(C4="delta",C8/SQRT(3),C8)	30.60	Amp
10	Speed		1465	rpm
11	Frequency		50	Hz
12	Full load Slip	(120*(C11/C3)-C10)/(120*(C11/C3))	0.023	p.u
13	Efficiency		88	%
14	Insulation		Class F	-
15	**No load test**			
16	Line Voltage, U		418.1	Volts
17	Line Current, I_{nl}		26.9	Amp
18	Phase current, I_{NL-ph}	IF(C4="delta",C17/SQRT(3),C17)	15.5	Amp
19	No load power input, P_{i-nl}		1875.7	Watts
20	Stator phase resistance after no load test		0.38	Ohms
21	Frequency, f		50.1	Hz
22	**Measurements at actual load**			
23	Voltage, U_L		420.0	Volts
24	Load current, I_L		42.0	Amp
25	Phase current at actual load , I_{L-ph}	IF(C4="delta",C24/SQRT(3),C24)	24.2	
26	Power input, P_L		22.92	kW
27	Operating speed, N_L		1475.0	rpm
28	Frequency, f		50.0	Hz
29	Slip at actual load	(120*C28/C3-C27)/(120*C28/C3)	0.017	p.u.
30	Stator phase resistance at actual load R_{ph-L}		0.460	Ohms
31	**Calculation of losses**			
32	Stator Copper loss- no load	3*C18^2*C20	274.97	Watts
33	Constant loss	C19-C32	1600.73	Watts
34	Friction & windage loss as % of full load	IF(C5="TEFC",0.012,0.01)	1.2%	%
35	Friction & windage loss	C34*C6*1000	360	Watts
36	Core loss at actual load voltage	(C33-C34)	1240.73	Watts
37	Stator Copper loss at actual load	3*C25^2*C30	811.44	Watts
38	Stray Loss as per % of input power	Take value from figure 5.3	1.75	%
39	Stray loss	(C26*1000*C38)/100	401.0	Watts
40	Rotor input at actual load	C26*1000-C37-C36-C39	20461.9	Watts
41	Rotor Copper loss	C40*C29	341.03	Watts

Table 6.2: Format of test results & Sample calculation **Cont'd..**

42	Total losses	C36+C34+C37+C41+C39	3154.2	Watts
43	Output	C26*1000-C42	19765.8	Watts
44	**% Shaft loading**	C43/(C6*100)	66%	%
44	**Efficiency at actual load**	C43/(C26*1000)	86.2%	%

7 UNCERTAINTY ANALYSIS

7.1 Introduction

Uncertainty denotes the range of error, i.e. the region in which one guesses the error to be. The purpose of uncertainty analysis is to use information in order to quantify the amount of confidence in the result. The uncertainty analysis tells us how confident one should be in the results obtained from a test.

Guide to the Expression of Uncertainty in Measurement (or GUM as it is now often called) was published in 1993 (corrected and reprinted in 1995) by ISO. The focus of the ISO *Guide* or GUM is the establishment of "general rules for evaluating and expressing uncertainty in measurement that can be followed at various levels of accuracy ".

The following methodology is a simplified version of estimating uncertainty at field conditions, based on GUM.

7.2 Methodology

Uncertainty is expressed as X +/- y where X is the calculated result and y is the estimated standard deviation. As instrument accuracies are increased, y decreases thus increasing the confidence in the results.

