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Air handling equipment design and its impact on performance

Understanding components and their operation simplifies the equipment selection and application process

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Editor's Note: Robert W. Flanagan was an ASHRAE member for 50 years before his death on April 21, 1989. He became a Fellow in 1963, was a member of the Journal Committee and, most recently, was a member of the Journal Editorial Screening Board. He was also a frequent guest speaker, seminar leader and presenter of technical papers. This is one of the last papers presented by Mr. Flanagan.

Factory assembled central station air handling equipment is generally one of the first items of air conditioning equipment selected after the cooling load estimate is completed. Because of the effect on system design and performance, it is important to understand what constitutes good equipment and how it should be selected and applied.

A wide variety of equipment is available. This ranges from small factory-assembled units handling approximately 300 cfm of air with one-ton capacities, to large, component-selected units handling more than 60,000 cfm of air with capacities up to 240 tons.

In all cases, the equipment selected must: provide air movement; cool and dehumidify air; provide heating or tempering of air; provide air filtration; permit

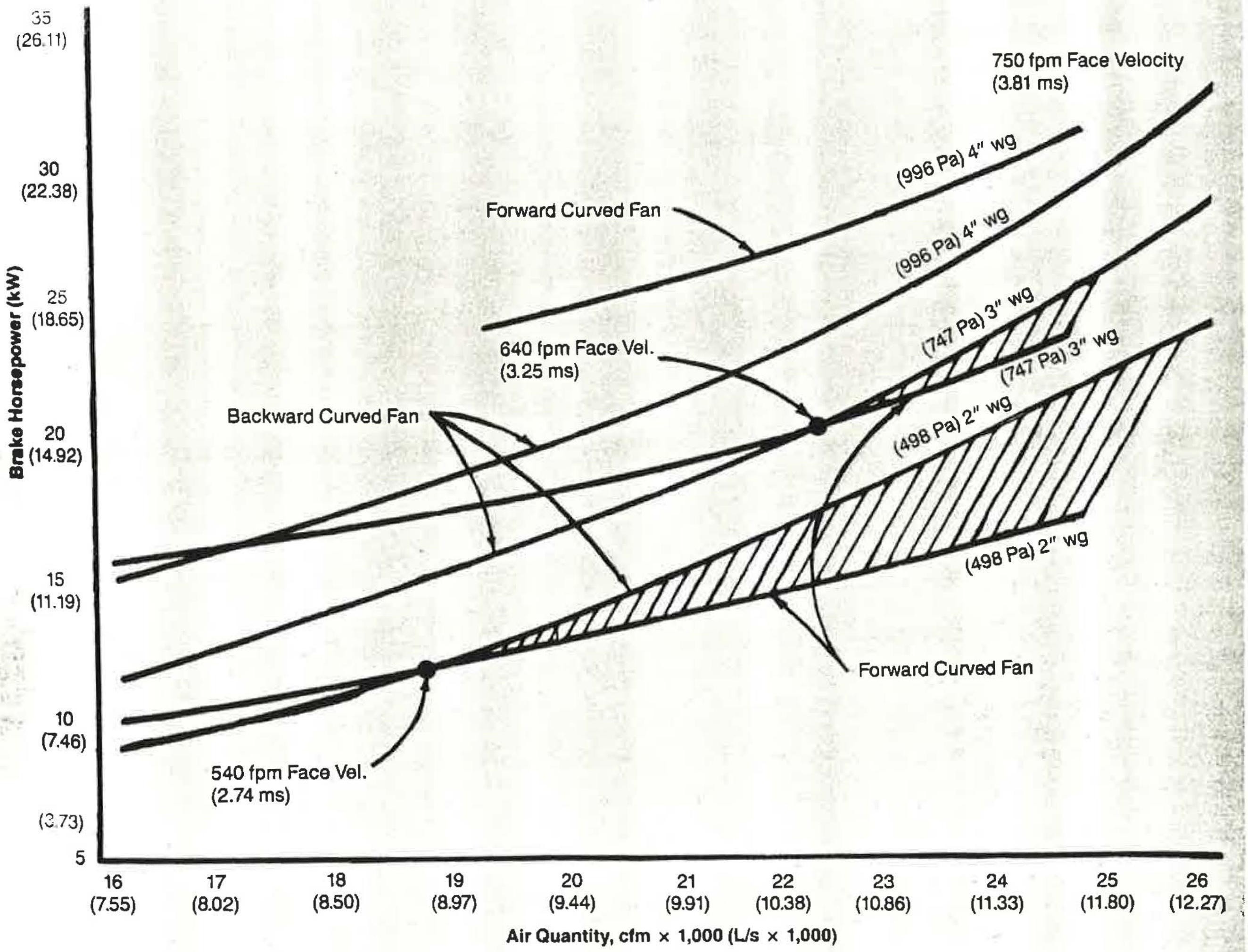

Figure 1. Performances of cabinet-type forward curved and backward curved fans.

