AC 2007-206: A LABORATORY EXERCISE TO DEMONSTRATE HOW TO EXPERIMENTALLY DETERMINE THE OPERATING POINT FOR A FAN

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A Laboratory Exercise to Demonstrate How to Experimentally Determine the Operating Point for a Fan

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Abstract:

Students often have a difficult time understanding how to determine the operating point for a fan when it is placed into a system. They first have to gain some understanding of fan curves and system flow impedance curves. Then they must superimpose the curves to determine the actual operating point. This can be explained within the context of a lecture, but students seem to gain a better understanding of the concept by actually finding the operating point of a fan in a laboratory setting. This paper describes one such exercise than can be used for this purpose.

In order to run this exercise the students must first learn to generate fan curves and system impedance curves. These preliminary exercises are briefly discussed in this paper. Once they have acquired those skills they proceed to test a real system to determine the fan operating point. An ordinary power supply from a personal computer is used for the demonstration because most of the students are very familiar with the device. The students are required to plot a system flow impedance curve for the enclosure and a fan curve for the fan. They plot both curves and predict what the actual operating point for the fan is when installed in the power supply. Finally, they physically install the fan and measure the actual operating point to see how close they have predicted the actual value.

For exercises like this to be instructive, the students must have a real chance to be successful. The results of this exercise depend heavily on how carefully the students take their measurements for the fan curve and the flow impedance curve, but when reasonable care is taken they can predict the actual operating point within 5% or less. Values within 1% are not uncommon. This gives the students an outstanding chance of a successful outcome.

This paper discusses the equipment used, the preliminary work to learn to produce the necessary curves, the final exercise, and a set of typical results.

Introduction:

The amount of air delivered by a centrifugal fan to an application is not a fixed rate. It varies depending on the amount of resistance to flow that is inherent in the application. This resistance varies with the amount of flow going through the device. A fan needs to be selected which matches the characteristics of both the fan and the device to assure that the required amount of flow will exist within the system.

This concept can be difficult for students to understand. It makes it much easier to understand if an experiment is used to demonstrate this idea. The experiment is even more useful if the device being used for the demonstration is a common device that the students are familiar with. A typical desktop computer power supply which has an integral fan used to cool the components in the device is very familiar to the students, making it a good selection for the demonstration.

In order to determine how much air is being forced through the supply by the fan it is necessary to know the characteristic flow curve for the fan and the flow impedance curve for the case and components. In this experiment the fan is removed from the case. The fan curve is created for the fan and a system flow impedance curve is created for the housing. The students plot the two curves to predict an operating point. The fan is then reinstalled in the case and the actual operating point is measured. The actual operating point is typically very close to the predicted point.

Equipment:

The following equipment is needed to perform this experiment:

- Desktop computer power supply. (Figure 1)
- Power supply fan from the above power supply. (Figure 2)
- Fixtures for mounting the fan and the case to the air flow bench. (Figures 1 and 2)
- Air flow bench. (Figure 3)

Figure 1

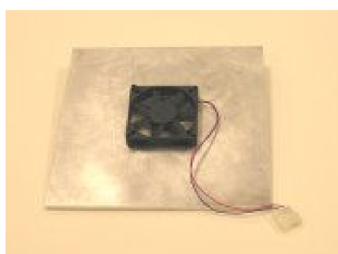

Figure 2

Figure 3

Figure 1 shows the power supply attached to a mounting plate. The mounting plate is used to attach the power supply to the air flow bench. This is done twice during the experiment, once without the fan to create a flow impedance curve for the supply and once with the fan to determine the actual operating point.

Figure 2 shows the fan from the power supply attached to a separate mounting plate. This is used to create a fan curve.

Figure 3 shows the key piece of equipment that is needed for this experiment – an air flow bench. Benches of this type are commercially available, but it is not difficult to make one. The bench shown in figure 3 was built as a student senior project by mechanical engineering technology students.

