AIR FLOW MEASUREMENTS

USING A

VARIABLE FREQUENCY AC GENERATOR

BY

JEFFREY H. STEINKAMP, P.E.

BROADCAST ELECTRONICS, INC.

QUINCY, ILLINOIS

BROADCAST ELECTRONICS

4100 N. 24th ST. • P.O. BOX 3606 • QUINCY, IL. 62301 • TELEPHONE (217)224-9600

TITLE

AIR FLOW MEASUREMENTS USING A VARIABLE FREQUENCY AC GENERATOR

BY

JEFFREY H. STEINKAMP, P.E.

BROADCAST ELECTRONICS, INC.

QUINCY, ILLINOIS

ABSTRACT

This paper deals with a systematic engineering approach to determine airflow requirements for the proper cooling of RF power tubes used in broadcasting transmitters.

Points of discussion will include power tube thermal limitations, temperature recording technique, airflow measurement by the use of a blower/variable frequency AC generator system and finally a section concerning guidance on proper blower selection.

Included in this paper are the author's explanation of test equipment set-up, method of measurement and actual test results from a 30KW FM transmitter design project.

RF POWER TUBE TEMPERATURE MEASURING

The external surface temperatures of an operating RF power tube can be safely and successfully measured by the following methods.

Temperature Sensitive Paints - One of the easiest and reliable ways to measure tube surface temperature is by the use of temperature sensitive paints. These paints are available in a range of 125^{o} to $250^{o}C$ in steps of less than $10^{o}C$. Small, thin dots of paint are applied to the tube surface (see FIG. 1). If the specified temperature is exceeded, the paint will melt and change appearance from dull to glossy. For best results use a group of paint dots with each dot having a different sensitivity. These groups (3 minimum) should be equally spaced around the tube to compensate for possible temperature gradients.

The paint used in the actual 30KW test was called "OMEGALAQ" (Omega Engineering, Stamford, CT) with temperature sensitivity of 128^{o}, 149^{o}, 177^{o}, 204^{o}, 226^{o}, and $253^{o}C$.

Thermocouples - The most common electrical method of temperature measurement uses the thermocouple. When two dissimilar metals are joined together a DC voltage develops which is proportional to the temperature of this junction. If this thermally generated voltage is carefully measured as a function of temperature then such a junction can be utilized for temperature measurement.

The thermocouple can be mechanically attached to the tube filament stem (see FIG. 1) for direct temperature readings via a data acquisition system. Caution must be used when making direct contact with any operating RF power tube because of the potential electrical hazard and/or RF radiation.

The thermocouple system used consisted of a Copper/Constantan Type T thermocouple working in conjunction with a HP3421A data acquisition unit.

