FAN ENGINEERING

TCF TWIN CITY FAN

Direct Drive Fan Selections

Introduction

Direct drive fans are usually specified because, under the right circumstances, they offer the user the most compact, lowest cost and lowest maintenance fan available. They also have fewer sources of vibration and are often used where very low levels of vibration is a requirement. However, because the fan speeds are limited to available motor speeds, the number of selections are limited, and may not be at maximum impeller efficiency. Also, because of the limited motor speeds available, a direct drive fan may require selecting a more expensive lower speed motor to meet the performance requirements.

The actual final operating RPM of the motor varies with motor design and the power required to drive the fan. Typical operating speeds are given in Table 1. Motors greater than 8 pole are rarely used in fans.

Inverter drives make speed selections for direct drive fans as flexible as belt drive fans. This significantly increases the overall installed first cost, however this cost may be offset by the ability to reduce the fan speed when full flow is not required. This article will be restricted to the mechanics of matching an axial or centrifugal fan to constant motor speeds.

Axial Fans

Typically, direct drive fan performance for cast fixed pitch propellers is presented in tabular form similar to that shown in Table 2.

For a given fan diameter, the tables are set up to cover a set range of performance at available motor horsepower and speed. An assortment of propellers having different numbers of blades, different pitch settings or design style may be used to match up performance with specific motor horsepower and speed. Since the number of selections available in the table are limited, it is unlikely that any of the offerings will exactly satisfy the performance requirements. Accordingly, either the requirements must be relaxed or a non standard fan must be selected.

While it is not practical for a fan manufacturer to publish all available fan curve data in their catalogs, they more than likely have additional performance information available in the form of a computer selection program.

For example: Select a 24" diameter propeller fan to deliver 8200 CFM at ¼" SP.

From Table 2 we can find two selections, that while close, do not exactly satisfy the performance requirements. A model 24L230 propeller shows a performance of 7650

Table 1. Operating Speeds

NOMINAL RPM		NUMBER	USABLE RPM RANGE	
60 Hz	50 Hz	OF POLES	60 Hz	50 Hz
3600	3000	2	3450 - 3580	2875 - 2980
1800	1500	4	1725 - 1790	1435 - 1490
1200	1000	6	1140 - 1190	950 - 990
900	750	8	850 - 890	710 - 740

Table 2. Fixed Pitch Propeller Fan Performance

CATALOG NUMBER				CUBIC FEET PER MINUTE & HORSEPOWER AT STATIC PRESSURE															
				0" SP		1/8" SP		1/4" SP		3/8" SP		1/2" SP		3/4" SP		1" SP		1¼" SP	1½" SP
PROP	FAN TYPE	RPM	HP	CFM	BHP	CFM	BHP	CFM	BHP	CFM	BHP	CFM	BHP	CFM	BHP	CFM	BHP	CFM BHP	CFM BHP
24L232	DDP	1160	1/3	6110	.350	5100	.350	3200	.310										
24L428	DDP	1160	1/2	6790	.460	6150	.500	5370	.510	4350	.510								
24L432	DDP	1160	3/4	7550	.610	6900	.610	6100	.600	5050	.620								
24L220	DDP	1750	1/2	7070	.530	6440	.570	5700	.570	4850	.580	3790	.560						
24L225	DDP	1750	3/4	8100	.800	7450	.820	6750	.830	5930	.820	4890	.800						
24L420	DDP	1750	1	8020	.870	7600	.930	7190	.970	6750	1.00	6240	1.02	4950	1.07				
24L230	DDP	1750	1	8950	1.09	8320	1.10	7650	1.10	6900	1.09	5710	1.02						
24L426	DDP	1750	1½	9680	1.38	9350	1.41	8880	1.46	8450	1.50	7950	1.53	6700	1.57				
24L432	DDP	1750	2	11400	2.05	10950	2.05	10500	2.04	10000	2.04	9500	2.03	8300	2.07	6100	2.03		
24S726	DDP	1160	1/2	6410	.390	5920	.430	5340	.470	4480	.500								
24S728	DDP	1160	3/4	6710	.490	6220	.530	5620	.560	4800	.500								
24S719	DDP	1750	1	7440	.780	7150	.890	6820	.900	6480	.960	6100	1.01	5110	1.09	3350	1.08		

CFM at ¼" SP with a 1750 RPM, 1 HP motor, which is less than our requirement, and a model 24L426 propeller that shows a performance of 8880 CFM at ¼" SP with a 1750 RPM, 1½" HP motor, which is more than our requirement.

