Baldor Basics: Motors

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A continuing series of articles, courtesy of the Baldor Electric Co., dedicated primarily to motor basics; e.g. — how to specify them; how to operate them; how — and when — to repair or replace them, and considerably more. Stay tuned!

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Motor Temperature Ratings

A frequently misunderstood subject related to electric motors is insulation class and temperature ratings. This paper tries to describe, in basic terms, the temperature relationships that are meaningful in standard AC induction motors. Some of the same information can be applied to DC motors but DC motors are more specialized and some of the ratings are slightly different. *Perhaps the best way to start is to define the commonly used terms.*

Definitions

Ambient temperature. Ambient temperature is the temperature of the air surrounding the motor or the room temperature in the vicinity of the motor. This is the "threshold point" or temperature that the entire motor would assume when it is shut off and completely cool.

Temperature rise. Temperature rise is the *change* in temperature of the critical electrical parts within a motor when it is being operated at full load. For example: if a motor is located in a room with a temperature of 78° F, and then is started and operated continuously *at full load*, the winding temperature would rise from 78° F to a higher temperature. The difference between its starting temperature and the final elevated temperature, is the motor's *temperature rise*.

Hot-spot allowance. Since the most common method of measuring "temperature rise" of a motor involves taking the difference between the cold and hot ohmic resistance of the motor winding (s*ee Appendix for formula to determine temperature rise by resistance*), this test gives the *average* temperature change of the entire winding including the motor leads and end turns, as well as wire placed deep inside the stator slots. Since some of these spots are bound to be hotter than others, an allowance factor is made to "fudge" the average temperature to give a reflection of what the temperature might be at the hottest spot. This allowance factor is called the "hot spot allowance."

Insulation class. Insulations have been standardized and graded by their resistance to thermal aging and failure. Four insulation classes are in common use. For simplicity, they have been designated by the letters A, B, F, and H. The temperature capabilities of these classes are separated from each other by 25° C increments. The temperature capabilities of each insulation class are defined as being the maximum temperature at which the insulation can be operated to yield an average life of 20,000 hours. The rating for 20,000 hours of average insulation life is as shown below.

Insulation Class	Temperature Rating
A	105° C
B	130° C
F	155° C
H	180° C

Insulation system. There are a number of insulating components used in the process of building motors. The obvious ones are the enamel coating on the magnet wire and the insulation on the leads that come to the conduit box. Some less obvious components of the "system" are the sleeving that is used over joints where leads connect to the magnet wire, and the lacing string that is used to bind the end turns of the motor. Other components are the slot liners that are used in the stator laminations to protect the wire from chafing. Also, top sticks are used to hold the wire down in place inside the stator slots. Another important component of the system is the varnish in which the completed assembly is dipped prior to being baked. The dipping varnish serves the purpose of sealing nicks or scratches that may occur during the winding process. The varnish also binds the entire winding together into a solid mass so that it does not vibrate and chafe when subjected to the high magnetic forces that exist in the motor. Much like a chain that is only as strong as its weakest link, the classification of an insulation system is based on the temperature rating of the lowest rated component used in the system. For example, if one Class B component is used along with F and H components, the entire system must be called Class B.

Putting It All Together

Now that the basic terms have been identified, we can move on to understand the total picture and how the factors of temperature go together in the motor rating.

The basic ambient temperature rating point of nearly all electric motors is 40° C. This means that a motor, rated for 40° C ambient, is suitable for installation in applications where the normal surrounding air temperature does not exceed 40° C. This is approximately 104° F — a *very* warm room. This is the starting point.

When the motor is operated at full load, it has a certain amount of temperature rise. The amount of temperature rise is *always additive* to the ambient temperature. For example, U frame motors were designed for Class A insulation and a maximum temperature rise by resistance of 55° C. When operated in a 40° C ambient temperature, this would give a total average winding temperature of 40° (ambient) + 55° (rise) or 95° C. The ten degree difference between 95° C and the 105° C rating of Class A insulation is used to handle the "hot spot allowance". Now, if you use the same motor design but change the system to Class B, there is an extra 25° C of thermal capability available. This extra thermal capability can be used to handle:

- Higher than normal ambient temperatures
- Higher than normal temperature rise brought on by overloads
- Extra capability can be used to extend motor life and make it more tolerant of overheating factors caused by high or low voltages; voltage imbalance; blocked ventilation; high inertia loads; frequent starts; and any other factors that can produce above-normal operating temperatures.