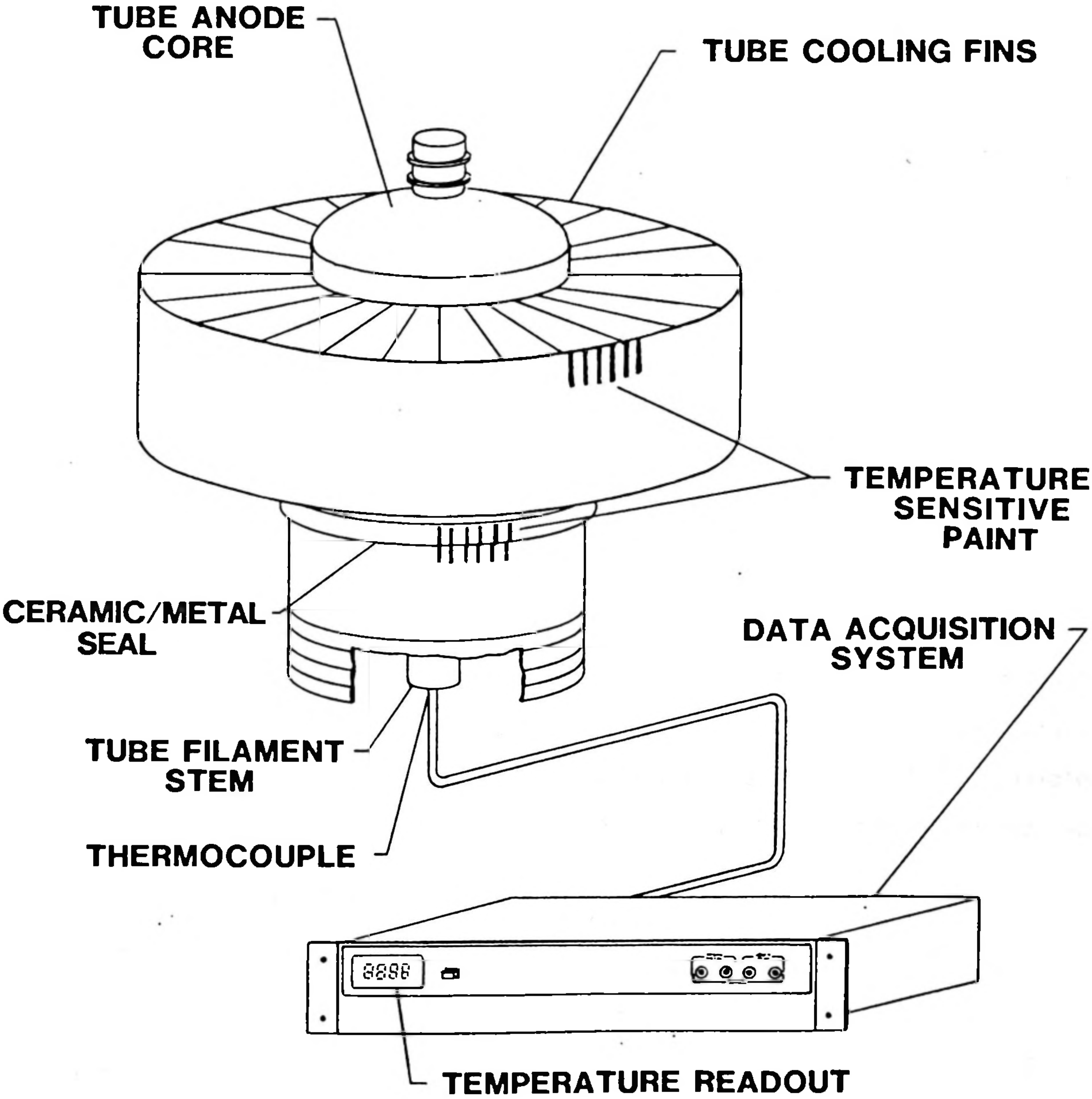


FIGURE 1. TUBE TEMPERATURE MEASUREMENT SYSTEM

AIRFLOW MEASUREMENT

Airflow can be measured in many different fashions. Some of the more common methods include calibrated nozzles, orifice plates, pitot tubes, hot wire aneomometers and flow meters. These methods have an accuracy range of poor to excellent and cost from moderate to expensive.

In searching for an accurate, portable and cost effective transmitter airflow measuring device the author has developed a system consisting of a standard blower and a variable frequency AC generator (see FIG. 2). By using an AMCA tested blower (Cincinnati Fan #PB14) with a 3450RPM @ 60Hz AC induction motor and driven by a variable frequency generator (Toshiba Model #VF10P), the engineer can adjust the motor speed from 0 to 3450RPM by controlling the input frequency from 0 to 60Hz respectively.

To utilize this variable speed blower in airflow measurement, the engineer must first determine the performance characteristics of this system. Constant speed blower performance is usually shown graphically by comparing airflow in cubic feed per minute (CFM) versus the static pressure (SP) against which the blower is trying to move air (see FIG. 3, 60Hz curve). These constant speed performances can be modified by the following fan laws:

$$\mathrm{CFM(XXHz)} = \left[\frac{\mathrm{RPM(XXHz)}}{\mathrm{RPM(60Hz)}}\right] \times \mathrm{CFM(60Hz)} \qquad \text{(EQ. 1)}$$

$$\mathrm{SP(XXHz)} = \left[\frac{\mathrm{RPM(XXHz)}}{\mathrm{RPM(60Hz)}}\right]^2 \times \mathrm{SP(60Hz)} \qquad \text{(EQ. 2)}$$

These mathematical formulas allow the engineer to generate a complete set of performance curves for a known blower at any airflow, static pressure or speed configuration (see FIG. 3).

With this graphical data, the variable speed blower and a manometer, the engineer now has essential tools for measuring airflow.