Should a computer generated curve be available, we can see that the model 24L230 propeller actually results in 7780 CFM at 0.225" SP and 1.11 BHP (Figure 1) and the model 24L426 propeller would deliver 8760 CFM at 0.29" SP and 1.48 BHP (Figure 2).

If these selections are not close enough, it may be possible by interpolation in the performance table or through the computer program, to select a different propeller that may meet or come very close to meeting the design performance.

For example: If we were to plot out multiple angle (pitch) curves for the 24L4 propeller (Figure 3) it can be seen that a 24L424 propeller comes very close to meeting the design performance of 8200 CFM at ¼" SP. The intersection of the 24 degree performance curve and the system curve results in an actual performance of 8300 CFM at 0.26" SP with 1.3 BHP.

With the wonders of the computer, this looks to be the ideal selection; however, as stated previously in the article, we are dealing with fixed pitch cast propellers. It would be best to check with the factory to see if this particular propeller is available with that blade pitch.

Manually adjustable pitch propellers, where available, offer the user more flexibility than a cast solid propeller, in selecting a direct drive fan and has the added advantage of being field adjustable should the need arise.

We can also increase the number of direct drive selections by using different speed motors and/or changing the propeller diameter. These can have advantages and disadvantages. By selecting a 2 pole (3500 RPM) motor we can reduce the overall fan cost by using a lower cost motor and a smaller diameter fan, but at a higher sound level. Conversely, by selecting a 6 pole (1160 RPM) motor we can decrease the sound level at the expense of a higher cost motor and a larger diameter fan.

Because the motor on a direct drive axial fan is located in the airstream, its ability to handle hot and/or contaminated air is severely limited when compared to belt driven fans. Typically a direct drive axial fan is limited to 104°F air temperature. By using a motor with class H insulation, the next larger size horsepower, high temperature grease and breather pipes, a direct drive fan can be made suitable for temperatures to 275°F.

Centrifugal Fans

The most common method used to select direct drive performance for a centrifugal fan is to change the fan blade width. Backward inclined fans have an allowable blade width range from 50 to 105%. For a given RPM and SP the CFM and BHP reduction/increase is proportional to the percentage reduction/increase in the blade width.

Centrifugal fan performance data is normally presented in catalogs in what are referred to as "blower tables" (Table 3), and is not as user friendly as performance curves when selecting direct drive performance, because the data is presented at random speeds and not specific motor speeds.

For example: Select a fan from Table 3 to deliver 12000 CFM at 3" SP using a 1750 RPM motor.

Inspection of the 3" SP column indicates that we need to interpolate between 1710 RPM and 1884 RPM to obtain the base line performance at 1750 RPM.

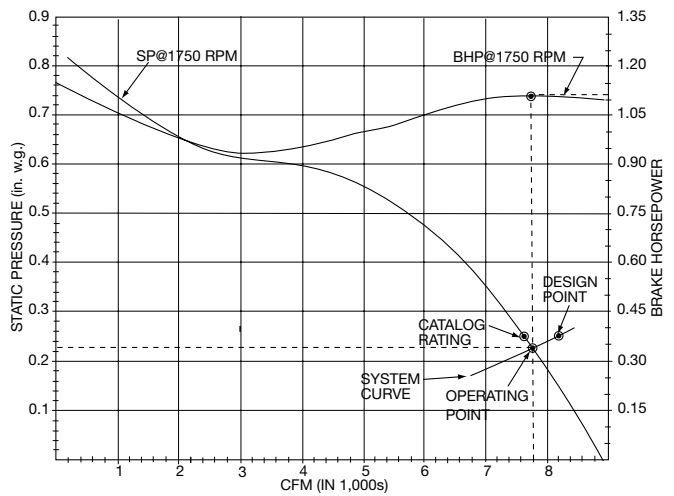Figure 1. 24L230 Performance Curve
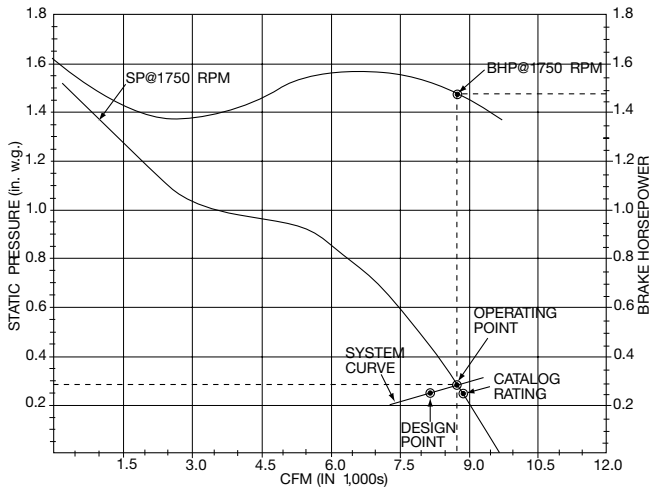