For example: if a motor with Class A "design" (55° C) temperature rise is built with Class B insulation, then it could be expected to give a normal insulation life, even when subjected to ambient temperatures of 65° C. Most "T" frame motors are designed for use with Class B insulation. In a "T" frame motor with Class B insulation, the extra 25° of thermal capacity (Class B compared to Class A), is utilized to accommodate the higher temperature rise associated with the physically smaller "T" frame motors. For example: a standard T frame, open drip-proof motor might have the following rating: 40° C ambient, 80° C temperature rise, and a 10° hot spot allowance. When these three components are added together you will find that the total temperature capability of Class B insulation (130° C) is used up.

Changing insulation classes. By taking a Class B, totally enclosed fan cooled, T frame motor, and building it with Class F insulation, it is usually possible to increase the service factor from 1.0 to 1.15. As mentioned previously, this same change of one insulation class can be used to handle a higher ambient temperature or to increase the life expectancy of the motor. The same change could also make the motor more suitable for operation in high elevations where thinner air has a less cooling effect.

Actual insulating practice. Over the years, great improvements have been made in insulating materials. With these improvements have come cost reductions. As a result of these changes, most motor manufacturers use a mixture of materials in their motors, many of which have higher than required temperature ratings. For example, Baldor does not use Class A materials. This means that even though many fractional horsepower motors are designed for Class A temperature rise, the real insulation is Class B or better. Similarly, many motors designed for Class B temperature rise actually have insulation systems utilizing Class F and H materials. This extra margin gives the motor a "life bonus." At the present time Baldor has standardized an ISR (inverter spike-resistant) magnet wire in all three phase motors 1 HP and larger. This wire has a Class H temperature rating and excellent resistance to high voltage spikes.

As a rule, insulation life will be doubled for each 10 degrees of *unused* insulation temperature capability. For example: if a motor is designed to have a total temperature of 110° C (including ambient, rise, and hot spot allowance), and is built with a Class B (130° C) system, an unused capacity of 20° C would exist. This extra margin would raise the expected motor insulation life from 20,000 hours to 80,000 hours. Similarly, if a motor is not loaded to full capacity its temperature rise will be lower. This automatically makes the total temperature lower and extends motor life. Also, if the motor is operated in a lower than 40° C ambient temperature, motor life will be extended.

The same "ten degree rule" also applies to motors operating at above-rated temperatures. In such cases insulation life is "halved" for each 10° C of over-temperature.

Motor surface temperatures. Motor surface temperature is frequently a concern. The motor surface temperature will never exceed the internal temperature of the motor. However, depending upon the design and cooling arrangements in the motor, motor surface temperature in modern motors can be high enough to be very uncomfortable to the touch. Surface temperatures of 75° to 95° C can be found on T frame motor designs. These temperatures do not necessarily indicate overload or impending motor failure.

Other factors. Insulation life is affected by many factors aside from temperature. Moisture, chemicals, oil, vibration, fungus growth, abrasive particles, and mechanical abrasion created by frequent starts — all work to shorten insulation life. On some applications, if the operating environment and motor load conditions can be properly defined, suitable means of winding protection can be provided to obtain reasonable motor life despite external, disturbing factors.

Old and current standards. U frame 184 through 445U frames were designed based on using Class A insulation. Temperature rise was not precisely defined by the resistance method. Temperature rise by thermometer for Class A, open drip-proof motors was 40° C. This was generally thought to be equivalent to approximately 50° C by resistance. U frame motors were the industry standard from 1954 to 1965 and are still preferred in some industries and plants. T frame, 143T through 449T motors are generally designed based on using Class B insulation with temperature rises by resistance of approximately 80° C. Production of T frame motors started in the mid-sixties and they continue to be the industry standard at this time.

Table 1 Temperature ratings, temperature rise allowances and hot-spot allowances for various enclosures and service factors of standard motors

Insulation System Class	A	B	F	H
Temperature Rating in Degrees Centigrade	105°	130°	155°	180°
Temperature Rise Allowance by Resistance (Based on 40° C Ambient Temperature)				
All Motors with 1.15 Service Factor	70	90	115	—
(Hot Spot Allowance)	*	*	*	*
Totally Enclosed Fan Cooled Motors	60	80	105	125
(Hot Spot Allowance)	(5)	(10)	(10)	(15)
Totally Enclosed Non-Ventilated Motors	65	85	110	135
(Hot Spot Allowance)	(0)	(5)	(5)	(5)
Motors other than those listed above	60	80	105	125
(Hot Spot Allowance)	(5)	(10)	(10)	(15)

* When operating at service factor loading the hot spot temperatures can actually exceed the insulation rating resulting in shortened motor life.