A calculated result, r, which is a function of measured variables X_1, X_2, X_3,….., X_n can be expressed as follows:

$r = f(X_1, X_2, X_3, \ldots, X_n)$

The uncertainty for the calculated result, r, is expressed as

$$\partial r = \left[\left(\frac{\partial r}{\partial X_1} \times \delta x_1 \right)^2 + \left(\frac{\partial r}{\partial X_2} \times \delta x_2 \right)^2 + \left(\frac{\partial r}{\partial X_3} \times \delta x_3 \right)^2 + \ldots\ldots. \right]^{0.5} \quad \text{----(1)}$$

Where:

∂r = Uncertainty in the result

δxi = Uncertainties in the measured variable X_i

$\frac{\partial r}{\partial X_i}$ = Absolute sensitivity coefficient

In order to simplify the uncertainty analysis, so that it can be done on simple spreadsheet applications, each term on RHS of the equation-(1) can be approximated by:

$$\frac{\partial r}{\partial X_1} \text{ x } \partial X_1 = r(X_1 + \partial X_1) - r(X_1) \text{ ----(2)}$$

The basic spreadsheet is set up as follows, assuming that the result r is a function of the four parameters X_1, X_2, X_3 & X_4. Enter the values of X_1, X_2, X_3 & X_4 and the formula for calculating **r** in column A of the spreadsheet. Copy column A across the following columns once for every variable in **r** (see table 7.1). It is convenient to place the values of the uncertainties $\partial(X_1)$, $\partial(X_2)$ and so on in row 1 as shown.

Table 7-1: Uncertainty evaluation sheet-1

	A	B	C	D	E
1		∂X_1	∂X_2	∂X_3	∂X_4
2					
3	X_1	X_1	X_1	X_1	X_1
4	X_2	X_2	X_2	X_2	X_2
5	X_3	X_3	X_3	X_3	X_3
6	X_4	X_4	X_4	X_4	X_4
7					
8	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1, X_2, X_3, X_4)$

Add ∂X_1 to X_1 in cell B3 and ∂X_2 to X_2 in cell C4 *etc*., as in Table 7.2. On recalculating the spreadsheet, the cell B8 becomes $f(X_1+\partial X_1, X_2, X_3, X_4)$.

Table 7-2: Uncertainty evaluation sheet-2

	A	B	C	D	E
1		∂X_1	∂X_2	∂X_3	∂X_4
2					
3	X_1	$X_1+\partial X_1$	X_1	X_1	X_1
4	X_2	X_2	$X_2+\partial X_2$	X_2	X_2
5	X_3	X_3	X_3	$X_3+\partial X_3$	X_3
6	X_4	X_4	X_4	X_4	$X_4+\partial X_4$
7					
8	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1^{'}, X_2, X_3, X_4)$	$r=f(X_1, X_2^{'}, X_3, X_4)$	$r=f(X_1, X_2, X_3^{'}, X_4)$	$r=f(X_1, X_2, X_3, X_4^{'})$

In row 9 enter row 8 minus A8 (for example, cell B9 becomes B8-A8). This gives the values of $\partial (r, X_1)$ as shown in table 7.3.

$\partial (r, X_1)=f(X_1+\partial X_1), X_2, X_3\ldots) - f(X_1, X_2, X_3..)$ *etc*.

To obtain the standard uncertainty on *y*, these individual contributions are squared, added together and then the square root taken, by entering $\partial (r, X_1)^2$ in row 10 (Figure 7.3) and putting the square root of their sum in A10. That is, cell A10 is set to the formula, SQRT(SUM(B10+C10+D10+E10)) which gives the standard uncertainty on r, $\partial (r)$

Table 7-3: Uncertainty evaluation sheet-3

	A	B	C	D	E
1		∂X_1	∂X_2	∂X_3	∂X_4
2					
3	X_1	$X_1+\partial X_1$	X_1	X_1	X_1
4	X_2	X_2	$X_2+\partial X_2$	X_2	X_2
5	X_3	X_3	X_3	$X_3+\partial X_3$	X_3
6	X_4	X_4	X_4	X_4	$X_4+\partial X_4$
7					
8	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1^{'}, X_2, X_3, X_4)$	$r=f(X_1, X_2^{'}, X_3, X_4)$	$r=f(X_1, X_2, X_3^{'}, X_4)$	$r=f(X_1, X_2, X_3, X_4^{'})$
9		$\partial (r,X_1)$	$\partial (r,X_2)$	$\partial (r,X_3)$	$\partial (r,X_4)$
10	$\partial (r)$	$\partial (r,X_1)^2$	$\partial (r,X_2)^2$	$\partial (,X_3)^2$	$\partial (r,X_4)^2$

7.3 Uncertainty evaluation of motor efficiency testing:

Based on above discussions, the methodology for estimating uncertainty in motor efficiency testing is explained below. This example refers to measurements and methodology given in Method-2 to estimate efficiency of a motor at the operating load.