Forward curved fan operating characteristics

Numerous questions have been asked regarding how a manufacturer can show, in its rating of a forward curved fan, two widely different air quantities at the same rpm and the same static pressure. For example, one rating chart lists 10,600 cfm for 2 in. wg static pressure and a speed of 700 rpm. Also listed is 21,200 cfm for the same 2 in. wg static pressure and the same speed of 700 rpm.

The explanation for this is simple and is probably best shown in *Figure 4,* which presents a 700 fpm pressure volume curve. Point 1 represents 10,600 cfm at 2 in. wg, and Point 2 represents 21,200 cfm at 2 in. wg. Thus, *Figure 4* shows the fan curve for a particular unit that has been determined from laboratory tests and calculations.

Since the system was designed by someone else, the operating point will be at the intersection of the system resistance line and the fan curve. For example, if the system resistance is 2 in. wg for 21,200 cfm, the system resistance line will pass through Point 2 and, in order to obtain the proper cfm and total static pressure, will require a fan speed of 700 rpm. On the other hand, if only 10,600 cfm are required for the same system, the system resistance will be 0.5 in. wg and the fan speed will be 350 rpm. Consequently, a fan and system combination can only operate at one point, where the fan (pressure-volume) curve and the system resistance curve intersect.

The fan brake horsepower of one manufacturer's unit is often said to be lower than that of another. This may or may not be true. It depends entirely on the point at which selection is made. There are areas in which the efficiency of one fan is better than another and vice-versa.

Certainly, it is natural that, with the same total static pressure, the brake horsepower will be the lowest for the most efficient fan. For the same coil face velocity, however, the resistance of the coil may be considerably higher than the resistance of the coil in another unit. Thus, in cases where bidding is close, these facts may be helpful in making a final decision.

Fan noise, velocity and stability

The forward curved fan, by nature of its design, discharges air at a relatively high velocity. This may result in a low fan efficiency because of the need to convert velocity energy to potential energy or static pressure. Yet, this same velocity discharge is responsible for its prime advantage of relatively low speed compared with other types of fans.

The lower required speed may result in lower noise level, smaller shaft size requirement for the same design strength, and increased bearing life. Also, any unbalanced condition caused by dirt buildup or damage to the wheel is less apt to become objectionable at the lower operating speed.

Another advantage of the forward curved wheel is the flat pressure-volume characteristic as compared with the backward curved wheel. This can readily be seen on the fan curves of the forward curved wheel versus the backward curved wheel.

An argument against the forward curved wheel is that very often it must operate in an unstable condition. Two areas should be considered when discussing unstable fan operation. First, a situation arises when the forward curved wheel is operating to the left of