Table 2 Temperature-related, life-shortening factors — with symptoms and cures

Temperature Related Life-Shortening Factors		
PROBLEMS	**SYMPTOMS**	**CURES**
Low Voltage	Overload Tripping High current Short motor life	Correct power supply or match motor to actual power supply voltage rating.
High Voltage	Overload tripping High current Short Motor Life	Correct power supply or match motor to actual power supply voltage rating
Unbalanced Voltage	Unbalanced phase currents Overload tripping	Determine why voltages are unbalanced and correct.
Overload	Overload tripping High current Short motor life	Determine reason for overload. Increase motor size or decrease load speed.
High Ambient Temperatures	Short motor life	* Rewind motor to higher class of insulation. Oversize motor to reduce temperature rise. Ventilate area to reduce ambient temperature.
Blocked Ventilation	Short motor life Runs hot Amperage o.k.	Clean lint and debris from air passageways or use proper motor enclosure for application.
Frequent Starts	Short motor life	** Use a reduced voltage starting method. Upgrade class of insulation.
High Inertia Loads	Short motor life Overload tripping during starting	Oversize motor frame Use higher class of insulation. ** Use a reduced voltage starting method.

* Bearing lubrication must also be matched to high operating temperature.

** Reduced voltage starting method and motor characteristics must be matched to the load requirement.

Summary

A key ingredient in motor life is the insulation system used in the motor. Aside from vibration, moisture, chemicals, and other non-temperature related life-shortening items, the key to insulation and motor life is the maximum temperature that the insulation system experiences and the temperature capabilities of the system components (see Tables 1 and 2).

Appendix

Temperature Rise by Resistance Method

$$\text{Degrees C Rise} = \frac{Rh - Rc}{Rc}(234.5 + T)$$

Where

R_c = Cold winding resistance (Ohms)
R_h = Hot winding resistance (Ohms)
T = Cold (ambient) temperature in degrees (Centigrade)

Note: This formula assumes that the ambient temperature does not change during the test.

Example: A small motor has a cold temperature resistance of 3.2 ohms at 25° C (77° F) ambient temperature. After operating at full load for several hours the resistance measures 4.1 ohms, and the ambient has increased to 28° C.

Calculate the temperature rise:

$$\text{Apparent rise} = \frac{4.1 - 3.2}{3.2}(234.5 + 25) = 73^\circ\text{C}$$

Correcting for 3° C increase in ambient:

$$\text{Actual rise} = 73^\circ - 3^\circ = 70^\circ\text{C}$$

Centigrade Fahrenheit Conversions (Actual Temperatures)

To change Fahrenheit to Centigrade:

$$C^\circ = (F^\circ - 32)\ \tfrac{5}{9}$$

To change Centigrade to Fahrenheit:

$$F^\circ = (C^\circ \times \tfrac{9}{5}) + 32$$

Rise values only:

Degrees "C" rise = ° F (Rise) × .56
Degrees "F" rise = ° C (Rise) × 1.8

Metric Motors

The influx of foreign equipment have put great numbers of metric motors in plants. As a result of this and the age of these motors, we are seeing inquiries for replacement motors that will match the IEC (International Electrical Commission) standards.

To help identify these motors and make suitable replacements, the following information could be useful.

Rating system. One of the first things is that ratings are given in kilowatts (KW) rather than horsepower. The first thing to do is to convert from kilowatts to horsepower. It is important to note that even though KW is an electrical term, in this case it is associated with mechanical output (just as horsepower is in this country). A simple factor will make the conversion. *Multiply the KW rating of the motor by 1.34 to get the horsepower of the motor*. For example, a 2 KW motor would be equal to approximately 2.7 HP and the closest NEMA equivalent would be 3 HP.