Specification of the motor is given in table 7.4.

Table 7-4: Test Motor specifications

Motor specifications	**Value**	**Unit**
No of poles	4	-
Winding connection	DELTA	
Type	TEFC	
Output	30	kW
Voltage	415	Volts
Full load current, I_{FL}	53	Amp
Phase current at Full load, $I_{FL\text{-}ph}$	30.60	Amp
Speed	1465	rpm
Frequency	50	Hz
Full load Slip	0.023	p.u
Efficiency	88	%
Insulation	Class F	-
Full load winding temperature	115	Deg. C

An instrument accuracy table can be prepared as given in table 7.5, based on instrument specified accuracies and calibration certificates. It is necessary that all instruments are calibrated in the measurement ranges and the error at measurement points be known.

If actual calibration certificates are used, error at the measured value should be used in the instrument accuracy table.

Table 7-5: Instrument accuracy table

Condition	Description	Voltage	Current	Power	Resistance	Temperature	Frequency
		δU	δI	δP	δR	δT	δf
No load measurements	Error as % of measured value from calibration certificate	0.25%	-1.0%	5.00%	0.25%	1.00%	0.25%
Measurements at load		0.25%	-0.75%	0.5%	0.25%	1.00%	0.25%

In Table 7.6, absolute value each uncertainty term from the instrument accuracy table is added to the corresponding measured value, one parameter at a time.

Table 7-6: Effects of instrument error for each parameter

No load test	Measurements	δU_{nl}	δI_{nl}	δP_{nl}	δR_{ph-nl}	δT_{α}	δf
% error at measured value		0.25%	-1.00%	5.00%	0.25%	1.00%	0.25%
Absolute error at measured value		1.05	-0.27	93.79	0.00	0.35	0.13
Voltage, U	418.1	**419.15**	418.1	418.1	418.1	418.1	418.10
Current, I_{nl}	26.9	26.9	**26.63**	26.9	26.9	26.9	26.90
No load power input, P_{i-nl}	1875.7	1875.7	1875.7	**1969.49**	1875.7	1875.7	1875.7
Stator phase resistance after no load test, R_{ph-nl}	0.380	0.380	0.380	0.380	**0.381**	0.380	0.380
Ambient Temperature, T_a	35	35	35	35	35	**35.35**	35.00
Frequency, f	50.1	50.1	50.1	50.1	50.1	50.1	**50.23**

Measurements at actual load	Measurements	δU_L	δI_L	δP_L	δR_{ph-L}	δN_L	δf
% error at measured value		0.25%	-0.75%	0.50%	0.25%	1.0%	0.25%
Absolute error at measured value		1.05	-0.32	0.11	0.00	1.00	0.13
Voltage, U_L	420.00	**421.05**	420.00	420.00	420.00	420.00	420.00
Load current, I_L	42.00	42.00	**41.69**	42.00	42.00	42.00	42.00
Power input, P_L	22.92	22.92	22.92	**23.03**	22.92	22.92	22.92
Winding resistance at operating temperature, Rph-L	0.460	0.460	0.460	0.460	**0.461**	0.460	0.460
Operating speed, N_L	1475.00	1475.00	1475.00	1475.00	1475.00	**1476.00**	1475.00
Frequency, f	50.00	50.00	50.00	50.00	50.00	50.00	**50.13**

Estimation of uncertainty in results based on no load test and actual load measurements is summarized below in table 7.7.