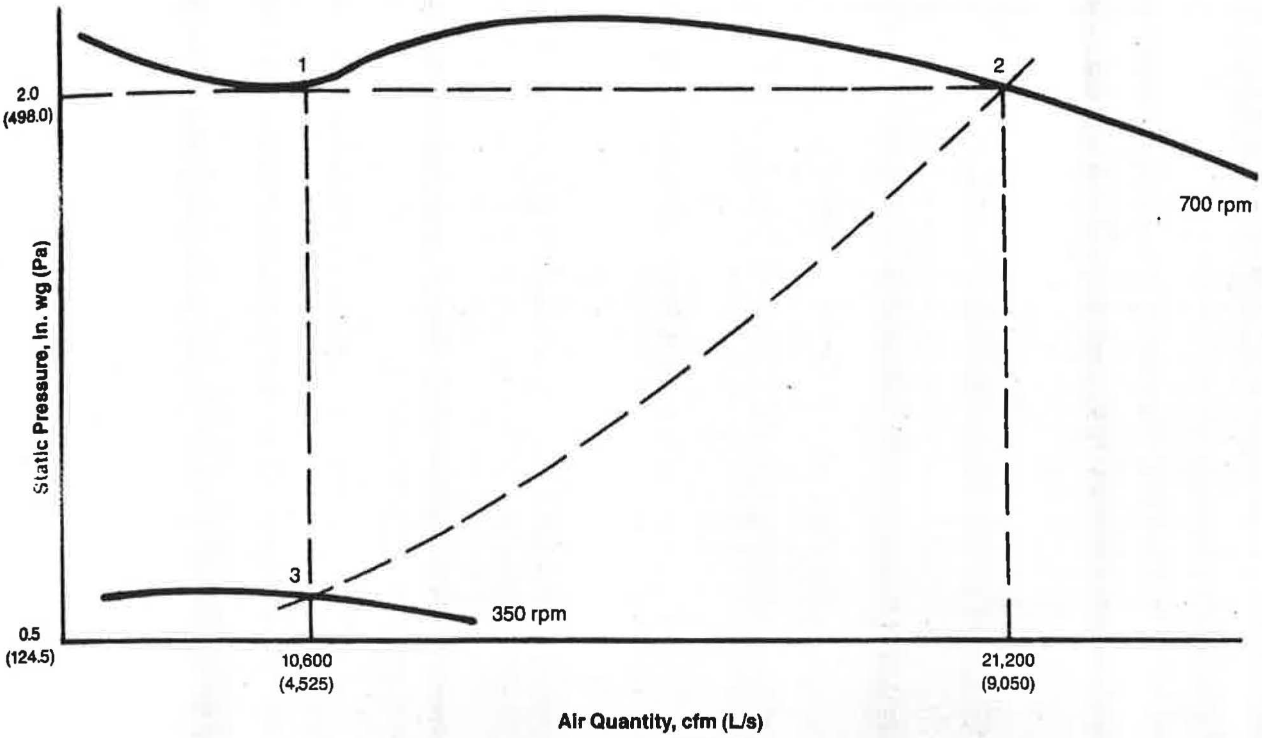

Figure 4. Pressure volume curve for a forward curved fan.

the peak and the possibility of hunting occurs. This situation is peculiar to both the forward curved and backward curved wheels and occurs when the system line very closely parallels the fan performance curve and slight changes in static pressure result in fairly large changes in air quantity, as shown in *Figure 5* and *Figure 6*.

A small decrease in static pressure reduces the air quantity, which decreases the static, and the fan unit may tend to hunt up and down the fan performance curve and lack stability. This generally occurs when the system line closely approaches the fan performance curve.

The second area to be considered in unstable fan operation is the possibility of parallel fan operation. This is a situation that occurs when two fans of the same diameter operate on a common shaft at the same rpm. Because of variations in static pressure, either internal or external to the unit, the two fans could approach the operating point on a different system line. If this occurs, one fan operates to the left of the hump and the other fan to the right. Under worse conditions, the former appears way to the left.

Recognizing this fact, the fan performance for a two-fan unit will often be drawn with a double curve, indicating that the two fans are operating on a different system line and at the same static pressure. This situation could occur anywhere between system line 1 and system line 2. If it does occur, the unit will be noisy, could conceivably jump from one air quantity to another, and will draw more horsepower than is normally expected because it is not operating at the proper efficiency. The answer, of course, is to install outlet dampers.