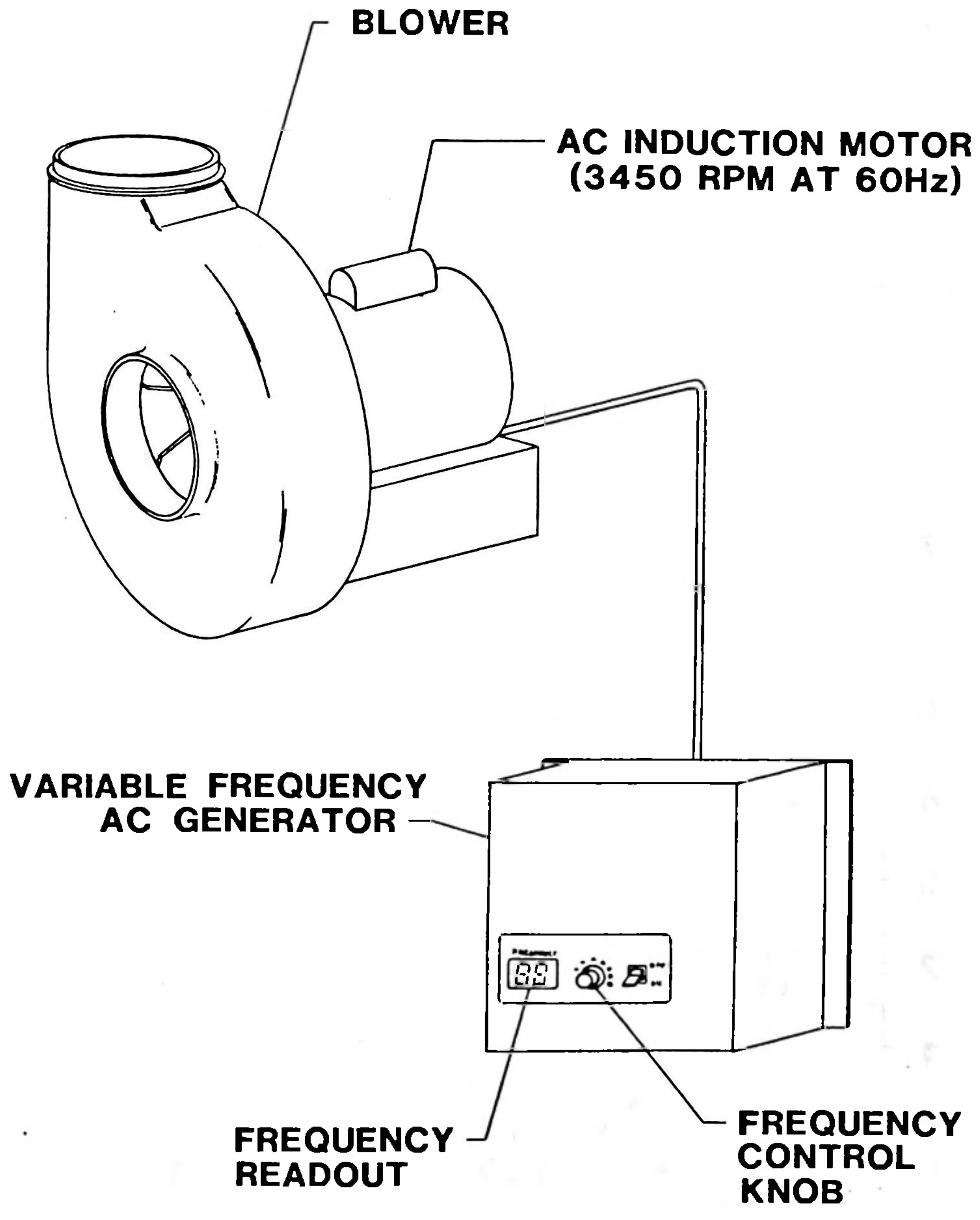


FIGURE 2. BLOWER/VARIABLE FREQUENCY AC GENERATOR