Table 7.7: Estimation of uncertainty in results

Calculation of losses							
Stator Copper loss- no load	274.97	274.97	269.50	274.97	275.66	274.97	274.97
Constant loss	1600.73	1600.73	1606.20	1694.51	1600.04	1600.73	1600.73
Friction & windage loss	360	360	360	360	360	360	360
Core loss	1240.73	1240.73	1246.20	1334.51	1240.04	1240.73	1240.73
Stator Copper loss at actual load	811.44	811.44	799.31	811.44	813.47	811.44	811.44
Slip at actual load	0.017	0.017	0.017	0.017	0.017	0.016	0.019
Stray losses actual load	401.0	401.0	401.0	403.0	401.0	401.0	401.0
Rotor input at actual load	20461.9	20461.9	20468.5	20480.6	20460.5	20461.9	20461.9
Rotor copper loss at actual load	341.03	341.03	341.14	341.34	341.01	327.39	391.21
Total losses	3154.2	3154.21	3147.67	3250.32	3155.53	3140.57	3204.39
Delta		0.00	6.54	-96.10	-1.32	13.64	-50.18
Delta square		0.00	42.81	9235.82	1.74	186.08	2517.69
Uncertainty in Total loss estimation, watts		109.47					
% Uncertainty in Total loss estimation		3.5%					
Efficiency	86.2%	86.2%	86.3%	85.9%	86.2%	86.3%	86.0%
Delta		0.000000	-0.000286	0.003488	0.000058	-0.00059	0.002189
Delta Square		0.000000	8.15E-08	1.21E-05	3.31E-09	0.000008	0.000005
% uncertainty in efficiency estimation		**0.4%**					

The motor efficiency at operating load is thus expressed as **86.2 ± 0.4%**

7.4 Comments on Uncertainty Analysis:

- The uncertainty in efficiency is 0.4%. This means that the actual motor efficiency lies somewhere in the range of (86.2 –0.4) and (86.2+0.4). i.e. between 85.8 & 86.6%. When calculating energy saving by replacement of this motor with a high efficiency motor, calculate the savings using both efficiency values separately, which can help in building up optimistic and pessimistic scenarios.

- Note that the % error in no load power input measurement using the portable power analyser in the above measurement is 5% (from calibration table). If a power analyser which is specifically calibrated to measure power accurately at low p.f. is used, the error can be limited to 1.0%. In that case, the uncertainty in efficiency would reduce from 0.4% to 0.2%.

- For measuring slip at actual load, speed of the motor and frequency of supply should be measured simultaneously. Accurate instruments should be used for frequency measurements.

- The error in measurement of voltage, current, resistance etc. does not have much significance of overall error in efficiency estimation.

- Major contribution to overall error is the error in no load power measurement.

8 GUIDELINES FOR IDENTIFYING ENERGY SAVING OPPORTNITIES

8.1 Preparation of History Sheet

It is recommended to establish a record of all relevant information about the motor. The contents of such a system will vary from plant to plant and can include some the following features:

8.1.1 Motor record

- Motor identifier
- Date of purchase
- Manufacturer and model
- Enclosure
- Rated power
- Synchronous speed (number of poles)
- Frame size
- Rated voltage
- Full load current
- Full load speed
- Efficiency and power factor at 50 per cent, 75 per cent and full load

8.1.2 Motor maintenance log

- Date and reasons for failure
- Repairs and repair shop details
- Motor condition
- Maintenance history
- Scheduled maintenance

8.1.3 Plant records

- Plant number, motor number and repair priority
- Plant description, manufacturer and model
- Location in plant
- Information on spare components
- Load type
- Duty cycle
- Estimated load
- Starting method

8.2 Checklist of opportunities

8.2.1 Estimate life cycle cost of equipments

Life cycle cost analysis is a proven and accepted financial principle, which involves:

- Assessing purchase price
- Assessing operating costs
- Using a method, which accounts for the time value of money.

Compare life cycle cost when buying new motors.

