Baldor Basics: Motors

Edward Cowern, P.E.

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!

THIS ISSUE:
The Mystery of Motor Frame Size
Primer on Two-Speed Motors

Introduction

Industrial electric motors have been available for nearly a century. In that time there have been a great many changes. One of the most obvious has been the ability to pack more horsepower in a smaller physical size. Another important achievement has been the standardization of motors by the National Electric Manufacturers Association (NEMA).

A key part of motor interchangeability has been the standardization of frame sizes. This means that the same horsepower, speed, and enclosure will normally have the same frame size from different motor manufacturers. Thus, a motor from one manufacturer can be replaced with a similar motor from another company provided they are both in standard frame sizes.

Three Generations

The standardization effort over the last forty-plus years has resulted in one original grouping of frame sizes called "original." In 1952, new frame assignments were made. These were called "U frames." The current "T frames" were introduced in 1964. "T" frames are the current standard and most likely will continue to be for some time in the future.

Even though "T" frames were adopted in 1964, there are still a great many "U" frame motors in service that will have to be replaced in the future. Similarly there are also many of the original frame size motors (pre-1952) that will reach the end of their useful life and will have to be replaced. For this reason it is desirable to have reference material available on frame sizes and some knowledge of changes that took place as a part of the so-called re-rate programs.

Frame Size Reference Tables

Tables 1 and 2 show the standard frame size assignments for the three different eras of motors. As you will note, these tables are broken down for open drip proof (Table 1) and totally enclosed (Table 2). You will also find that for each horsepower rating and speed, there are three different frame sizes — first is the original frame size; the middle one is the "U frame" size; and the third one is the "T frame." These are handy reference tables since they give general information for all three vintages of three-phase motors in integral horsepower frame sizes.

One important item to remember is that the base mounting hole spacing ("E" and "F" dimensions) and shaft height ("D" dimension) for all frames having the same three digits — regardless of vintage — will be the same.

Rerating and Temperatures

The ability to re-rate motor frames to get more horsepower in a frame has been brought about mainly by improvements made in insulating materials. As a result of this improved insulation, motors can now be run much hotter. This allows more horsepower in a compact frame. For example, the original NEMA frame sizes ran at very low temperatures. The "U" frame motors were designed for use with Class A insulation, which has a rating of 105° C. The motor designs were such that the capability would be used at the hottest spot within the motor. "T" frame motor designs are based on utilizing Class B insulation with a temperature rating of 130° C. This increase in temperature capability made it possible to pack more horsepower into the same size frame. To accommodate the larger mechanical horsepower capability, shaft and bearing sizes had to be increased. Thus, you will find that the original 254 frame (5 HP at 1,800 RPM) has a 1⅛" shaft. The 254U frame (7½ HP at 1,800 RPM) has a 1⅜" shaft, and the current 254T frame (15 HP at 1800 RPM) has a 1⅝" shaft. Bearing diameters were also increased to accommodate the larger shaft sizes and heavier loads associated with the higher horsepower.

Frame Size Basis

On page 14 you will find a Baldor frame size chart that is a great reference on "T" frame, "U" frame and original frame motors. Most of the dimensions are standard dimensions that are common to all motor manufacturers. One exception to this is the "C" dimension (overall motor length) which will change from one manufacturer to another.

Fractional Horsepower Motors

The term "fractional horsepower" is used to cover those frame sizes having two-digit designations as opposed to the three-digit designations that are found in Tables 1 and 2. The frame sizes that are normally associated with industrial fractional horsepower motors are 42, 48, and 56. In this case, each frame size designates a particular shaft height, shaft diameter, and face or base mounting hole pattern. In these motors specific frame assignments have not been made by horsepower and speed, so it is possible that a particular horsepower and speed combination might be found in three different frame sizes. In this case, for replacement it is *essential that the frame size be known as well as the horsepower, speed and enclosure*. The derivation of the two-digit frame number is based on the shaft height in sixteenths of an inch.