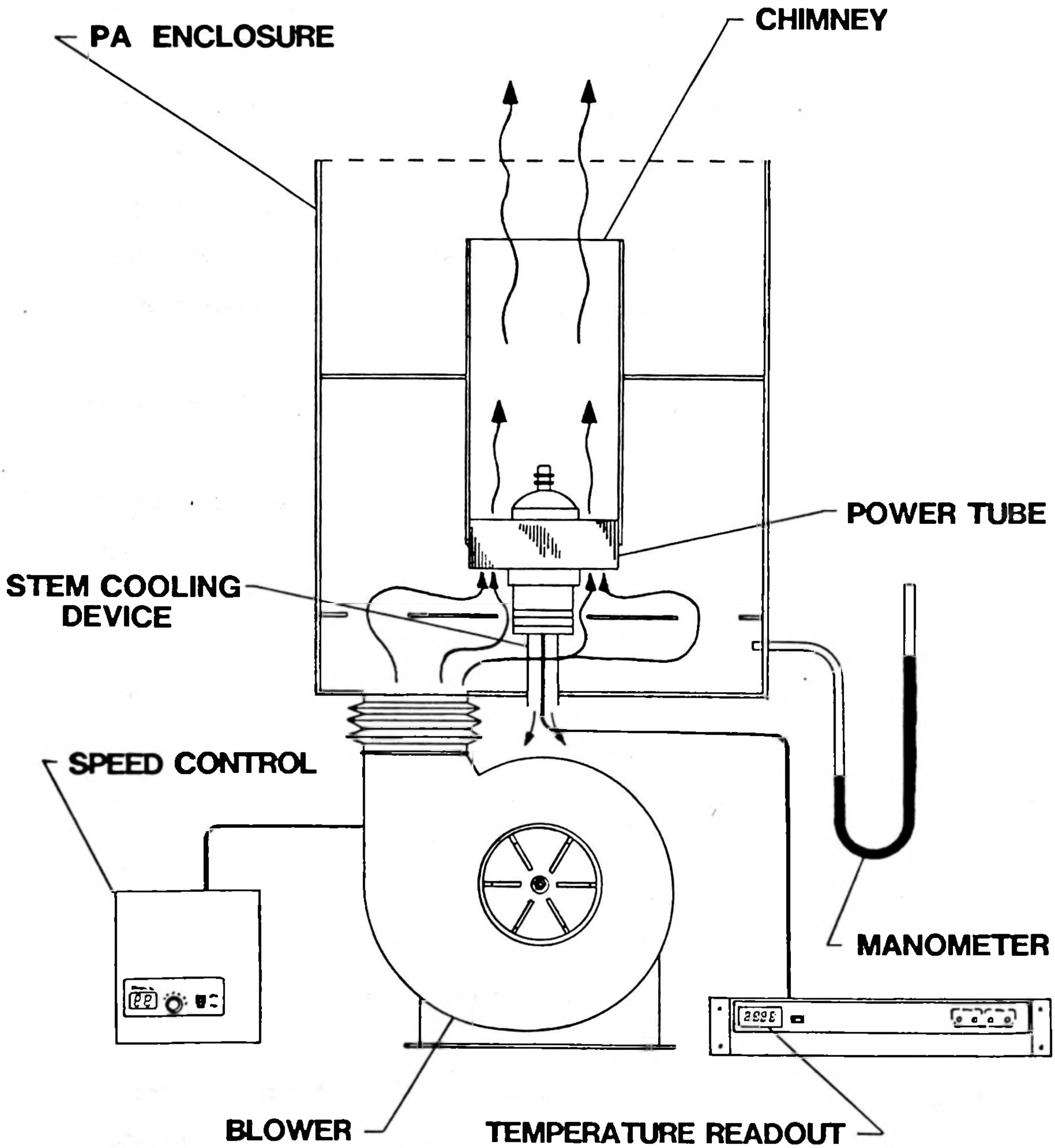
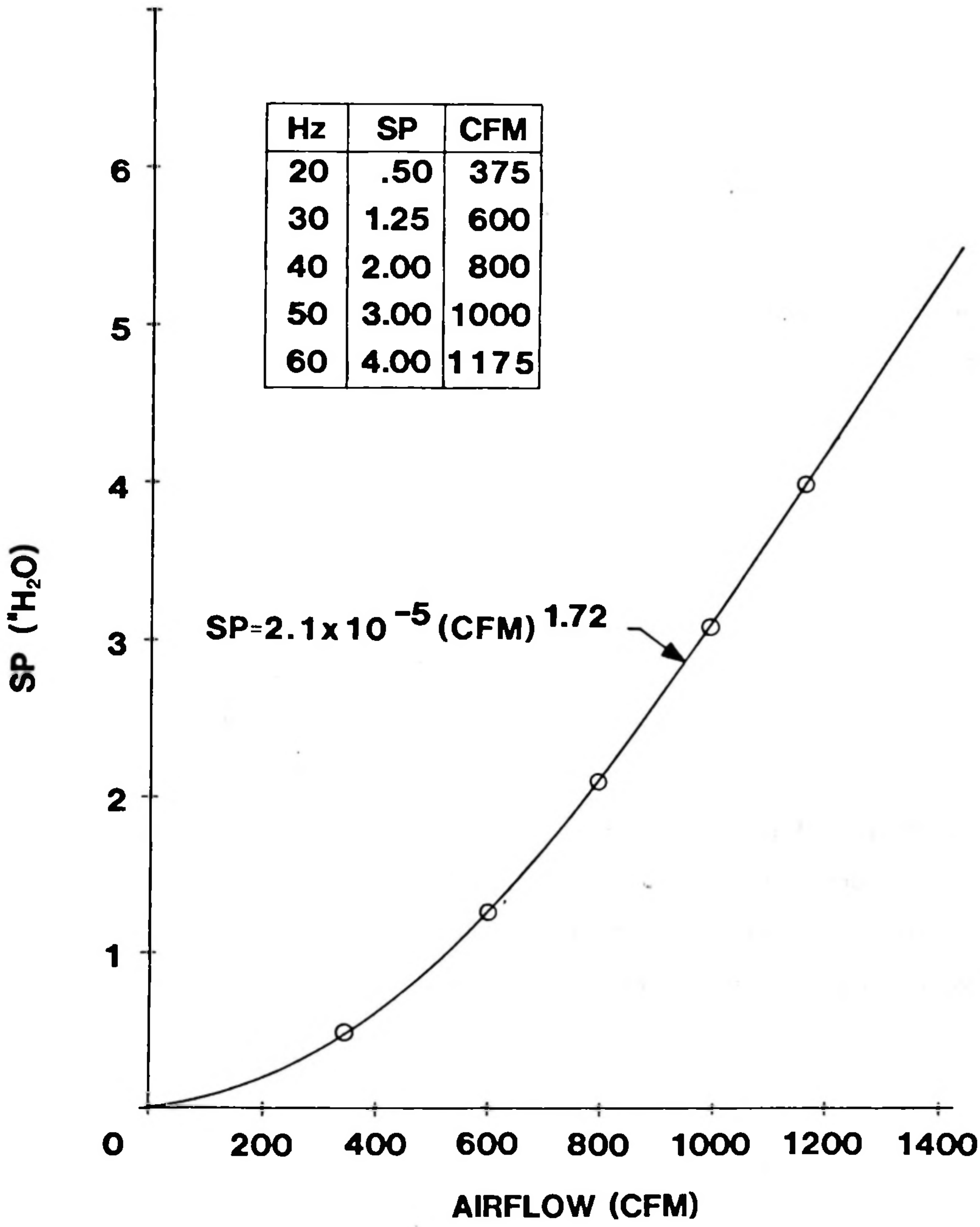