The next item of concern would be the speed of the motor. Generally, somewhere on the nameplate of the foreign motor, you find the speed listed in RPM. The convention in Europe seems to be to show the no load speed of the motor and occasionally, the 50 cycle speed may be shown rather than the 60 cycle speed. Table 3 shows a crossover from the 50 cycle speeds to the equivalent 60 cycle speeds. In some cases, both the 50 and 60 cycle speeds are shown generally separated with a slash, for example, 1,500/1,800 RPM. This would be a 4 pole motor that U. S. manufacturers would show nameplated with its full load speed. In this case it might be 1725 to 1760 RPM depending on the size of the motor.

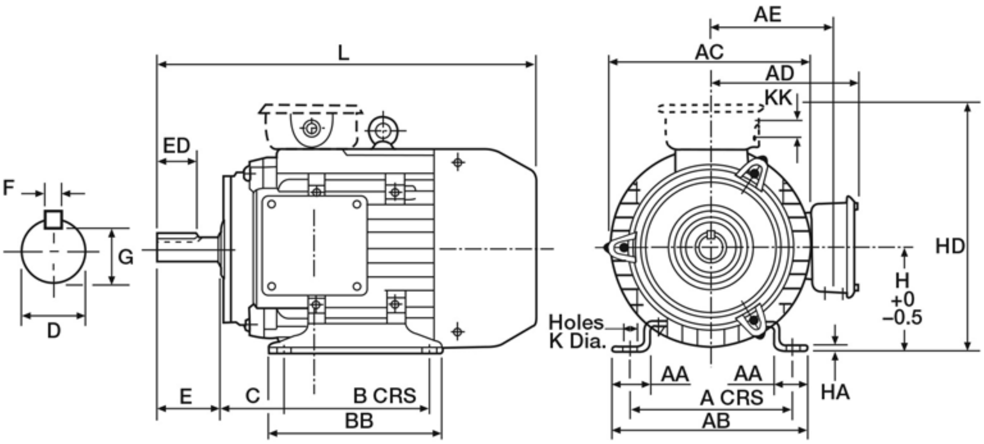
Efficiency. IEC 60034-30 specifies the efficiency levels for metric 50 Hz motors. The equivalent to our EPAct level of energy efficient motors (NEMA MG 1, table 12-11) is IE2; and premium efficient motors (NEMA MG 1, table 12-12) are IE3. Baldor manufactures metric motors to both levels. A new IEC

Table 3 Crossover from 50 cycle speeds to equivalent 60 cycle speeds

	FREQUENCY			
	50 HZ SPEEDS (RPM)		60 HZ SPEEDS (RPM)	
POLES	SYNCHRONOUS	FULL LOAD (Typical)	SYNCHRONOUS	FULL LOAD (Typical)
2	3000	2850	3600	3450
4	1500	1425	1800	1725
6	1000	950	1200	1150
8	750	700	900	850