8.2.2 Maintenance

- Machine cleaning: To ensure that ventilation and motor cooling is proper
- Machine set up and alignment: To ensure that the belt drives are set up properly,
- Bearing selection, fitting techniques and lubrication: Verify that they are lubricated and sealed properly
- Machine condition assessment: Vibration, unusual temperature rise etc indicate problems
- Electrical performance assessment: Regularly measure supply voltage variations. Voltage imbalance leads to higher losses

8.2.3 Avoiding Idle/Redundant running of motors

- Prolonged idling of machine tools, conveyors, exhaust fan, lights etc. can be avoided.
- Idle running of auxiliaries like cooling towers, air compressors, pumps etc. during prolonged stoppage of production machines.

8.2.4 Proper sizing of motors

- The efficiency of motors operating at loads below 40% is likely to be poor and energy savings are possible by replacing these with properly sized motors, new or interchanging with another load.
- If purchasing new motors, purchase high efficiency motor of proper size.

8.2.5 Operation in STAR connection for under loaded motors

- At light loads (30% or less), operation of 'Delta' connected motor in 'Star' connection can save energy. If a motor is oversized and continuously loaded below 30% of its rated shaft load, the motor can be permanently connected in Star.
- If the load is below 30% most of the time, but if the load exceeds 50% some times, automatic Star-Delta changeover Switches (based on current or load sensing) can be used.
- Savings can be 5 to 15% of the exiting power consumption

8.2.6 Improve Drive Transmission efficiency

- V-belt drives may have an efficiency of 85% to 90%. Replace them with modern synthetic flat belts, which have an efficiency of 96% to 98%.
- Worm gears, though have the quality of largely reducing ratios comes with inconsistent efficiency varying from 75% to 90%. A Helical bevel gear has efficiency of about 95%. Replacement of worm gear can be done if application is feasible.

8.2.7 Use of High efficiency Motors

- Saving vary from 5% for a 5 HP motor to 1% for a 100 HP motor.
- Values of motor efficiency as given in IEEMA Standard 19-2000 can be used. There are two efficiency catagories of efficiency viz. Eff1 & Eff2. To get good high efficiency motors, users are advised to specify efficiencies of new motors as per Eff1 values of IEEMA standards.
- Always mention efficiency values and do not just mention 'high efficiency motor'.

8.2.8 Follow good rewinding practices

- Rewind the motors as per the original winding data.
- Do not allow rewinders to use open flame or heat the stators above 350°C for extracting the old, burned out winding. This can increase core losses.

- Sand blasting of the core and/or grinding of laminations can create shorts in the core, leading to higher core losses.
- Keep data on no load inputs (current, power at a measured voltage) for all new motors, including motors returning after rewinding.
- Measure motor winding resistance after each rewinding

ANNEXURE-1: UNIT CONVERSION FACTORS

Parameter	SI Units	METRIC Units	US Units
Voltage	Volts	Volts	Volts
Current	Ampere	Ampere	Ampere
Resistance	Ohms	Ohms	Ohms
Speed	rpm	rpm	rpm
Power	1 kW	1 kW	1.341 HP
Temperature	1 K	1 ºC	1 ºF
time	1 Seconds	1 Seconds	1 Seconds

ANNEXURE-2: CALIBRATION TABLE

Instrument: Power Analyser
Range: 0-600V, 1000 A, 600 kW

Voltage:

Sr. No.	Standard meter reading, Volts	Test meter reading, Volts	% Error
1	50	50.3	0.60
2	100	100	0.00
3	200	202	1.00
4	300	301	0.33
5	400	401	0.25
6	500	501	0.20

Current:

Sr. No.	Standard meter reading, Amp	Test meter reading, Amp	% Error
1	5	4.95	-1.00
2	10	9.90	-1.00
3	20	19.80	-1.00
4	30	29.70	-1.00
5	40	39.70	-0.75
6	50	49.6	-0.80
7	100	99.1	-0.90
8	200	198	-1.00
9	300	298	-0.67
10	400	397	-0.75
11	500	497	-0.60

