Flow Bench Measurement

of Fan and System Curves in Air-Cooled Electronics

Introduction

A flow bench is a laboratory device used to determine the curve of a fan or the system curve of an enclosure [1]. A flow bench can also provide a controllable and measurable air flow through electronic equipment undergoing thermal testing. A typical flow bench includes a blower, instrumentation and a combination of nozzles. The choice of components will determine the flow rate measurement range and maximum pressure. The flow bench described in this article is based on the ANSI/AMCA/ASME Standard 210-99 [2]. The article discusses the various components of the flow bench apparatus and the experimental procedure and data processing when it is used.

Apparatus

The primary components of the bench are a blower, nozzle wall, plenums and a blast gate (damper) for adjusting the flow rate [1] as shown in Figure 1. The Device Under Test (DUT) in Figure 1 is shown attached to the inlet of the flow bench.

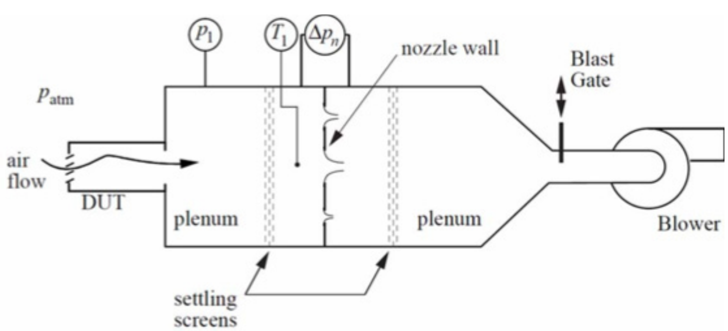

Figure 1. Schematic of a Flow Bench Configured to Measure the System Curve of an Electronic Enclosure, The Device Under Test (DUT) [1].

Principle of Operation

The blower draws air through the flow bench, and in so doing, overcomes the flow resistance of the DUT, the flow bench ducting and the metering nozzle(s) [1]. The nozzles are used to measure the volumetric flow rate of the air. The blower operates at constant speed and the blast gate is opened and closed to control the flow through the system.

If the system curve of an enclosure is needed, then the DUT is the enclosure. The blower provides the flow through the flow bench and the DUT [1]. The system curve is obtained by performing a range of measurements at different flow rates to obtain

$$p_{sys} = f(G) \tag{1}$$

Where $p_{sys} = p_{atm} - p_1$ is the DUT system pressure drop, p_{atm} is the local ambient pressure, p_1 is the pressure in the upstream plenum, and G is the volumetric flow rate.

If the fan curve is required, then the DUT is a fan. The fan pushes air into the flow bench thereby creating an elevated pressure in the first plenum [1]. The purpose of the flow bench blower in a fan curve experiment is to maintain the pressure in the first plenum to some desired level by drawing air through the flow bench. The fan curve is obtained by performing different measurements at different flow rates to obtain

$$p_{fan} = f(G) \tag{2}$$

Where $p_{fan} = p_1 - p_{atm}$ is the pressure rise provided by the fan.

For the fan curve and system curve experiments, the flow rate, G, is determined by measuring the pressure drop across the nozzle wall. The nozzle wall can have multiple ASME standard, long radius nozzles. Usually, just one nozzle is used at a time, although simultaneous use of two or three nozzles in parallel is allowed by standard 210-99. All inactive nozzles are sealed with plugs that are inserted manually via an access door on the downstream plenum.

To compute the flow rate through the flow bench one needs to measure: p_n, the pressure drop across one or more of the flow nozzles; p_1, the pressure in the upstream plenum; and T_1, the temperature of the air in the upstream plenum.

Instrumentation

Upstream Plenum Pressure

The pressure in the upstream plenum, p_1, is needed for both the fan and system curve measurements and to determine the air density through the nozzles. It is measured by a ring of four pressure taps, one on the center of each of the four plenum walls. The four taps are connected by a common tube which is connected to the pressure sensors. This configuration results in a measurement of the average of the pressures sensed at the four tap locations.

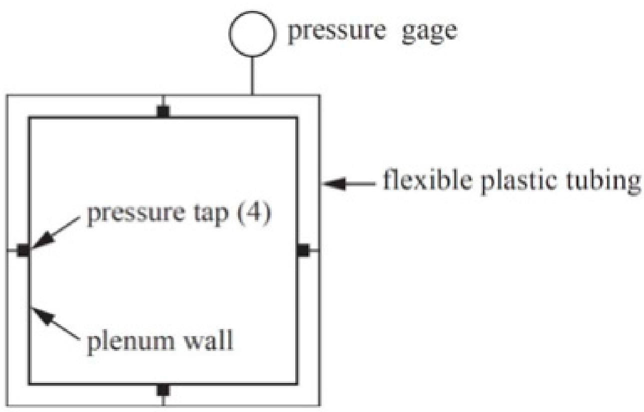

Figure 2. End View of Plenum Cross Section Showing Location of Pressure Taps.

Nozzle Pressure Drop

Two pairs of pressure tap rings (four taps per ring) are used to sense p_n, the pressure drop across the nozzle wall. One set of four taps is located just upstream of the nozzle wall in the upstream plenum. Another set of four taps is located just downstream of the nozzle wall in the downstream plenum.

Plenum Air Temperature

The temperature in the upstream plenum can be measured by thermocouples. One thermocouple is suspended upstream of each flow nozzle in the space downstream from the settling screens.