Figure 4 shows a schematic for the flow bench. A blower pulls air through the plenums. Between the front and back plenums there is a plate with a set of flow nozzles. This gives the user a selection of nozzle sizes for different flow rates. The test specimen is mounted on the inlet to the bench so all of the air goes through it. A differential pressure gauge is used to measure the pressure drop across the specimen, and another differential pressure gauge is used to measure the pressure drop across the nozzle. The differential pressure across the nozzle is used to determine the total flow rate through the flow bench. A gate at the outlet is used to control the flow.

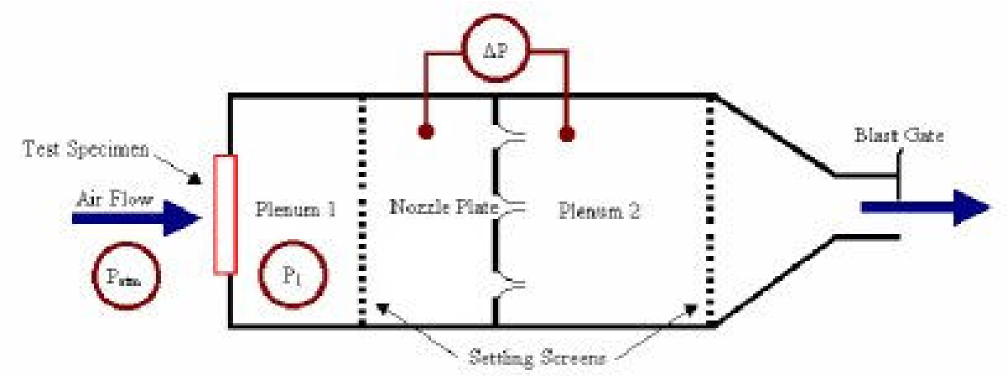

Figure 4

Notice in Figure 3 that there are four gauges for measuring the two differential pressures. The reason for using extra gauges is to have very sensitive gauges for the low end of the differential pressure range. Once the differential pressure exceeds the range of the low pressure gauge a higher range gauge is used for the measurements.

Background:

Fans are used extensively in cooling applications. A typical data sheet for a fan includes a maximum flow value, maximum pressure value, and a performance curve. The maximum flow value tends to be used for fan selection. Unfortunately, this will result in an undersized fan because the maximum flow value is never attained in a real application. In fact, the fan usually operates significantly below the maximum due to back pressure caused by the system it is being attached to.

To determine what the actual flow will be for a particular fan a flow impedance curve for the system is superimposed over the flow characteristic curve for the fan. The point where the two curves intersect is the only operating point the system and fan have in common making it the actual operating point for the fan (Figure 5).

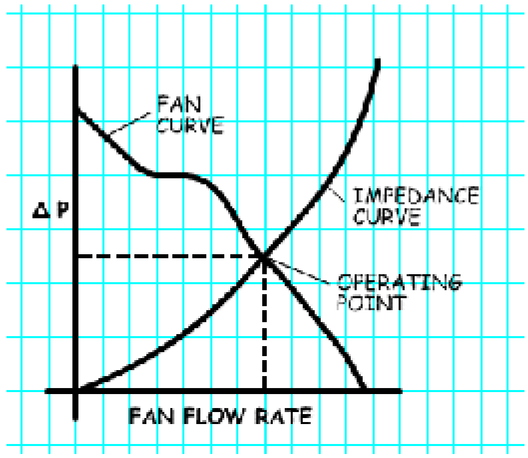

Figure 5

Fan curves are available from manufacturers' data sheets. For the exercise described in this paper actual measurements are used to generate a flow characteristic curve instead of using a curve from the manufacturer. That way the students get to see for themselves how the curve is generated.

Various methods can be used to develop a flow impedance curve for the system. Manual calculations can be used to generate the flow impedance curve. Standard pressure drop calculations can be used to determine drops across various parts of the system such as perforated plates, other types of vents, and various types of obstructions inside the system. Many "rules of thumb" are available for estimating pressure drops. Companies may have their own ways of estimating pressure losses based on years of experience with their products. Most cooling applications have very complex geometries inside the housings making manual calculations very uncertain. A good example of this is an electronics housing containing components, circuit boards, wire bundles, etc. There are multiple, complex flow paths for the fluid. By using these methods estimates can be significantly off, maybe by 100% or more. One problem with this method is that the calculations are usually based on a particular flow rate. Several iterations may be needed to generate and entire curve. Fans are often oversized to account for this uncertainty.

