TRANSMITTER COOLING SYSTEMS: DESIGN, OPERATION AND MAINTENANCE

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I. INTRODUCTION

The design, operation and maintenance of broadcast transmitter cooling systems must be properly addressed by the design engineer, system engineer, and station engineer to insure acceptable electrical and mechanical performance. The transmitter design engineer must apply expert thermal management to the heart of his product, the RF power tube. This internal cooling system must provide proper airflow around the tube filament stem, ceramic seals and cooling fins if good performance and long tube life are desired. The system engineer is responsible for providing an acceptable environment to the transmitter. This external cooling system is accomplished by the delicate balance of supply and exhaust air to the transmitter room. Finally, the station engineer must take the resultant efforts of the design and system engineers and properly operate and maintain this equipment within the specified limitations on a daily basis.

Using theoretical calculations to determine the amount of airflow required for power tube cooling presents a problem for the design engineer. The major obstacles to using mathematical solutions are the indeterminate fluid flow characteristics and heat transfer coefficients of the tube. Due to the complex nature of the flow path typically found in electronic equipment, pressure drop calculations do not yield easily to the customary fluid flow equations. Likewise, the heat transfer coefficients of tube surfaces and cooling fins are continually changing with flow velocity. Thus, the designer must resort to empirical testing to determine tube cooling requirements. This paper will present a systematic engineering approach to solving the problem of providing proper cooling for RF power tubes.

The system engineer does not usually have to resort to empirical testing of the external cooling system. The equipment used in supplying fresh air to the transmitter and then exhausting the heated air is used quite commonly in HVAC (Heating, Ventilating and Air Conditioning) systems. Information concerning the airflow and pressure drop characteristics of standard ductwork components is readily available and complete. The system engineer must review this data and then assemble these components in the proper order and function to provide the correct environment for the transmitter. This paper will explore the approach used by the system engineer in an example installation.

The station engineer has the task of operating and maintaining this equipment within the given design limitations to minimize unnecessary "off-air" time. This paper will address proper operation and specific maintenance advice for a typical arrangement of equipment.

II. DESIGN

The design of transmitter cooling systems consist of two major parts, internal cooling and external cooling. Internal cooling is concerned with the thermal requirements of components inside the transmitter (i.e. RF power tube, rectifiers, resistors, heatsinks, etc.). External cooling deals with the environmental needs outside the transmitter, namely the temperature control of the transmitter room.

2.1 INTERNAL COOLING

RF POWER TUBE THERMAL LIMITATIONS - The power tube has certain electrical and mechanical limitations. The proper voltages and currents applied to the tube are of utmost importance to the electrical engineer in order to achieve correct transmitter performance. Likewise, the mechanical engineer must be concerned with the packaging and cooling requirements of the tube to provide adequate temperature control during operation. For the engineer to better understand the thermal limitations of the tube it is best to consult the manufacturer's specification/application sheet. This data sheet will specify the maximum temperature allowed on the external surfaces of the tube to prevent destruction of the ceramic to metal seal and thermal warpage of the grids. Special air directors may be required for localized spot cooling of particularly hotter portions of the tube. Also contained in this technical literature will be data for airflow and static pressure requirements for rated plate dissipation. Since these curves represent just one particular type of tube socket configuration, they must be used with caution.

RF POWER TUBE TEMPERATURE MEASURING - The external surface temperatures of an operating 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° to 250°C in steps of less than 10°C. Small, thin dots of paint are applied to the tube surface and 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.

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 measurements.

The thermocouple can be mechanically attached to the tube filament stem 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.

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. 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. By using an AMCA (Air Movement and Control Association) tested blower with a 3450RPM @ 60Hz AC induction motor and driven by a variable frequency generator, 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 feet per minute (CFM) versus the static pressure (SP) against which the blower is trying to move air. These constant speed performances can be modified by the following fan laws:

$$CFM(XXHz) = \frac{RPM(XXHz)}{RPM(60Hz)} \times CFM(60Hz) \qquad (EQ.1)$$

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

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

<u>SYSTEM RESISTANCE MEASUREMENTS</u> - System resistance is the term used to define the impedance to airflow presented by a restrictive system. The system could be a combination of sheet metal ductwork, filters, finned heatsinks, RFI honeycomb, tubes, tube sockets, etc. The motion of air through electronic equipment can only be accomplished by the creation of a pressure drop across the piece of equipment, in the same manner that current can only be caused to flow through a resistance by the application of a voltage across it. System resistance is usually expressed graphically by the system resistance curve (SRC) with coordinates of CFM versus SP. The importance of knowing the SRC of a particular obstructive configuration allows the engineer to better understand the flow characteristics of that system during the blower selection process.

By operating the blower into the restrictive system at different frequencies, recording the static pressures with a manometer, and using the variable frequency blower curves to determine the airflow, the SRC can be generated. Besides this graphical representation, the SRC can be shown by the general equation of:

$$SP = K(CFM)^n \qquad \text{(EQ. 3)}$$

Where K = a constant determined by the characteristics of the system

and n = a constant depending upon the type of flow.

Note that any change in the position or quantity of the restrictive elements within the test system will cause a change in the system resistance and should be retested for the correct SRC.