FIGURE 4 TRANSMITTER AIRFLOW/TEMPERATURE TEST ARRANGEMENT



Hz	SP	CFM
20	.50	375
30	1.25	600
40	2.00	800
50	3.00	1000
60	4.00	1175

FIGURE 5. AIRFLOW SYSTEM RESISTANCE CURVE

TEMPERATURE/AIRFLOW TEST

Now that the engineer understands the RF power tube thermal limitations and has the equipment to measure airflow and temperature, it is now time to proceed with the actual tube temperature versus airflow test.

Assured that the test system and equipment is functional, the engineer energizes the transmitter at a fixed tube power dissipation. Starting with the maximum airflow (1400 CFM) a reading of static pressure and temperature should be recorded. By decreasing the speed of the blower less airflow will result and an increase in tube temperature will occur. The SP reading taken at each data point can be used to calculate the airflow in CFM by using either the system resistance curve (FIG. 5) or the system resistance equation (EQ. 3).

The results of this test are shown in the tube temperature/airflow curve (see FIG. 6). The filament stem temperature (T_3) is the most critical in this example. At a flow rate of 720 CFM the stem reaches the recommended design temperature of 225^{o}C. Note the 25^{o}C safety margin. Thus, the airflow of 720 CFM is sufficient at the environmental test conditions of 600' altitude and 25^{o}C temperature with 13 KW plate dissipation. As shown in the next section this flow rate will need to be adjusted for different operating altitude and temperature conditions.