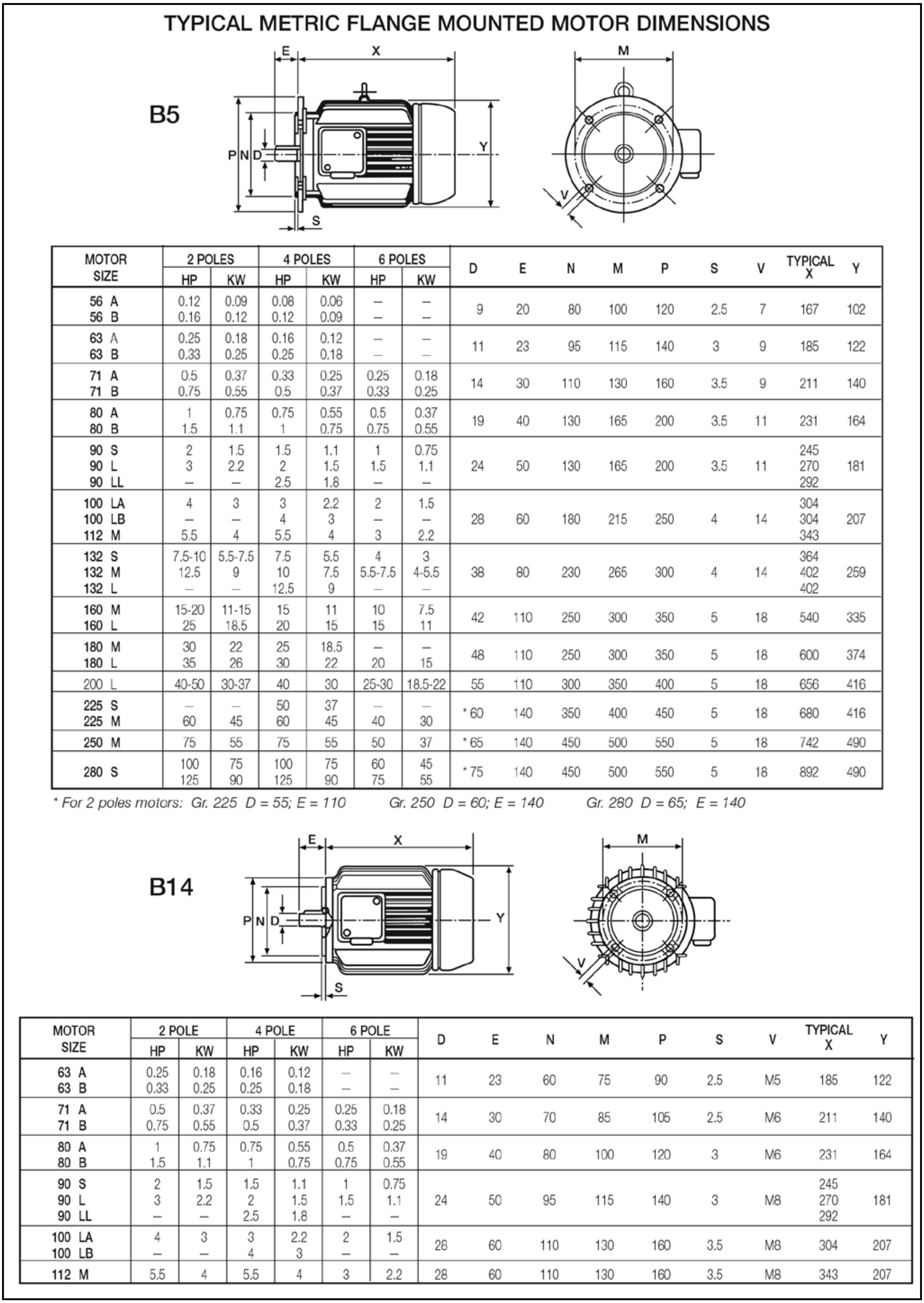
Table 4 Typical metric foot mounted dimensions frame sizes for rigid-base motors and associated metric dimensions (dimensions are in millimeters — divide by 25.4 to get inch equivalents)

TYPICAL METRIC FOOT MOUNTED DIMENSIONS



Frame Size	Fixing					Shaft					General							
	A	B	C	H	K	D	E	F	G	ED	AA	AB	BB	Typical L	HA	AC	AD	HD
D63	100	80	40	63	7	11	23	3	8.5	10	19	119	100	207	2	126	–	169
D71	112	90	45	71	7	14	30	5	11	14	19	131	110	251	2	126	–	177
D80	125	100	50	80	10	19	40	6	15.5	25	27	157	127	295	4	158	132	212
D90S	140	100	56	90	10	24	50	8	20	32	28	174	127	314	4	178	140	230
D90L	140	125	56	90	10	24	50	8	20	32	28	174	152	339	4	178	140	230
D100L	160	140	63	100	12	28	60	8	24	40	28	184	170	371	4	208	138	251
D112M	190	140	70	112	12	28	60	8	24	40	37	214	170	384	4	243	192	233
D132S	216	140	89	132	12	38	80	10	33	56	38	243	208	463	5	243	234	371
D132M	216	178	89	132	12	38	80	10	33	56	38	243	208	463	5	243	234	271
D160M	254	210	108	160	15	42	110	12	37	80	49	304	304	598	5	329	278	328
D160L	254	254	108	160	15	42	110	12	37	80	49	304	304	598	5	329	278	328
D180M	279	241	121	180	15	48	110	14	42.5	80	51	329	329	698	8	388	317	375
D180L	279	279	121	180	15	48	110	14	42.5	80	51	329	329	698	8	388	317	375
D200L	318	305	133	200	19	55	110	16	49	80	60	380	379	745	10	453	357	410

Table 5 Typical metric flange-mounted motor dimensions (note that dimensions are given in millimeters)