Nozzle Selection

Long radius flow nozzles, the primary flow measurement elements in the flow bench, are installed in the nozzle wall of the flow bench as shown in Figure 1 [1]. Each nozzle is suitable for measurements over a limited range of flow rates. Below the minimum flow rate (for a particular nozzle), the pressure drop across the nozzle is too small to be measured accurately by the pressure sensors. Above the maximum flow rate, the pressure drop is greater than the maximum allowable pressure for the pressure sensor. In addition, as the flow rate through a given nozzle increases, the velocity in the nozzle throat may become large enough for compressibility effects to become significant.

Single Nozzle Operation	
Flow rate [m³/h]	Nozzle diameter [mm]
15.3 to 32.3	19.05
25.5 to 59.5	25.4
66.3 to 163	40.64
Multiple Nozzle Operation	
Flow rate [m/s]	Nozzle diameter [mm]
40.8 to 68.0	19.05 and 25.4
81.6 to 121	19.05 and 40.64
107 to 255	19.05, 25.4 and 40.64

Table 1. Recommended Nozzle Selection as a Function Of Flow Rate [1].

Attaching the DUT

An adapter plate is needed to attach a fan or an electronic enclosure to the opening in the flow bench. The adapter plate must be large enough to cover the opening in the upstream plenum. In the center of the adapter plate, there should be a hole of the same size and shape as the exhaust hole of the DUT. Duct tape can be used to ensure that the joints between the DUT and adapter plate are leak proof.

Data Reduction

The final result of a flow bench experiment is either a system curve or a fan curve for the DUT. To obtain these curves, the pressure and temperature measurements for the nozzles must be converted to flow rates. The pressure transducer and thermocouple conversion involve standard practices and will not be discussed here.

Flow Rate

The flow rate through the flow bench is measured by long radius flow nozzles built to the specifications in Standard 210-99. The volumetric flow rate through the nozzle can be calculated iteratively using Equation 5.

$$\alpha = (p - \Delta p)/p \tag{3}$$

$$Y = \left[\frac{\gamma}{\gamma - 1}\alpha^{2/\gamma}\frac{1-\alpha^{(\gamma-1)/\gamma}}{1-\alpha}\right]^{1/2}\left[\frac{1-\beta^4}{1-\beta^4\alpha^{2/\gamma}}\right]^{1/2} \tag{4}$$

$$G = C_d Y A_n \sqrt{\frac{2\Delta p}{\rho(1-\beta^4)}} \tag{5}$$

Where C_d is the nozzle discharge coefficient, Y is the expansion factor, $A_n = \pi d_t^2/4$ is the area of the nozzle throat, d_t is the throat diameter, Δ_p is the measured pressure drop across the nozzle, ρ is the fluid density upstream of the nozzle, $\beta = d_t/D$ is the contraction ratio, D is the diameter of the upstream duct, and γ is the ratio of specific heats. This can be taken as 1.4 for air.

If the nozzles used are specified in standard 210-99, Equation 7 can be used to determine C_d [1]. However, ideally each of the nozzles should be calibrated.

$$Re_t = \frac{\rho V_t d_t}{\mu} = \frac{\rho 4G}{\pi d_t \mu} \tag{6}$$

$$C_d = 0.9986 - \frac{7.006}{\sqrt{Re_t}} + \frac{134.6}{Re_t} \tag{7}$$

Curve Fit for System Curve

The enclosure system pressure drop determined by the flow bench is best given in the form shown in Equation 8, where c is a constant and Q is the volumetric flow rate through the flow bench.

$$\Delta p_{sys} = cQ^2 \tag{8}$$

$$c = \frac{\sum_{i=1}^{n} Q_i^2 \Delta p_{sys,i}}{\sum_{i=1}^{n} Q_i^4} \tag{9}$$

Where Q_i and $\Delta p_{sys,i}$ is a single data point from the system curve measurements and there are n data points in total. Essentially Equation 9 is the least square fit of Equation 8. For characterizing fans, Advanced Thermal Solutions, Inc. has developed a fan characterization module as shown in Figure 3.

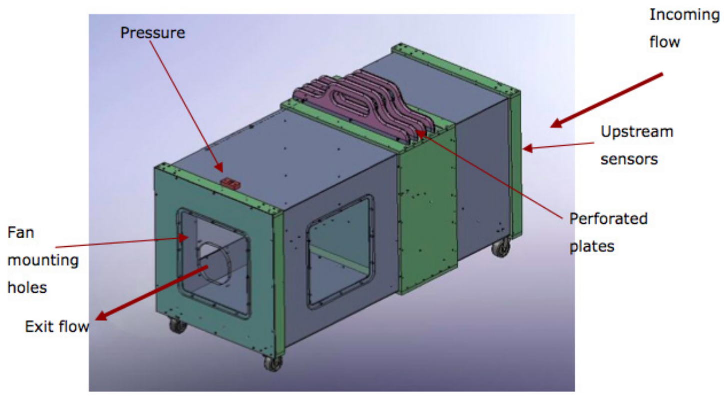

Figure 3. FCM (Fan Characterization Module) Schematic from ATS [3].

With this module, the user inserts perforated plates into the device. With different combinations of perforated plates, the pressure drop at the upstream of the fans can be varied. The air flow rate can be measured by hot wire anemometer sensors located at the upstream of the device. The volumetric flow rate will be the product of the average of the velocity readings and the cross sectional area. A set of volumetric flow rates and pressure drops will determine the fan curve.

References:

1. Recktenwald, G., A Flow Bench for Measuring Fan Curves and System Curves of Air-Cooled Electronic Equipment, Mechanical Engineering Department, Portland State University, 2006.
2. Laboratory Methods of Testing Fans for Aerodynamic Performance Rating, ANSI/AMCA Standard 210-99. Air Movement and Control Association International, Inc, 2000.
3. Advanced Thermal Solutions,Inc., www.qats.com.