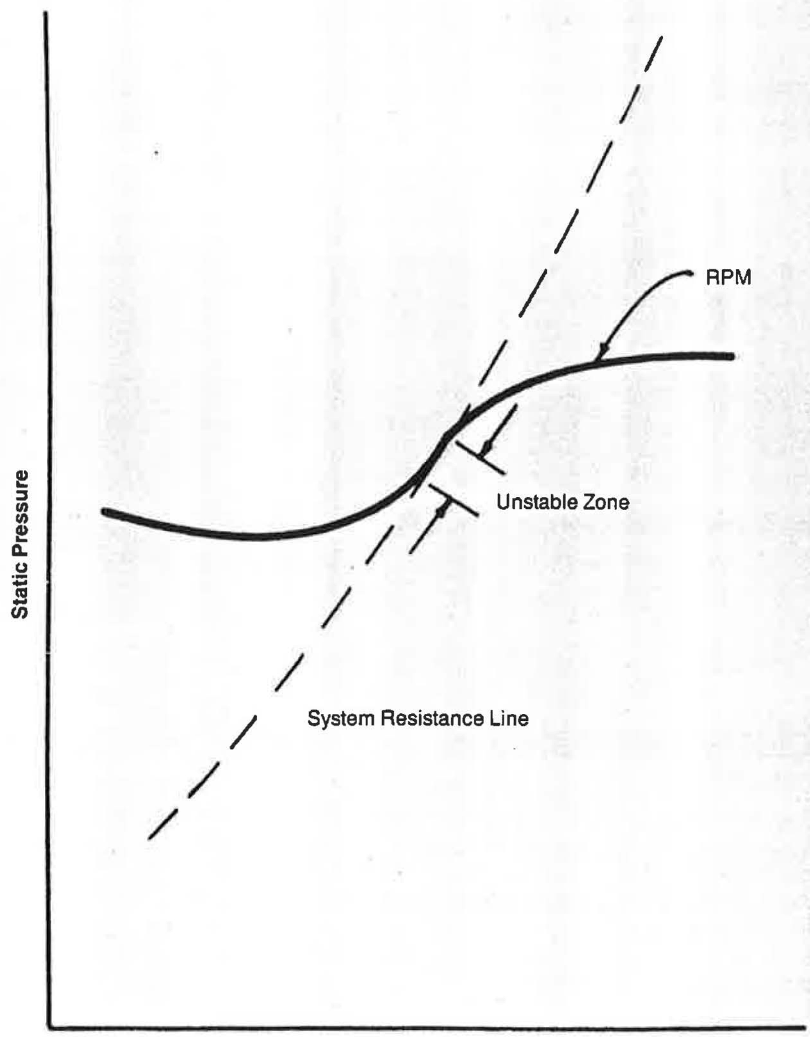

Figure 5. Unstable fan operation.

External and internal bearings

What do external bearings have to offer and how do they compare with high quality internal bearings? Consider the advantages of externally located bearings. First, since they are external, they can easily be replaced when failure occurs. Second, the bearings are located out of the air stream, which may be somewhat of an advantage if the unit is used primarily for heating.

The grease life of bearings is greatly affected by temperature. If the temperature of the air passing over internal bearings is such that heat generated in the bearing is not dissipated as fast as from external bearings, the latter would have a longer grease life.

This may be questionable, however, because a moving air stream with a high degree of air turbulence, even though at a higher temperature, will tend to dissipate larger amounts of heat than can be accomplished in the still blanket of ambient air surrounding the external bearings. Also, the unit may be circulating cool air approximately half the time, in which case the internal bearings would have the advantage.

The danger of contamination from dust and dirt in the moving air stream might be a factor to consider. Perhaps in a few cases this is true. But generally, the air circulated is for air conditioning or process applications, and the circulated air is generally cleaner than the ambient air in the equipment room. Also, the seal in today's bearings has greatly eliminated the danger of lubricant contamination.

It is claimed that externally located bearings will not contribute to an increased noise level when they begin to wear and that this wear will be more easily detected. If a noisy bearing is located on a large hollow shaft, the noise will be transmitted to the air stream and might even be amplified when transmitted through the shaft.

Fan assembly shaft

In no case is a discussion of bearings alone valid. The entire fan assembly and all the static and dynamic forces involved, both in size and direction, must be considered. The fan shaft and bearings assembly must be designed to transmit all force in the three planes to the bearings and permit the torque to be delivered freely to the wheel. Smoothness implies a lack of vibration, as the unit must operate well below the first critical speed with a minimum of shaft deflection and without shaft whip.

All units should be selected to operate well below their first critical speed. The value of the critical speed depends on the length and diameter of the shaft, the manner in which it is supported, and the magnitude and distribution of the loads. This is one of the reasons that the entire assembly must be considered in any discussion of bearings.

To illustrate the effect of the assembly on shaft and bearing design, assume a shaft has been designed for internally mounted bearings. If the bearings are positioned externally, a longer shaft must be used in accordance with the dictates of the coil size or the cabinet design. The shaft now weighs more because of the added length and the bearings are farther apart. Also, the bending moment and deflection are greater.

Consequently, if the first design was correct, the second one must have a larger diameter shaft for the same quality. Now, the shaft weight becomes heavier and bearing loads are increased.

The solution lies in a large diameter hollow shaft. Bringing the weight down and increasing the allowable bending stress accomplishes a change in the shaft design. The shaft weight can now be made approximately the same, but a 3- or 4-in. bearing is not desired because of higher costs.

To eliminate this problem, manufacturers spin down the ends of the shaft. This introduces the problem of quality control. The shaft must be concentric everytime for good, smooth operation. The manufacturers do a truly good job, but the inherent design weakness is present and they do experience some problems.