CFD analysis is being used more to assist in determining flow characteristics for cooling applications. The accuracy of the CFD results depends on the complexity of the model. With very complex devices it is common to try to simplify the model as much as possible while trying to maintain the flow characteristics of the actual device as much as possible. Results with errors in the 15% to 60% range are certainly possible using this type of analysis. One nice feature of using a CFD model is that fan characteristics can often be incorporated directly into the model, so the estimated flow rate is determined by the program. Flow paths through the system can also be readily visualized helping the designer to see if the fluid is getting to areas where it is needed for cooling.

Testing an actual device will give the most accurate results. Running a test is not difficult and can produce a complete characteristic curve in a fairly short time. One problem with this approach is that the equipment needed for running such tests can be large and costly for larger sized systems. This is the method that is used for the exercise described in this paper.

Fan Curve:

The fan is mounted to the inlet of the flow bench such that the flow from the fan is into the first plenum. The fan and the flow bench blower are turned on. The fan will build pressure in the first plenum, upstream of the nozzles. The gate at the plenum outlet is adjusted until the differential pressure across the fan is zero. This condition simulates a no load on the fan, and will yield the maximum flow rate for the fan. The differential pressure across the nozzle is recorded and used to determine the flow rate. The gate is readjusted for a small differential across the fan, and the flow rate is determined. This procedure is continued until the gate is fully closed. This gives the no flow condition for the fan and will yield the maximum differential pressure for the fan. (If the gate will not fully close then the maximum pressure can be determined by plugging all of the nozzles in the nozzle plate). This data are plotted on a spreadsheet to produce the fan curve. Figure 6 shows the characteristic curve for the fan used in this particular power supply as measured on the air flow bench.

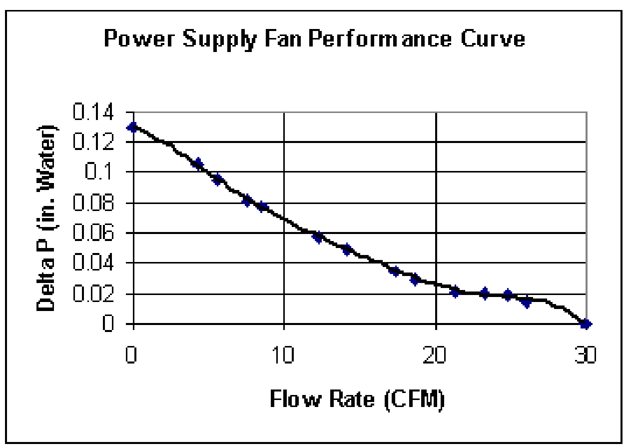

Figure 6

Flow Impedance Curve:

The power supply case and internal components are mounted to the inlet of the flow bench. The flow bench blower is turned on. The gate is adjusted to vary the flow rate through the power supply, and the differential pressure across the power supply case is recorded for each flow rate. This data is plotted on the same plot as the fan curve. The point where the two curves cross is the predicted operating point. Figure 7 shows the system flow impedance curve for this particular power supply as measured on the air flow bench. Figure 8 shows the two curves superimposed on the same graph. The intersection of the curves is the predicted operating point when the fan is reinstalled in the power supply housing.