Figure 2. 24L426 Performance Curve
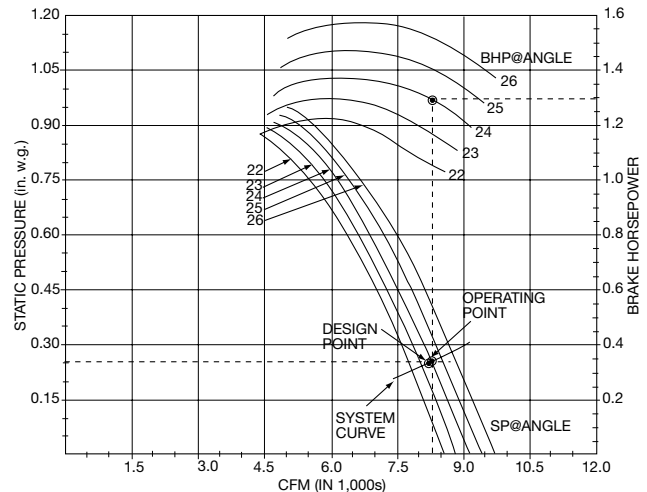

Figure 3. 24L424 Performance Curve

Table 3. Backward Inclined Centrifugal Fan Performance

		WHEEL DIAMETER = 27.95 in.						OUTLET AREA = 4.49 ft²									
		WHEEL CIRCUMFERENCE = 7.32 ft.						MAX. BHP = 4.60 (RPM÷1000)³									
CFM	OV	0.5" SP		1" SP		2" SP		3" SP		4" SP		5" SP		6" SP		7" SP		8" SP	
		RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP
4490	1000	493	0.55	604	0.99														
6735	1500	653	1.15	722	1.71	868	2.98	1016	4.45										
8980	2000	826	2.18	882	2.89	986	4.40	1094	6.07	1208	7.88	1319	9.86	1427	12.03				
11225	2500	1006	3.80	1053	4.64	1139	6.44	1222	8.35	1308	10.39	1396	12.56	1487	14.81	1577	17.18	1665	19.74
13470	3000	1190	6.14	1230	7.13	1305	9.20	1374	11.37	1444	13.69	1515	16.07	1587	18.57	1660	21.16	1735	23.82
15715	3500	1375	9.32	1410	10.47	1477	12.84	1540	15.32	1599	17.87	1658	20.53	1718	23.25	1780	26.11	1841	28.98
17960	4000	1562	13.52	1593	14.82	1653	17.50	1710	20.25	1764	23.09	1816	26.02	1867	29.00	1919	32.07	1973	35.27
20205	4500	1750	18.88	1778	20.34	1832	23.31	1884	26.36	1934	29.48	1981	32.64	2027	35.90	2073	39.26	2119	42.69
22450	5000	1939	25.54	1964	27.14	2013	30.41	2060	33.73	2106	37.13	2151	40.62	2194	44.50	2236	47.80	2277	51.47
24695	5500	2128	33.62	2151	35.39	2195	38.91	2239	42.57	2282	46.29	2324	50.08	2364	53.87	2404	57.81	2442	61.75
26940	6000	2317	43.26	2338	45.17	2379	49.03	2420	53.00	2460	57.02	2499	61.10	2537	65.21	2574	69.36	2610	73.58

CFM	OV	9" SP		10" SP		11" SP		12" SP		13" SP		14" SP		16" SP		18" SP		20" SP	
		RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP
4490	1000																		
6735	1500																		
8980	2000																		
11225	2500	1751	22.42	1836	25.28														
13470	3000	1812	26.61	1887	29.48	1960	32.48	2033	35.64	2104	38.87	2175	42.28						
15715	3500	1904	32.01	1967	35.06	2032	38.21	2097	41.40	2162	44.71	2226	48.15	2351	55.35	2474	62.97	2594	70.98
17960	4000	2026	38.47	2080	41.78	2134	45.14	2189	48.61	2245	52.15	2301	55.68	2415	63.00	2528	70.72	2638	78.85
20205	4500	2166	46.19	2213	49.72	2261	53.37	2308	56.99	2356	60.73	2405	64.60	2503	72.45	2603	80.43	2705	88.72
22450	5000	2318	55.20	2360	59.06	2402	62.93	2444	66.82	2487	70.83	2530	74.89	2616	83.14	2703	91.65	2792	100.46
24695	5500	2479	65.71	2517	69.84	2554	73.94	2592	78.17	2630	82.40	2669	86.75	2746	95.45				
26940	6000	2646	77.93	2680	82.20	2715	86.66	2749	91.09	2783	95.58								