In a hollow shaft, the metal is spread in a thin wall and a keyway can no longer be cut in the shaft. Consequently, a clamping device is used to fix the wheel to the shaft.

There is more to the location of the bearings as they affect the overall design than just obtaining the highest possible first critical speed from the shaft. If the bearings are to be selected economically, the design should obtain approximately equal loading or various size bearings should be used.

Having analyzed all the bearing forces, shaft deflections, critical speeds and bearing locations, one more point must be considered very seriously. How are these static and dynamic forces that are placed on the bearings eliminated to prevent them from being transmitted to the building or support structure? A fan, by its nature, is a vibrating source, so every effort must be made to provide a simple yet direct means of transmitting this disturbance to a damping source. Vibration eliminators may or may not be used. The frame also serves to damp the vibration.

Conclusions

As can be readily seen from this discussion, no clear-cut path to the selection of an air handling unit exists. This article provides an insight to the characteristics of these units and its main purpose is to set guidelines by which all units may be evaluated. No one manufacturer meets all of the desired features 100 percent of the time.

Manufacturers are always faced with the decision of producing a piece of equipment that will meet the majority of the requirements in the market range. Consulting engineers, architects and owners have the responsibility to help set this range for each application. ■

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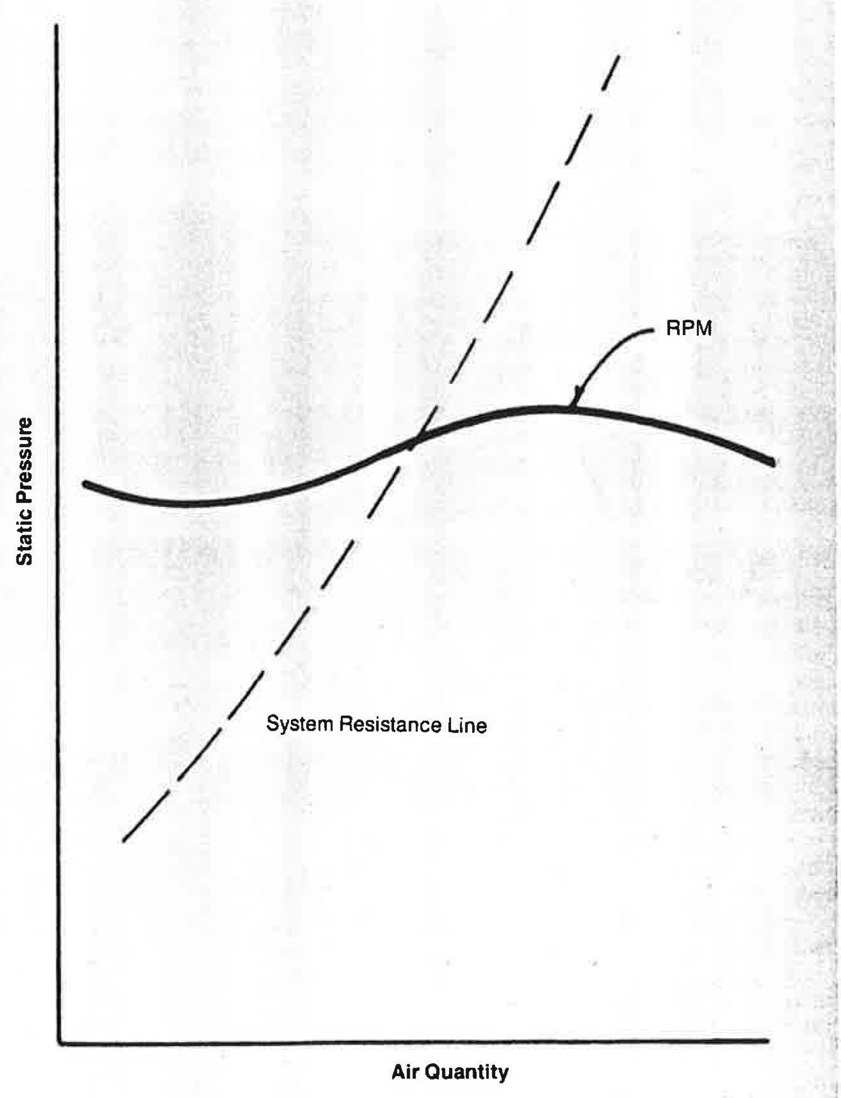

Figure 6. Stable fan operation.