Power:

Range	Standard meter reading, Watts	Test meter reading, Watts	% Error
415V, 5 A, 0.3 lag	622.5	648	4.1
415V, 5 A, 0.8 lag	1660	1660	0.0
415V, 5 A, UPF	2050	2075	-1.2
415V, 10 A, 0.3 lag	1300	1245	4.42
415V, 10 A, 0.8 lag	3330	3320	0.30
415V, 10 A, UPF	4110	4150	-0.96
415V, 20 A, 0.3 lag	2580	2490	3.61
415V, 20 A, 0.8 lag	6640	6640	0.00
415V, 20 A, UPF	8210	8300	-1.08
415V, 30 A, 0.3 lag	3860	3735	3.35
415V, 30 A, 0.8 lag	9960	9960	0.00
415V, 30 A, UPF	12300	12450	-1.20
415V, 50 A, 0.3 lag	6450	6225	3.61
415V, 50 A, 0.8 lag	16600	16600	0.00
415V, 50 A, UPF	20600	20750	-0.72
415V, 100 A, 0.3 lag	12900	12450	3.61
415V, 100 A, 0.8 lag	33200	33200	0.00
415V, 100 A, UPF	41100	41500	-0.96
415V, 200 A, 0.3 lag	25700	24900	3.21
415V, 200 A, 0.8 lag	66500	66400	0.15
415V, 200 A, UPF	82300	83000	-0.84
415V, 400 A, 0.3 lag	51400	49800	3.21
415V, 400 A, 0.8 lag	13300	132800	0.15
415V, 400 A, UPF	16500	166000	-0.60
415V, 550 A, 0.3 lag	70300	68475	2.67
415V, 550 A, 0.8 lag	18300	182600	0.22
415V, 550 A, UPF	22700	228250	-0.55

ANNEXURE-3: LIST OF NABL ACCREDITED LABORATORIES

The following is a list of NABL accredited laboratories specialised in calibration of instruments.

Source: www.nabl-india.org

Belz Calibration Laboratory
Shed No. 133 A, HSIDC Sector 59,
Faridabad, Haryana,
india. Pin – 121004
Tel No. 0129 - 25239060
Fax No. 0129 – 25414855

Bharat Heavy Electricals Limited
Technical Services Department, Piplani,
Bhopal, Madhya Pradesh,
India. Pin – 462022
Tel No. 0755-2506328/2506692
Fax No. 0755-2500419/2201590

Central Electrical Testing Laboratory
District Tiruvallur,
Kakkalur, Tamil Nadu,
India. Pin – 602003
Tel No. 04116 260384/606302

Central Power Research Institute
Prof. C. V. Raman Road,
Sadashivnanagar Sub P.O. No. 8066,
Bangalore, Karnataka,
india. Pin – 560080
Tel No. 080 - 3602329
Fax No. 080 - 3601213.3606277

Electrical Research and Development Association
P. B. no. 760, Makarpura Road,
Vadodara, Gujarat,
india. Pin – 390010
Tel No. 0265 - 2642942/642964/642557
Fax No. 0265 - 2643182
Email erda@wilnetonline.net

Electroncis Regional Test Laboratory
Okhla Industrial Area, S Block, Phase II,
New Delhi, Delhi,
india. Pin – 110020
Tel No. 011 - 26386219 / 26384400
Fax No. 011 - 26384583
Email ertln@ernet.in

Electroncis Test and Development Centre
STQC Directorate , MIT,Malviya Industrial Area,
Jaipur, Rajasthan,
india. Pin – 302017
Tel No. 0141 - 2751636, 2751 506,2751884
Fax No. 0141 – 2751636

Electronics Test and Development Centre
B-108, Industrial Area, Phase 8, SAS Nagar,
Mohali, Punjab,
india. Pin – 160059
Tel No. 0172 - 256707,256639,256 711
Fax No. 0172 -256681
Email etdc@sancharnet.in