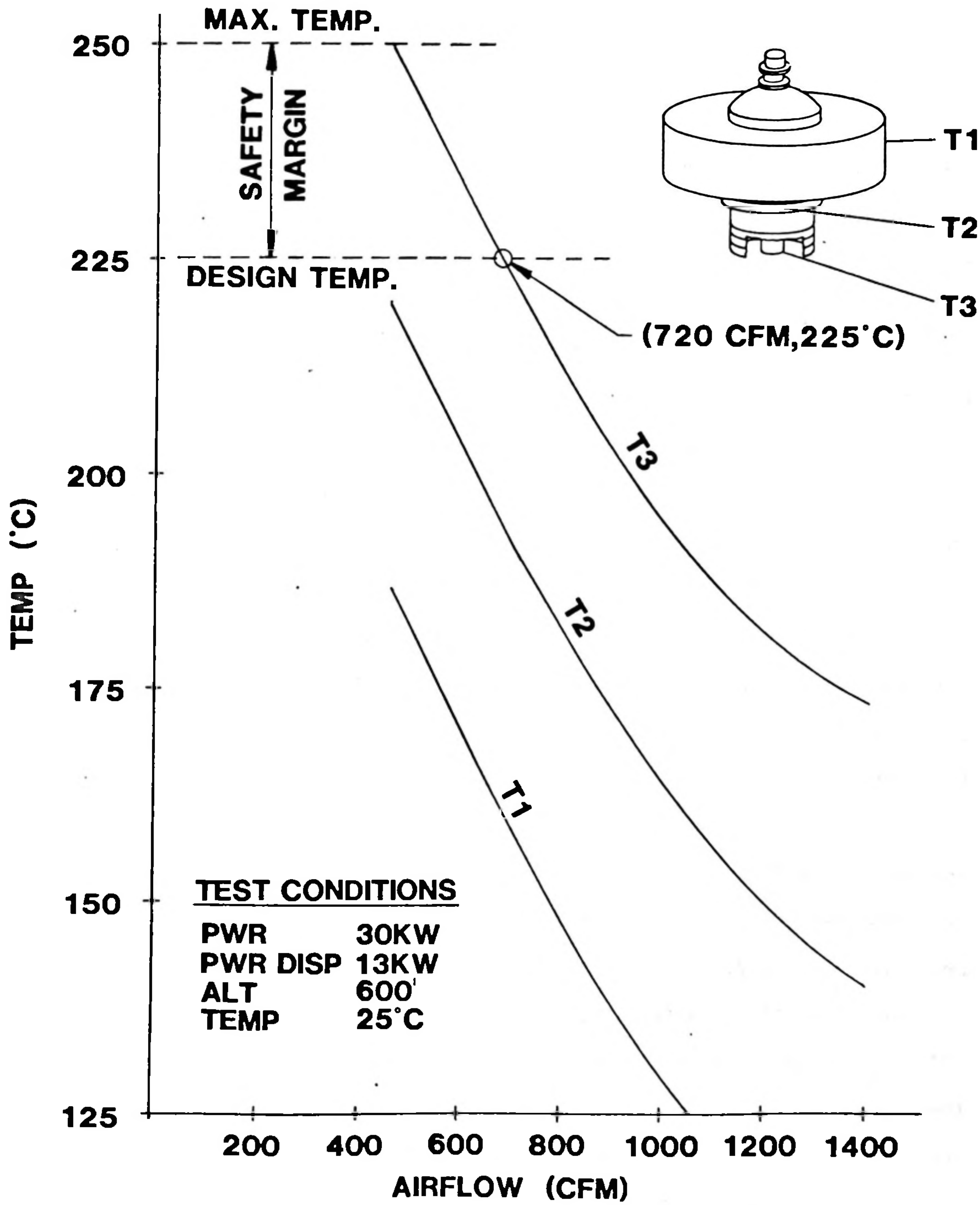


FIGURE 6. TUBE TEMPERATURE/AIRFLOW CURVE

BLOWER SELECTION

The selection of a blower depends upon many factors, some of which include: Size, weight, noise, mounting requirements, cost and the ability to supply a certain amount of airflow against a specified pressure. This paper will limit its discussion to the airflow and pressure requirements.

In the previous section it was determined that a certain amount of airflow (720 CFM) was sufficient to maintain the tube surface temperature at an acceptable level (225°C). This airflow is only adequate at the given environmental test conditions (600' and 25°C). To provide proper cooling at maximum transmitter ambient conditions, typically 7500' and 50°C, an altitude/temperature correction factor must be applied.

Since the cooling capacity of air is a function of its mass, not volume, any change in air density will affect this cooling ability. Increases in altitude and temperature decrease air density and thus reduce the cooling capacity of air. Therefore, if a tube is to be operated at increased altitudes or temperatures, a correction factor which is proportional to these density changes must be applied. Application of this correction factor to the volumetric flow rate will assure the greater volume of air which is required when cooling with lower density air. These correction factors are given in FIG. 7.