(1) 1884 RPM – 1710 RPM = 174 RPM
1750 RPM – 1710 RPM = 40 RPM
40 RPM ÷ 174 RPM = 0.23 ratio

(2) baseline CFM =
(20205 CFM – 17960 CFM) 0.23 + 17960 CFM = 18476 CFM

(3) baseline BHP =
(26.36 BHP – 20.25 BHP) 0.23 + 20.25 BHP = 21.66 BHP

(4) design CFM ÷ baseline CFM = wheel blade width %
12000 CFM ÷ 18476 CFM = 0.649 or a 65% blade width

(5) BHP at 65% blade width =
21.66 BHP x 0.65 = 14.08 BHP

After all this we know that a 28" backward inclined centrifugal fan with a 65% wheel width will deliver 12000 CFM at 3" SP at 1750 RPM and will require 14.08 BHP. But is this the best selection? It's difficult to tell from the data. We would have to repeat this process for other size fans to know for sure.

Computer generated curves (when available) provide a much easier selection process. Figure 4 shows the performance curve of this same 28" backward inclined centrifugal fan at 1750 RPM.

Reading horizontally from left to right, we intersect the performance curve at 18500 CFM.

(4) 12000 CFM / 18500 CFM = 0.649 or a 65% blade width

With a few simple key strokes we input the 65% blade width in the space provided and produce the fan curve as shown in Figure 5.

An inspection of this curve indicates we would be better served with a smaller fan. With the computer we can easily click back to a 100% blade width and then click on the next smaller size fan, and see that it matches our requirements rather nicely (Figure 6).

The 25" diameter fan performance shown in Figure 6 gives us the choice of using a 96% blade width to exactly match the design point of 12000 CFM at 3" SP, or we can accept a slightly higher operating performance of 12400 CFM at 3.2" SP, and avoid the added cost of narrow width construction. In addition, the 25" diameter fan costs less, has a higher operating efficiency and has a significantly lower sound level than the 28" diameter fan.

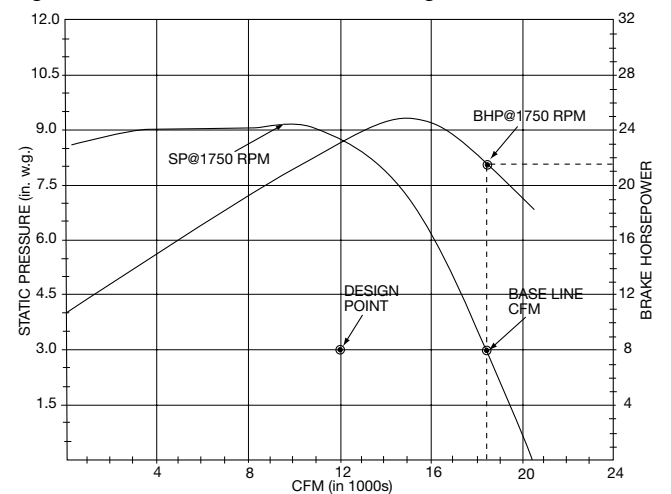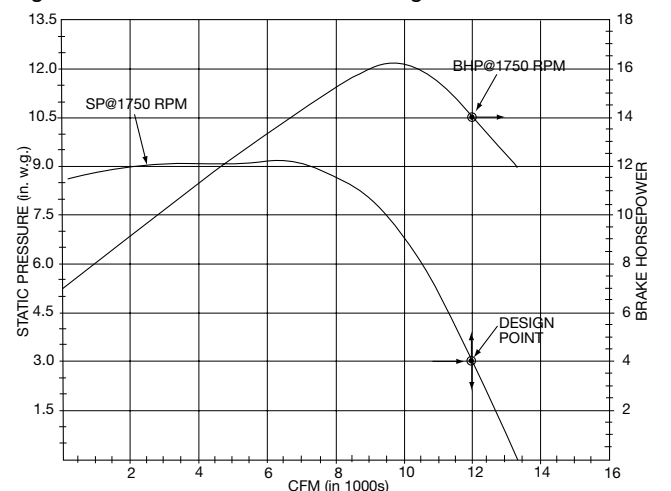Figure 4. 28" – 100% Width BI Centrifugal Performance Curve

Figure 5. 28" – 65% Width BI Centrifugal Performance Curve

Should we decide to use the 28" diameter fan selection, it would be necessary to adjust the fan housing width to be compatible with the narrow width wheel construction. To accomplish this, we would need to know both the 100% blade and housing widths. For this particular fan the wheel blade width is $10\frac{1}{16}$" and the housing width is $21\frac{3}{32}$".