TYPICAL METRIC FLANGE MOUNTED MOTOR DIMENSIONS

B5

MOTOR SIZE	2 POLES		4 POLES		6 POLES		D	E	N	M	P	S	V	TYPICAL X	Y
	HP	KW	HP	KW	HP	KW									
56 A 56 B	0.12 0.16	0.09 0.12	0.08 0.12	0.06 0.09	– –	– –	9	20	80	100	120	2.5	7	167	102
63 A 63 B	0.25 0.33	0.18 0.25	0.16 0.25	0.12 0.18	– –	– –	11	23	95	115	140	3	9	185	122
71 A 71 B	0.5 0.75	0.37 0.55	0.33 0.5	0.25 0.37	0.25 0.33	0.18 0.25	14	30	110	130	160	3.5	9	211	140
80 A 80 B	1 1.5	0.75 1.1	0.75 1	0.55 0.75	0.5 0.75	0.37 0.55	19	40	130	165	200	3.5	11	231	164
90 S 90 L 90 LL	2 3 –	1.5 2.2 –	1.5 2 2.5	1.1 1.5 1.8	1 1.5 –	0.75 1.1 –	24	50	130	165	200	3.5	11	245 270 292	181
100 LA 100 LB 112 M	4 – 5.5	3 – 4	3 4 5.5	2.2 3 4	2 – 3	1.5 – 2.2	28	60	180	215	250	4	14	304 304 343	207
132 S 132 M 132 L	7.5-10 12.5 –	5.5-7.5 9 –	7.5 10 12.5	5.5 7.5 9	4 5.5-7.5 –	3 4-5.5 –	38	80	230	265	300	4	14	364 402 402	259
160 M 160 L	15-20 25	11-15 18.5	15 20	11 15	10 15	7.5 11	42	110	250	300	350	5	18	540	335
180 M 180 L	30 35	22 26	25 30	18.5 22	– 20	– 15	48	110	250	300	350	5	18	600	374
200 L	40-50	30-37	40	30	25-30	18.5-22	55	110	300	350	400	5	18	656	416
225 S 225 M	– 60	– 45	50 60	37 45	– 40	– 30	* 60	140	350	400	450	5	18	680	416
250 M	75	55	75	55	50	37	* 65	140	450	500	550	5	18	742	490
280 S	100 125	75 90	100 125	75 90	60 75	45 55	* 75	140	450	500	550	5	18	892	490

** For 2 poles motors: Gr. 225 D = 55; E = 110 Gr. 250 D = 60; E = 140 Gr. 280 D = 65; E = 140*

B14

MOTOR SIZE	2 POLE		4 POLE		6 POLE		D	E	N	M	P	S	V	TYPICAL X	Y
	HP	KW	HP	KW	HP	KW									
63 A 63 B	0.25 0.33	0.18 0.25	0.16 0.25	0.12 0.18	– –	– –	11	23	60	75	90	2.5	M5	185	122
71 A 71 B	0.5 0.75	0.37 0.55	0.33 0.5	0.25 0.37	0.25 0.33	0.18 0.25	14	30	70	85	105	2.5	M6	211	140
80 A 80 B	1 1.5	0.75 1.1	0.75 1	0.55 0.75	0.5 0.75	0.37 0.55	19	40	80	100	120	3	M6	231	164
90 S 90 L 90 LL	2 3 –	1.5 2.2 –	1.5 2 2.5	1.1 1.5 1.8	1 1.5 –	0.75 1.1 –	24	50	95	115	140	3	M8	245 270 292	181
100 LA 100 LB	4 –	3 –	3 4	2.2 3	2 –	1.5 –	28	60	110	130	160	3.5	M8	304	207
112 M	5.5	4	5.5	4	3	2.2	28	60	110	130	160	3.5	M8	343	207

60034-2-1 test method now measures all losses and is equivalent to IEEE 112b and CSA 390.

Failure replacement. When an IEC (metric) motor fails in service the most practical way to proceed is to attempt to get an exact metric framed replacement motor. Baldor and other manufacturers offer a limited selection of the most popular ratings for direct replacement.

When direct replacements are not available, the following information should be helpful in adapting NEMA frame motors to the metric application.