Table 1 Open Drip-Proof

THREE PHASE FRAME SIZES - GENERAL PURPOSE

RPM NEMA Program HP	3600			1800			1200			900		
	Orig.	1952 Rerate	1964 Rerate	Orig.	1952 Rerate	1964 Rerate	Orig.	1952 Rerate	1964 Rerate	Orig.	1952 Rerate	1964 Rerate
1				203	182	143T	204	184	145T	225	213	182T
1.5	203	182	143T	204	184	145T	224	184	182T	254	213	184T
2	204	184	145T	224	184	145T	225	213	184T	254	215	213T
3	224	184	145T	225	213	182T	254	215	213T	284	254U	215T
5	225	213	182T	254	215	184T	284	254U	215T	324	256U	254T
7.5	254	215	184T	284	254U	213T	324	256U	254T	326	284U	256T
10	284	254U	213T	324	256U	215T	326	284U	256T	364	286U	284T
15	324	256U	215T	326	284U	254T	364	324U	284T	365	326U	286T
20	326	284U	254T	364	286U	256T	365	326U	286T	404	364U	324T
25	364S	286U	256T	364	324U	284T	404	364U	324T	405	365U	326T
30	364S	324US	284TS	365	326U	286T	405	365U	326T	444	404U	364T
40	365S	326US	286TS	404	364U	324T	444	404U	364T	445	405U	365T
50	404S	364US	324TS	405S	365US	326T	445	405U	365T	504	444U	404T
60	405S	365US	326TS	444S	404US	364T	504	444U	404T	505	445U	405T
75	444S	404US	364TS	445S	405US	365T	505	445U	405T	—	—	444T
100	445S	405US	365TS	504S	444US	404T	—	—	444T	—	—	445T
125	504S	444US	404TS	505S	445US	405T	—	—	445T	—		
150	505S	445US	405TS	—		444T	—					
200			444TS	—		445T	—					
250			445TS	—								

Table 2 Totally Enclosed, Fan-Cooled

THREE PHASE FRAME SIZES - GENERAL PURPOSE

RPM NEMA Program HP	3600			1800			1200			900		
	Orig.	1952 Rerate	1964 Rerate	Orig.	1952 Rerate	1964 Rerate	Orig.	1952 Rerate	1964 Rerate	Orig.	1952 Rerate	1964 Rerate
1				203	182	143T	204	184	145T	225	213	182T
1.5	203	182	143T	204	184	145T	224	184	182T	254	213	184T
2	204	184	145T	224	184	145T	225	213	184T	254	215	213T
3	224	184	182T	225	213	182T	254	215	213T	284	254U	215T
5	225	213	184T	254	215	184T	284	254U	215T	324	256U	254T
7.5	254	215	213T	284	254U	213T	324	256U	254T	326	284U	256T
10	284	254U	215T	324	256U	215T	326	284U	256T	364	286U	284T
15	324	256U	254T	326	284U	254T	364	324U	284T	365	326U	286T
20	326	286U	256T	364	286U	256T	365	326U	286T	404	364U	324T
25	365S	324U	284TS	365	324U	284T	404	364U	324T	405	365U	326T
30	404S	326US	286TS	404	326U	286T	405	365U	326T	444	404U	364T
40	405S	364US	324TS	405	364U	324T	444	404U	364T	445	405U	365T
50	444S	365US	326TS	444S	365US	326T	445	405U	365T	504	444U	404T
60	445S	405US	364TS	445S	405US	364T	504	444U	404T	505	445U	405T
75	504S	444US	365TS	504S	444US	365T	505	445U	405T	—	—	444T
100	505S	445US	405TS	505S	445US	405T		—	444T	—	—	445T
125			444TS	—		444T		—	445T	—		
150			445TS	—		445T						

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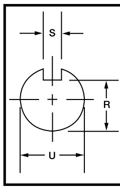
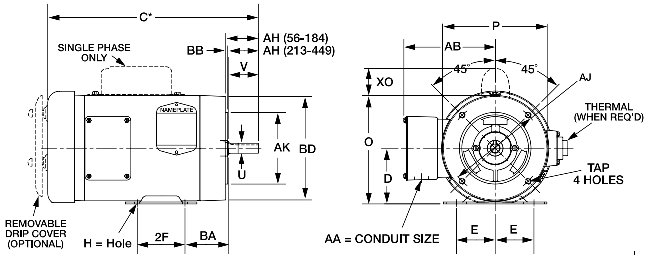
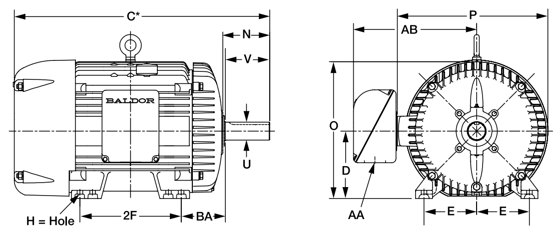