Electronics Test and Development Centre
Agriculture College Campus, Shivajinagar,
Pune, Maharashtra,
india. Pin – 410005
Tel No. 020 - 25537146/5537306
Fax No. 020 - 5539369
Email etdcpune@pn3.vsnl.net.in

Electronics Test and Development Centre
4/2 , B. T. Raod,
Kolkata, West Bengal,
india. Pin – 700056
Tel No. 033-25645520/25645370
Email etdccal@vsnl.net

Institute for Design of Electrical Measuring Instruments
Swatantryaveer Tatya Tope Marg, Chunabhatti,Sion P.O.,
Mumbai, Maharashtra,
india. Pin – 400022
Tel No. 022 - 25220302/25220303/25220304
Fax No. 022 – 25229016

Larsen & Toubro Limited
Quality Assurance Laboratory,
Electrical & Electronics Division, E
lectrical Sector, Powai,
Mumbai, Maharashtra,
india. Pin – 400072
Tel No. 022 - 28581401
Fax No. 022 – 28581023

Meter Testing and Standard Laboratory
Department of Electrical Inspectorate, Engineering College P.O,
Thiruvananthapuram, Kerala,
India. Pin – 695016
Tel No. 0471 330558

Palyam Engineers Pvt. Ltd.
"Milton Corners" No. 17, S.S.I. Area 5th Block, Rajajinagar,
Bangalore, Karnataka,
india. Pin – 560010
Tel No. 080 - 3355238
Fax No. 080 – 3350716
Regional Testing Centre
65/1, GST Raod, Guindy,
Chennai, Tamil Nadu,
india. Pin - 600 032
Tel No. 044 - 2343634, 2344684
Fax No. 044 – 2344684

Regional Testing Centre (E.R)
111/112 , B. T. Road,
Kolkata, West Bengal,
India. Pin - 700 108
Tel No. 033-2577 4055, 25772482
Fax No. 033 -2577 1353

Small Industries Testing and Research Centre
83 & 84, Avarampalyam Raod K.R. Puram PO,
Coimbatore, Tamil Nadu,
india. Pin – 641006
Tel No. 0422 - 2562612
Fax No. 0422 – 2560473

Sophisticated Test & Instrumentation Centre
Kochi University P.O Kochi, 6822022,
Kerala,
India. Pin - 68202
Tel No. 0484-2575908/2576697
Fax No. 0484-2575975

Yadav Metrolgoy Limited
P. O. Box No. 30, Pratap Nagar Industrial Area,
Udaipur, Rajasthan,
india. Pin – 313003
Tel No. 0249 - 2492300 -04
Fax No. 0249-2492310
Email balmukund.vyas@securemeters.com

ANNEXURE-4: REFERENCES

1. IEC 600 34-2: 1996 Rotating electrical machines- Part-2
2. IEC 600 34-2: Proposed draft document dated August 2003
3. IEEE Standard 112-1996: IEEE Test procedure for poly phase induction motors and generators
4. IS 4889: 1968 (reaffirmed 1996): Methods of determination of efficiency of rotating electrical machines
5. IS 4029: 1967 (Fifth Reprint 1984): Guide for testing Three phase induction motors
6. IS 325: 1996: Three Phase induction motors- Specification
7. Comparative Analysis of IEEE 112-B and IEC 34-2 Efficiency Testing Standards Using Stray losses in Low voltage Three Phase, cage Induction motors-
   Anibal T. de Almeda et. al *- IEEE Transactions on industry Applications, Vol. 38, no.2 March April 2002*
8. Can Field Tests Prove Motor Efficiency?
   Richard L. Nailsen - *IEEE Transactions on industry Applications, Vol. 25, no.2 May-June 1989*
9. Performance Optimization Tips: Measuring the Heart Rate of Motor Systems: Electric Current :***Don Casada*** *– Energy Matters- US Dept. of Energy, 2001*