Frame size. European frame sizes are handled in a different way from U. S. frame sizes. They are based on the shaft height (equivalent to our "D" dimension) *in millimeters*. For example, a 112 frame would have a 112 millimeters shaft height. Convert this to inches by dividing 112 by 25.4 to get an equivalent domestic shaft height. In this case, the shaft height of a 112 frame would be slightly over 4.4 inches and the closest NEMA frame motor would be a 180 series frame (182, 184, 182T or 184T) with a shaft height of 4.5 inches. This is true for IEC base mounted motors. In the case of this motor, it would be necessary to make adjustments on the machine that would allow for either using the 180 series frame domestic motor and aligning the shaft height difference or by selecting a 145T or 56 frame motor (3.5" shaft height) and shimming up to get the proper alignment. The bolt pattern on the bases of IEC motors are given as metric dimensions and it is impossible to get complete interchangeability with NEMA frame sizes. However, it is usually possible on foot mounted motors to adapt to domestic frame sizes by drilling new holes or making other accommodation to accept the different footprint of the NEMA frame motor. IEC frame sizes for rigid base motors and the associated metric dimensions are shown in Table 4. (Dimensions are in Millimeters — divide by 25.4 to get inch equivalents.)

Flange-mounted motors. Flange mounted motors become a real nemesis for conversion. There are two popular face mounting configurations used on the IEC motors. The most popular is the "B5" configuration, which is closest to NEMA "D" flange motors. The important thing to note is that with the B5 flange, *the clearance holes are in the flange* and the threaded holes are in the mating part, such as the pump, gear reducer or machine. The other popular IEC flange is the B14 flange. In this case, *the threaded holes are in the face of the motor* much the same as the NEMA "C" face motors.

IEC flange-mounted motors all have metric rather than inch shaft diameters and where threaded holes are involved, they are metric rather than "inch" threads. To replace metric flange mounted motors, an exact flange mounting equivalent would be necessary unless someone is resourceful enough to make adapter flanges that would convert NEMA "C" face motors to the metric dimensions required. Since this usually is not the case, metric flange mounted motors have to be replaced with metric motors. Table 5 shows typical metric dimensions for B5 and B14 metric motors. Note that dimensions are given in millimeters.

Baldor is now offering selections of metric, three-phase motors through 200kW. Also in stock are some permanent magnet DC motors that can be used as replacement units. On a custom basis when reasonable quantities are involved we can build many different metric equivalent motors.

Summary

This information should be useful in your day-to-day dealings in metric replacements. **PTE**

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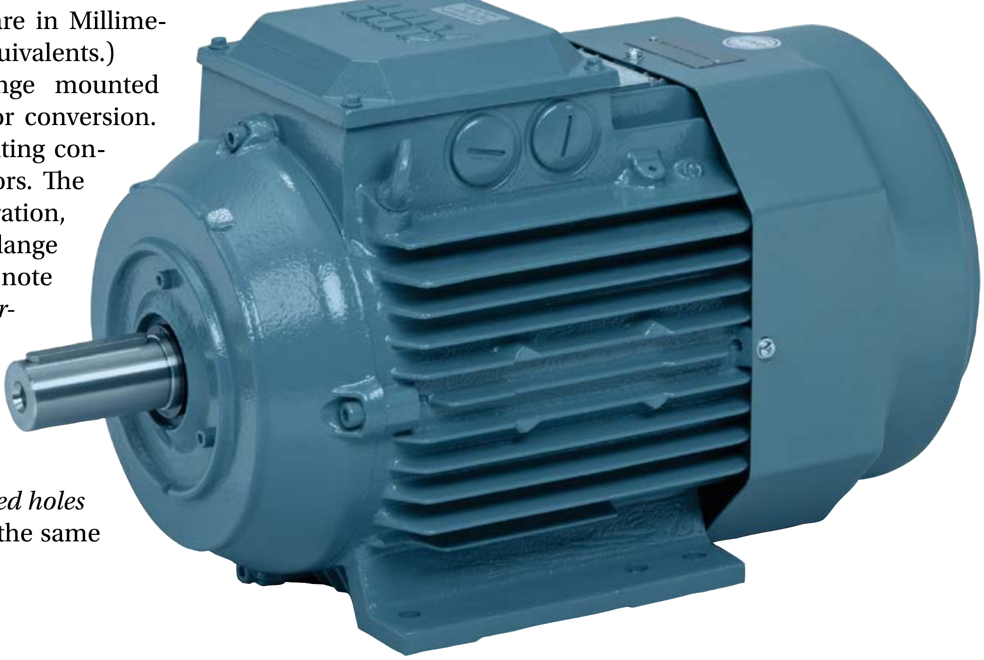

Example of an ABB motor available in IEC frame sizes and specifications in metric dimensions.