NEMA Shaft	Keyseat Dimensions		NEMA Shaft	Keyseat Dimensions	
(U)	(R)	(S)	(U)	(R)	(S)
3/8	21/64	FLAT	1-7/8	1-19/32	1/2
1/2	29/64	FLAT	2-1/8	1-27/32	1/2
5/8	33/64	3/16	2-3/8	2-1/64	5/8
7/8	49/64	3/16	2-1/2	2-3/16	5/8
1-1/8	63/64	1/4	2-7/8	2-29/64	3/4
1-3/8	1-13/64	5/16	3-3/8	2-7/8	7/8
1-5/8	1-13/32	3/8	3-7/8	3-5/16	1





Drawings represent standard TEFC general purpose motors.

*Dimensions are for reference only.

*Contact your local Baldor Sales Office for "C" Dimensions.

Dimensions - N, O, P, AB and XO are specific to Baldor.

NEMA QUICK REFERENCE CHART

NEMA FRAME	D	E	2F	H	N	O	P	U	V	AA	AB	AH	AJ	AK	BA	BB	BD	XO	TAP
42	2-5/8	1-3/4	1-11/16	9/32 SLOT	1-1/2	5	4-11/16	3/8	1-1/8	3/8	4-1/32	1-5/16	3-3/4	3	2-1/16	1/8	4-5/8	1-9/16	1/4-20
48	3	2-1/8	2-3/4	11/32 SLOT	1-7/8	5-7/8	5-11/16	1/2	1-1/2	1/2	4-3/8	1-11/16	3-3/4	3	2-1/2	1/8	5-5/8	2-1/4	1/4-20
56 56H	3-1/2	2-7/16	3 5	11/32 SLOT	2-7/16 2-1/8	6-7/8	6-5/8	5/8	1-7/8	1/2	5	2-1/16	5-7/8	4-1/2	2-3/4	1/8	6-1/2	2-1/4	3/8-16
143T 145T	3-1/2	2-3/4	4 5	11/32	2-1/2	6-7/8	6-5/8	7/8	2-1/4	3/4	5-1/4	2-1/8	5-7/8	4-1/2	2-1/4	1/8	6-1/2	2-1/4	3/8-16
182 184 182T 184T	4-1/2	3-3/4	4-1/2 5-1/2 4-1/2 5-1/2	13/32	2-11/16 2-11/16 3-9/16 3-9/16	8-11/16	7-7/8	7/8 7/8 1-1/8 1-1/8	2-1/4 2-1/4 2-3/4 2-3/4	3/4	5-7/8	2-1/8 2-1/8 2-5/8 2-5/8	5-7/8 5-7/8 7-1/4 7-1/4	4-1/2 4-1/2 8-1/2 8-1/2	2-3/4	1/8 1/8 1/4 1/4	6-1/2 6-1/2 9 9	2-3/8	3/8-16 3/8-16 1/2-13 1/2-13
213 215 213T 215T	5-1/4	4-1/4	5-1/2 7 5-1/2 7	13/32	3-1/2 3-1/2 3-7/8 3-7/8	10-1/4	9-9/16	1-1/8 1-1/8 1-3/8 1-3/8	3 3 3-3/8 3-3/8	1	7-3/8	2-3/4 2-3/4 3-1/8 3-1/8	7-1/4	8-1/2	3-1/2	1/4	9	2-3/4	1/2-13
254U 256U 254T 256T	6-1/4	5	8-1/4 10 8-1/4 10	17/32	4-1/16 4-1/16 4-5/16 4-5/16	12-7/8	12-15/16	1-3/8 1-3/8 1-5/8 1-5/8	3-3/4 3-3/4 4 4	1	9-5/8	3-1/2 3-1/2 3-3/4 3-3/4	7-1/4	8-1/2	4-1/4	1/4	10	—	1/2-13