The new blade width = $10\frac{1}{16}$" x 0.65 = 6.54" or $6\frac{9}{16}$"
The new housing width = $21\frac{3}{32}$" − ($10\frac{1}{16}$" − $6\frac{9}{16}$") = $17\frac{19}{32}$"

A new housing outlet area can be approximated by multiplying the standard housing outlet area (Table 2) by the ratio of the narrow to standard housing width.

Outlet area (new) =
outlet area (old) x housing width (new) ÷ housing width (old)

$$= 4.49 \text{ ft}^2 \ (17\tfrac{19}{32}" \div 21\tfrac{3}{32}") = 3.74 \text{ ft}^2$$

If the 25" diameter fan was our choice, no housing width adjustment would be required because even if we selected the 96% wheel width, housing widths are generally not adjusted until the blade width reduction is greater than one inch.

Narrow width construction is by far the best "low cost" method, for maximizing the number of direct drive centrifugal fan selections. Within a narrow range of limits, for a given size, the wheel diameter can be increased or decreased, usually only by 5%. Selection by varying the wheel diameter requires the use of computerized selection program.

Other methods could include varying the number, the chord width or chord angle of the blades, but this involves methodology beyond the scope of this article.

AMCA Spark Resistant Construction

Arrangement 4 centrifugal fans can be made to satisfy AMCA type "A," type "B," and type "C" construction. It may require a special motor shaft to allow for better sealing around the housing shaft opening. AMCA type "A" spark resistant construction requires completely enclosing the motor shaft, which protrudes inside the fan housing.

Arrangement 4 plenum fans do not comply with any fan spark resistant standards, since the lack of a fan housing forces the motor bearings to be in the airstream. Some applications have used explosion proof motors to reduce the risk of explosion.

Arrangement 8 construction should be considered for direct drive applications whenever possible. The bearings can be located away from the housing to accommodate better seals. Arrangement 7 direct drive fans are not allowed because of the bearing(s) in the airstream.

Figure 6. 25" – 100% Width BI Centrifugal Performance Curve
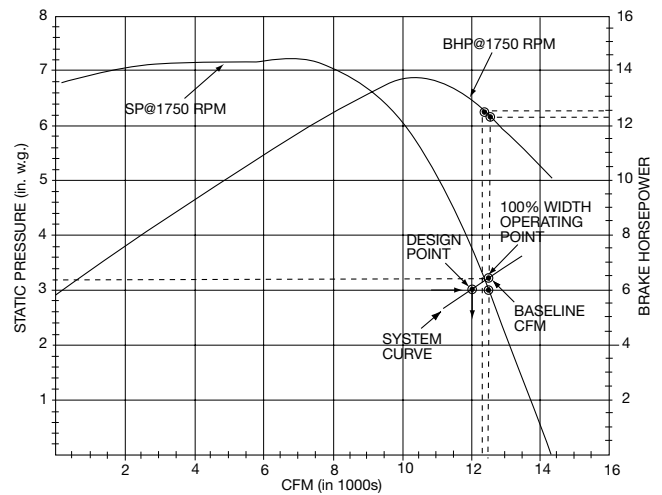
High Temperature Construction

Arrangement 4 centrifugal fans are typically limited to 180°F. However, temperatures to 275°F are attainable using special class H insulated motors. Direct drive selections above 275°F will be limited to Arrangement 8 construction. Arrangement 7 direct drive fans without inlet boxes are limited to 200°F maximum temperatures.

Corrosion Resistant Construction

Arrangement 4 centrifugal fans for corrosive applications face similar problems as encountered with spark resistant fans. Special shaft materials that resist corrosion or enclosing the motor shaft with a corrosive resistant sleeve may be required. Special length shafts for mounting shaft seals may be required along with adding thrust vanes to the backside of the impeller to help prevent corrosives from leaking out the shaft hole in the fan housing. As with the spark resistant fans, arrangement 8 should be the construction of choice. Arrangement 7 construction can be used, but only with an inlet box.

Conclusion

This article has covered but a few of the different types of axial and centrifugal fans that are available or that can be adapted to direct drive applications. Each fan type may have its own special rules, limitations or considerations for direct drive construction, but the methodology described herein remains the same.

A word of caution: special construction for direct drive fans such as high temperature applications, corrosive applications or spark resistant applications should always be confirmed through the factory.