Correcting the 30KW test results of 720 CFM at 600' and 25°C to 7500' and 50°C can be accomplished in the following manner. First, determine the correction factors (CF) from FIG. 7 for the above test conditions and required conditions. Then use the following formula:

$$\frac{CF(REQ.)}{CF(TEST)} \times CFM(TEST) = CFM(REQ.) \quad (EQ.\ 4) \quad \text{or} \quad \frac{1.43}{1.03} \times 720\ CFM = 1000\ CFM$$

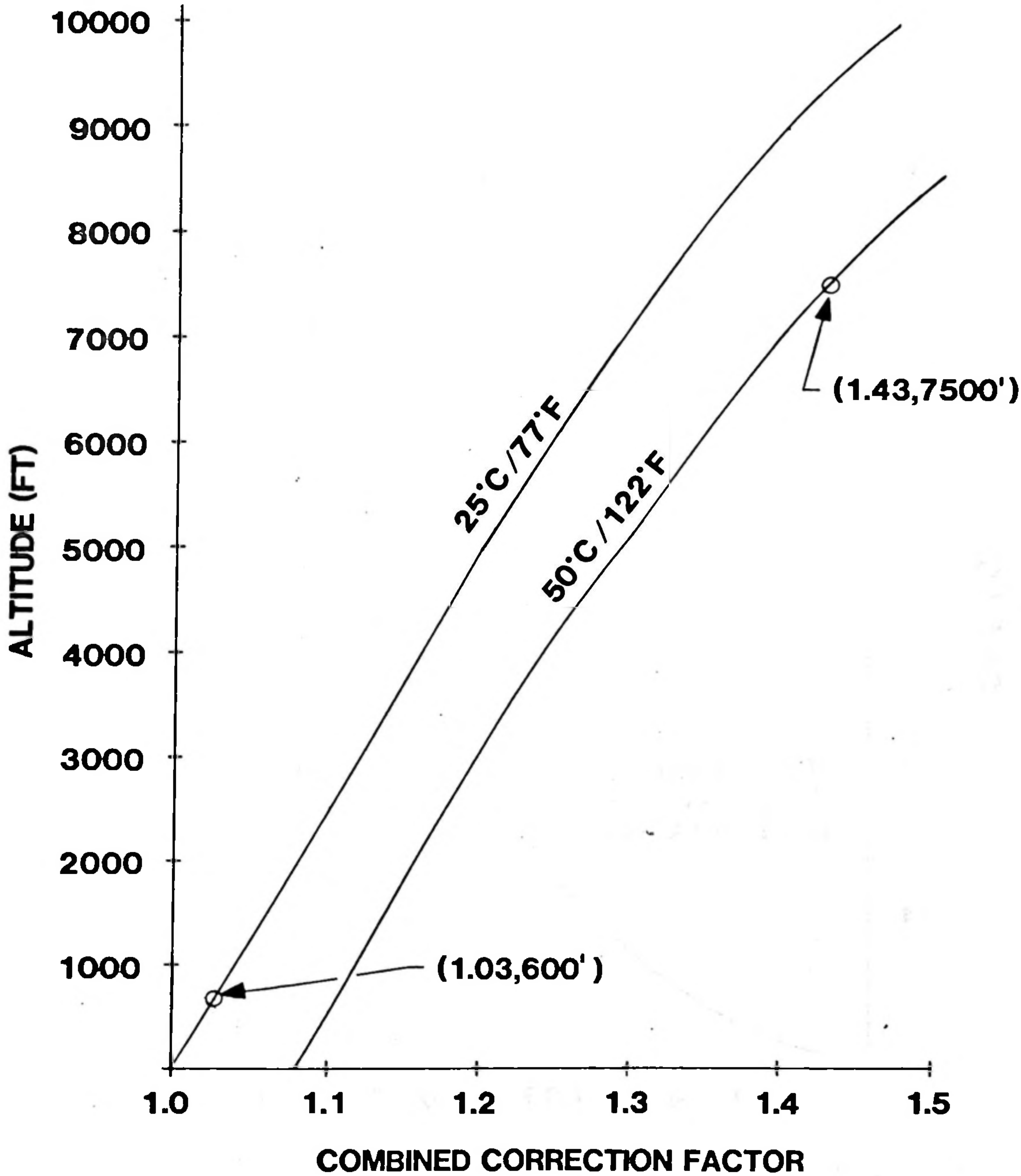


FIGURE 7. ALTITUDE/TEMPERATURE CORRECTION CURVE

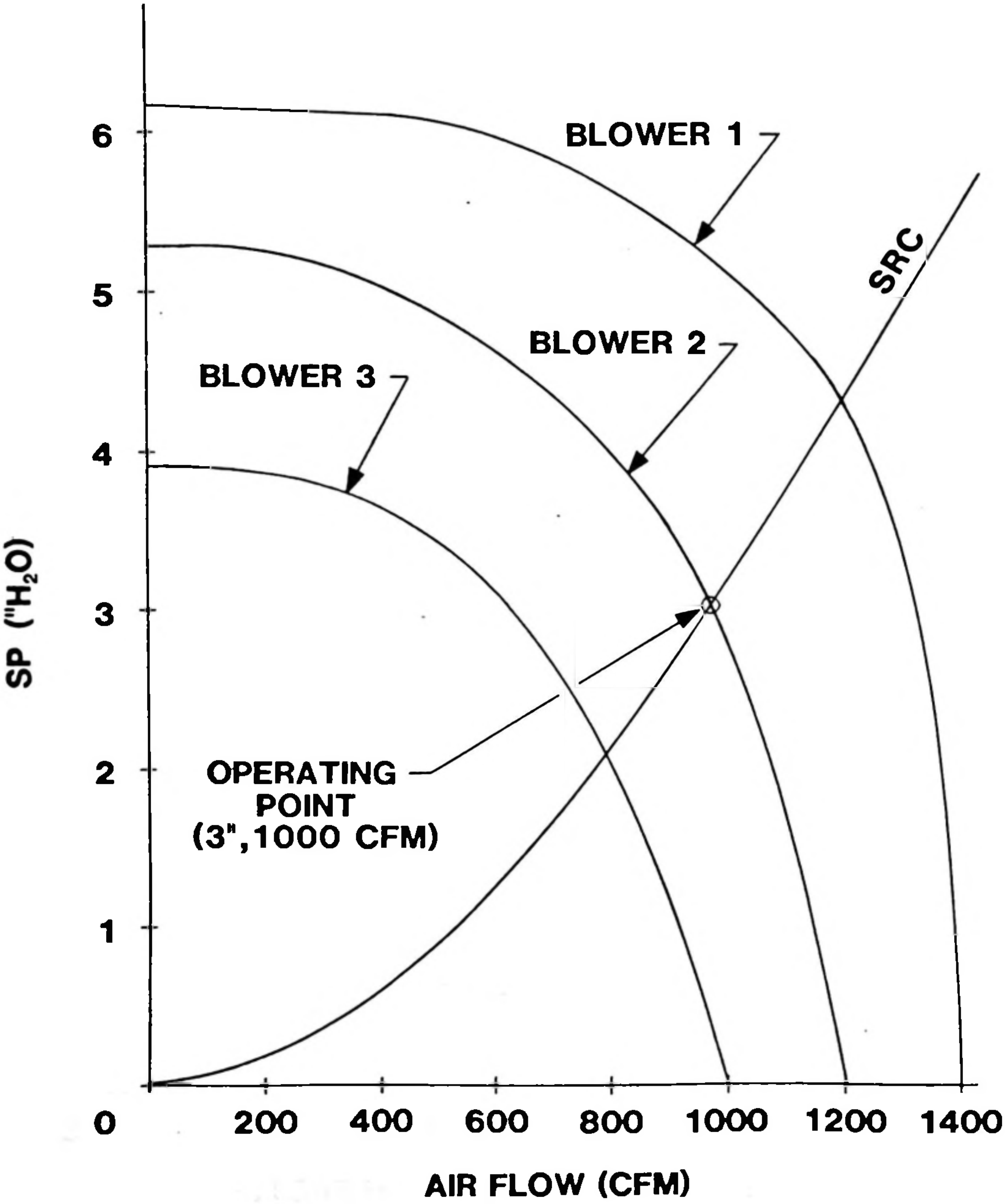


FIGURE 8. BLOWER SELECTION CURVE

Thus, to maintain proper tube cooling at the elevated ambient conditions 1000 CFM must be moved through the transmitter. By reviewing the system resistance curve (FIG. 5) it can be noted that a static pressure of 3" of water will exist at a flow rate of 1000 CFM for this transmitter arrangement. Thus the engineer now knows both the required CFM and static pressure needed to safely operate the transmitter.

With the flow rate and pressure data in hand it is a simple matter to select a blower. First, combine standard blower curves with the system resistance curve (see FIG. 8) and select the blower whose curve intersects the SRC at or above the 1000 CFM and 3" point. At this equilibrium point of operation the pressure available from the blower to force air through the system is equal to the pressure required by the system for that flow rate. Blower 2 would be the correct choice. If the transmitter must operate at various line frequencies (50/60 Hz) then the selected blower must supply the required air at the lowest line frequency.

CONCLUSIONS

Providing proper cooling to the RF power tube is a critical part of transmitter design. Mathematical formulas of fluid flow and heat transfer do not lend themselves to practical usage. Only when actual temperature versus airflow tests are conducted will the engineer feel confident about safe transmitter operation.

This paper has presented a systematic approach to measuring temperature and airflow with the use of an author devised variable speed blower system. In order to prove the practicality of this system a complete set of test data from a 30KW FM transmitter project was presented for review.