284U 286U 284T 286T 284TS 286TS	7	5-1/2	9-1/2 11 9-1/2 11 9-1/2 11	17/32	5-1/8 5-1/8 4-7/8 4-7/8 3-3/8 3-3/8	14-5/8	14-5/8	1-5/8 1-5/8 1-7/8 1-7/8 1-5/8 1-5/8	4-7/8 4-7/8 4-5/8 4-5/8 3-1/4 3-1/4	1-1/2	13-1/8	4-5/8 4-5/8 4-3/8 4-3/8 3 3	9	10-1/2	4-3/4	1/4	11-1/4	—	1/2-13
324U 326U 324T 326T 324TS 326TS	8	6-1/4	10-1/2 12 10-1/2 12 10-1/2 12	21/32	5-7/8 5-7/8 5-1/2 5-1/2 3-15/16 3-15/16	16-1/2	16-1/2	1-7/8 1-7/8 2-1/8 2-1/8 1-7/8 1-7/8	5-5/8 5-5/8 5-1/4 5-1/4 3-3/4 3-3/4	2	14-1/8	5-3/8 5-3/8 5 5 3-1/2 3-1/2	11	12-1/2	5-1/4	1/4	13-3/8	—	5/8-11
364U 365U 364T 365T 364TS 365TS	9	7	11-1/4 12-1/4 11-1/4 12-1/4 11-1/4 12-1/4	21/32	6-3/4 6-3/4 6-1/4 6-1/4 4 4	18-1/2	19-1/2	2-1/8 2-1/8 2-3/8 2-3/8 1-7/8 1-7/8	6-3/8 6-3/8 5-7/8 5-7/8 3-3/4 3-3/4	3	18 18 18-1/16 18-1/16 18-1/16 18-1/16	6-1/8 6-1/8 5-5/8 5-5/8 3-1/2 3-1/2	11	12-1/2	5-7/8	1/4	13-3/8	—	5/8-11
404U 405U 404T 405T 404TS 405TS	10	8	12-1/4 13-3/4 12-1/4 13-3/4 12-1/4 13-3/4	13/16	7-3/16 7-3/16 7-5/16 7-5/16 4-1/2 4-1/2	21-5/16	22-1/2	2-3/8 2-3/8 2-7/8 2-7/8 2-1/8 2-1/8	7-1/8 7-1/8 7-1/4 7-1/4 4-1/4 4-1/4	3	19-1/4 19-1/4 19-5/16 19-5/16 19-5/16 19-5/16	6-7/8 6-7/8 7 7 4 4	11	12-1/2	6-5/8	1/4	13-7/8	—	5/8-11
444U 445U 444T 445T 447T 449T 444TS 445TS 447TS 449TS	11	9	14-1/2 16-1/2 14-1/2 16-1/2 20 25 14-1/2 16-1/2 20 25	13/16	8-5/8 8-5/8 8-9/16 8-9/16 8-9/16 8-9/16 4-13/16 4-13/16 4-13/16 4-13/16	24.24 24.24 24.24 24.24 24.24 24.24 24.24 24.24 24.24 24.24	27.57 27.57 27.57 27.57 27.57 27.57 27.57 27.57 27.57 27.57	2-7/8 2-7/8 3-3/8 3-3/8 3-3/8 3-3/8 2-3/8 2-3/8 2-3/8 2-3/8	8-5/8 8-5/8 8-3/8 8-3/8 8-3/8 8-1/2 4-5/8 4-5/8 4-5/8 4-3/4	3 3 4 4 4 4 4 4 4 4	22.68 22.68 22.68 22.68 23.86 23.86 22.68 22.68 23.86 23.86	8-3/8 8-3/8 8-1/4 8-1/4 8-1/4 8-1/4 4-1/2 4-1/2 4-1/2 4-1/2	14	16	7-1/2	1/4	16-3/4	—	5/8-11