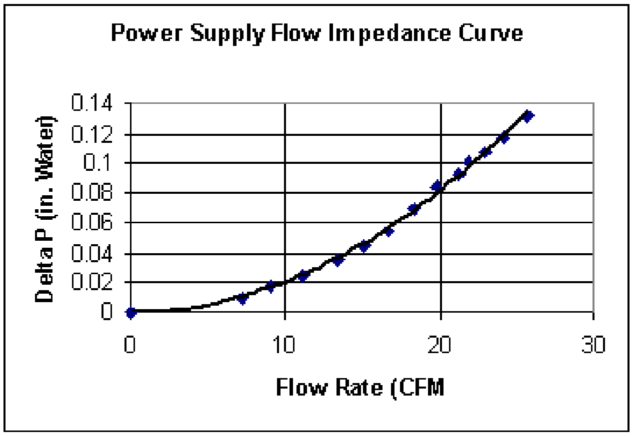

Figure 7

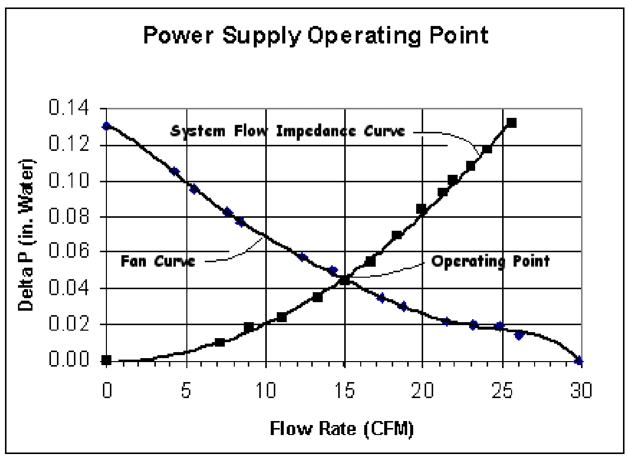

Figure 8

Actual Operating Point:

The students are required to complete all of the above work and to determine their predicted operating point before they are allowed to continue to measure the actual operating point. The actual operating point is the flow rate of air through the power supply housing when the fan is installed in the housing. For this example the inlet and outlet of the housing are both at the same pressure, or no net pressure loss across the device. The increase in pressure across the fan equals the loss in pressure across the housing. That is the condition we try to simulate with the air flow bench.

The fan is reinstalled in the power supply housing. The power supply is then mounted to the inlet of the flow bench (Figure 9). The power supply fan and the flow bench blower are turned on. The gate is adjusted until the differential pressure across the power supply is zero. The flow rate through the bench is determined using the differential pressure across the nozzle, which is the actual flow rate for the device. This value is compared to the predicted value from the previous measurements.

Figure 9

Results:

Figure 8 shows the measured fan curve and measured system flow impedance curve plotted on the same graph. From this graph it can be seen that the predicted operating point is just under 15 CFM. The actual operating point which was measured on the flow bench is 14.91 CFM. The difference between the actual measured value and the predicted value based on actual fan and system measurements is approximately 0.5%. Results vary depending on the patience of the students taking the measurements, but predictions within less than 2% of the actual measured value are typical.

Notice that the maximum flow rate for this fan is approximately 30 CFM. A designer that uses this value for selecting a fan for a particular application will end up with a significantly undersized sized fan.

Recommendations for Improvements to this Exercise:

This exercise is usually very effective in teaching students about fan sizing because they can see first hand what is happening in a real, common application. The potential for excellent results is helpful in teaching the concepts to the students. However, there are some problems with the current set-up that will be resolved in the future making it likely that even more accurate results will be obtained:

- Currently analog gauges are used for measuring the differential pressure. Students tend to prefer digital gauges because of their ease of use. Replacing the analog gauges with digital gauges will help the students get more accurate differential pressure readings. This does however come with an educational price tag. Students need to learn to read analog gauges. It is important to teach the students how to properly read the gauges, and to emphasize that they need to be careful to get as accurate a reading as possible. The plan is to make the change to digital.

- Currently the students take data manually. The plan is to add differential pressure transducers and to use low cost USB based data collection modules to collect the data. This will allow the students to take more readings in a shorter period of time. It is always good to have more data points to produce characteristic curves whenever possible, so it should be possible to produce better curves with this method. It also eliminates the argument for analog gauges since they will only be used sparingly anyway.
- Currently the data are analyzed on a spreadsheet. The plan is to not only computerize the data collection, but to have custom programs to analyze the data. It will be possible to plot the actual curves and to determine the predicted operating point. There will also be an option to export raw data so the students could still be required to do their own analysis.
- The gate used for flow adjustment is crude at best. The plan is to replace the adjustment gate with a variable speed motor giving much more control over the flow adjustment.

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