The above chart provides typical Baldor•Reliance motor dimensions. For more exact dimensional data, please check the specific drawing for each catalog number. NEMA states only a minimum value for AA dimension. AA dimensions shown in chart are Baldor typical values meeting or exceeding NEMA. Please check motor drawing for actual dimensions.

Frame L449T is not included in this chart. Please refer to the Large AC motor chart, or to the specific motor drawings for L449T dimensions.

NEMA C-Face	BA Dimensions
143-5TC	2-3/4
182-4TC	3-1/2
213-5TC	4-1/4
254-6TC	4-3/4

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Frame	NEMA FRAMES PRIOR TO 1953						
	D	E	F	N	U	V	BA
66	4-1/8	2-15/16	2-1/2	2-1/4	3/4	2-1/4	3-1/8
203 204	5	4	2-3/4 3-1/4	2-7/16	3/4	2	3-1/8
224 225	5-1/2	4-1/2	3-3/8 3-3/4	3-1/4	1	3	3-1/2
254	6-1/4	5	4-1/8	3-7/16	1-1/8	3-3/8	4-1/4
284	7	5-1/2	4-3/4	4-1/4	1-1/4	3-3/4	4-3/4
324 326	8	6-1/4	5-1/4 6	5-3/8	1-5/8	4-7/8	5-1/4
364 365	9	7	5-5/8 6-1/8	5-5/8	1-7/8	5-3/8	5-7/8
404 405	10	8	6-1/8 6-7/8	6-3/8	2-1/8	6-1/8	6-5/8
444 445	11	9	7-1/4 8-1/4	7-1/8	2-3/8	6-7/8	7-1/2
504 505	12-1/2	10	8 9	8-5/8	2-7/8	8-3/8	8-1/2

You can figure that a 48-frame motor will have a shaft height of 48 divided by 16 or 3 inches. Similarly, a 56-frame motor would have a shaft height of 3½ inches. The largest of the current fractional horsepower frame sizes is a 56-frame that is available in horsepower greater than those normally associated with fractionals. For example, 56-frame motors are built in horsepower up to 3 HP and, in some cases, 5 HP. For this reason calling motors with 2-digit frame sizes "fractionals" is somewhat misleading.

Integral Horsepower Motors

The term "integral-horsepower motor" generally refers to those motors having three-digit frame sizes such as 143T or larger. When dealing with these frame sizes one rule of thumb applies: the centerline shaft height ("D" dimension) above the bottom of the base is the first two digits of the frame size divided by four. For example, a 254T frame would have a shaft height of 25 ÷ 4 = 6.25 inches. Although the last digit does not directly relate to an "inch" dimension, larger numbers do indicate that the rear bolt holes are moved further away from the shaft end bolt holes (the "F" dimension becomes larger).

Variations

In addition to the standard numbering system for frames, there are some variations that will appear; these are itemized below along with an explanation of what the various letters represent.

C Designates a "C" face (flange) mounted motor. This is the most popular type of face-mounted motor and has a specific bolt pattern on the shaft end to allow mounting. The critical items on "C" face motors are the "bolt circle" (AJ dimension), register (also called rabbet), diameter (AK dimension) and shaft size (U dimension). C flange motors always have threaded mounting holes in the face of the motor.

D The "D" flange has a special type of mounting flange installed on the shaft end; i.e. — the flange diameter is larger than the body of the motor and it has clearance holes suitable for mounting bolts to pass through from the back of the motor into threaded holes in the mating part. "D" flange motors are not as popular as "C" flange motors.

H Used on some 56-frame motors, "H" indicates that the base is suitable for mounting in either 56, 143T, or 145T mounting dimensions.

J This designation is used with 56-frame motors and indicates that the motor is made for "jet pump" service with a threaded stainless steel shaft and standard 56C face.

JM The letters "JM" designate a special pump shaft originally designed for a "mechanical seal;" this motor also has a C face.

JP Similar to the JM style of motor having a special shaft, the JP motor was originally designed for a "packing" type of seal. The motor also has a C face.

S The use of the letter "S" in a motor frame designates that the motor has a "short shaft." Short shaft motors have shaft dimensions that are smaller than the shafts associated with the normal frame size. Short shaft motors are designed to be directly coupled to a load through a flexible coupling. They are not intended for applications where belts are used to drive the load.

T "T" at the end of the frame size indicates that the motor is of the 1964 and later "T" frame vintage.

U A "U" at the end of the frame size indicates that the motor falls into the "U" frame size assignment (1952 to 1964) era.

Y When a "Y" appears as a part of the frame size it means that the motor has a special mounting configuration. It is impossible to tell exactly what the special configuration is, but it does denote that there is a special non-standard mounting.

Z Indicates the existence of a special shaft that could be longer, larger, or have special features such as threads, holes, etc. "Z" indicates only that the shaft is special in some undefined way.

(* The NEMA chart provides typical Baldor•Reliance motor dimensions. For more exact dimensional data, please check the specific drawing for each catalog number. NEMA states only a minimum value for AA dimension. AA dimensions shown in chart are Baldor typical values meeting or exceeding NEMA. Please check motor drawing for actual dimensions.)

Frame L449T is not included in this chart. Please refer to the Large AC motor chart, or to the specific motor drawings for L449T dimensions.

Primer On Two-Speed Motors

There seems to be a lot of mystery involved in two speed motors but they are really quite simple. They can first be divided into two different winding types:

Two-speed, two-winding. The two winding motor is made in such a manner that it is really two motors wound into one stator. One winding, when energized, gives one of the speeds. When the second winding is energized, the motor takes on the speed that is determined by the second winding. The two-speed, two-winding motor can be used to get virtually any combination of normal motor speeds and the two different speeds need not be related to each other by a 2:1 speed factor. Thus, a two-speed motor requiring 1,750 RPM and 1,140 RPM would, of necessity, have to be a two-winding motor.

Two-speed, one-winding. The second type of motor is the two-speed, single-winding motor. In this type of motor, a 2:1 relationship between the low and high speed must exist. Two-speed, single-winding motors are of the design that is called "consequent pole." These motors are wound for one speed, but when the winding is reconnected the number of magnetic poles within the stator is doubled and the motor speed is reduced to one-half of the original speed. The two-speed, one-winding motor is, by nature, more economical to manufacture than the two-speed, two-winding motor. This is because the same winding is used for both speeds and the slots in which the conductors are placed within the motor do not have to be nearly as large as they would have to be to accommodate two separate windings that work independently. Thus, the frame size on the two-speed, single-winding motor can usually be smaller than on an equivalent two-winding motor.

Load classification. A second item that generates a good deal of confusion in selecting two speed motors is the load classification for which these motors are to be used. In this case, the type of load to be driven must be defined and the motor is selected to match the load requirement.

The three types available are: c*onstant torque, variable torque,* and *constant horsepower.* For more details on load types please refer to “Understanding Torque” in this booklet.

Constant torque. Constant torque loads are those types of loads where the torque requirement is independent of speed. This type of load is the normally occurring load on such things as conveyors, positive displacement pumps, extruders, hydraulic pumps, packaging machinery, and other similar types of loads.

Variable torque. A second load type that is very different from constant torque is the kind of load presented to a motor by centrifugal pumps and blowers. In this case, the load torque requirement changes from a low value at low speed to a very high value at high speed. On a typical variable torque load, doubling the speed will increase the torque requirement by 4 times and the horsepower requirement by 8 times. Thus, on this type load, brute force must be supplied at the high speed and much reduced levels of horsepower and torque are required at the low speed. A typical two-speed, variable torque motor might have a rating of 1 HP at 1,725 and .25 HP at 850 RPM.

The characteristics of many pumps, fans, and blowers are such that a speed reduction to one-half results in an output at the low speed which may be unacceptable. Thus, many two-speed, variable-torque motors are made with a speed combination of 1,725/1,140 RPM. This combination gives an output from the fan or pump of roughly one-half when the low speed is utilized.

Constant horsepower. The final type of two-speed motor utilized is the two-speed, constant-horsepower motor. In this case the motor is designed so that the horsepower stays constant when the speed is reduced to the low value. In order to do this it is necessary for the motor’s torque to double when it is operating in low-speed mode. The normal application for this type of motor is on metal working processes such as drill presses, lathes, milling machines, and other similar metal removing machines. The requirement for constant horsepower can perhaps be best visualized when you consider the requirements of a simple machine like a drill press. In this case, when drilling a large hole with a large drill, the speed is low but the torque requirement is very high. Compare that to the opposite extreme of drilling a small hole when the drill speed must be high but the torque requirement is low. Thus, there is a requirement for torque to be high when speed is low and torque to be low when speed is high. This is the “constant-horsepower” scenario.

The constant-horsepower motor is the most expensive two-speed motor. Three-phase, two-speed motors are quite readily available in constant torque and variable torque. Two-speed, constant-horsepower motors are usually only available on a custom order basis.

Two-speed, single-phase motors. Two-speed, single-phase motors for constant torque requirements are more difficult to supply since there is a problem in providing a starting switch that will operate at the proper time for both speeds. Thus the normal two-speed, single-phase motor is offered as a variable-torque motor in a permanent-split capacitor configuration. The permanent-split capacitor motor has very low starting torque but is suitable for use on small, centrifugal pumps and fans.

Summary

The use of two-speed motors in the future will grow quite rapidly as industrial motor users begin to realize the desirability of using this type of motor on exhaust fans and circulating pumps, so that air flow and water flow can be optimized to suit the conditions that exist in a plant or a process. Very dramatic savings in energy can be achieved by utilizing the two-speed approach. **PTE**

For more information:

Baldor Electric Company/Member of the ABB Group
5711 R. S. Boreham Jr. Street
Fort Smith AR 72901
Phone: (479) 648.5694
www.baldor.com