TEMPERATURE/AIRFLOW TEST - Now that the engineer understands the power tube thermal limitations and has the equipment to measure airflow and temperature, it is time to proceed with the actual tube temperature versus airflow test (See Figure 1).

The engineer first energizes the transmitter at a fixed tube power dissipation determined by the difference between the RF power output and the DC power input. Then starting with the maximum airflow, a reading of static pressure and tube 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 or the system resistance equation (EQ. 3).

At a certain flow rate some part of the tube will reach the maximum allowable surface temperature and the test should be terminated to avoid damage to the power tube. At this point the minimum allowable flow rate should be noted and as shown in the next section this flow rate will need to be adjusted for different operating altitude and temperature conditions.

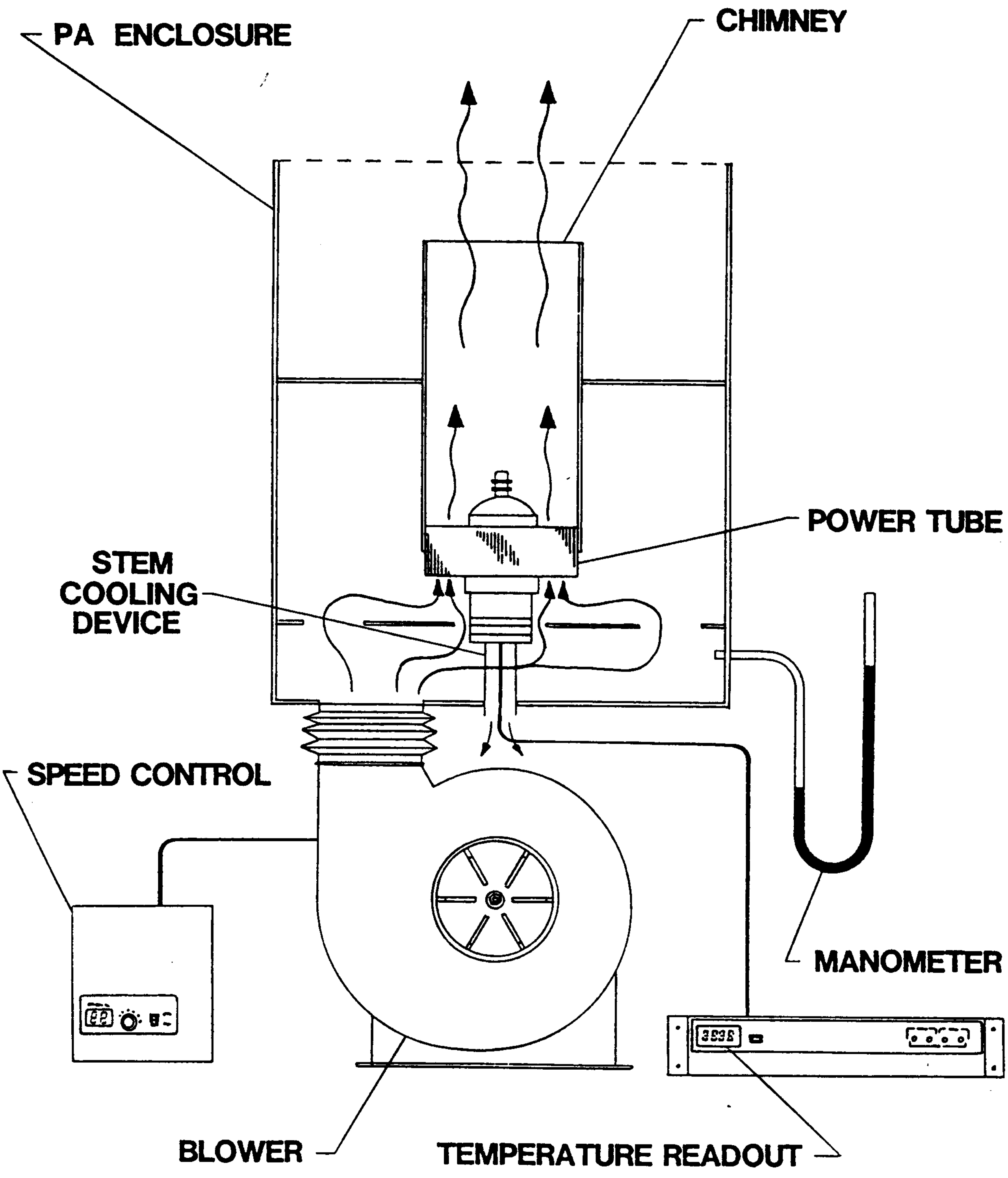

FIG. 1 TRANSMITTER TEMPERATURE/AIRFLOW TEST ARRANGEMENT

BLOWER SELECTION - The selection of a blower depends upon many factors, some of which include: Size, weight, noise, mounting requirements, power consumption, 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 was sufficient to maintain the tube surface temperature at an acceptable level. This airflow is only adequate at the given environmental test conditions of altitude and temperature. To provide proper cooling at maximum transmitter ambient conditions, typically 7500' and 50°C (122°F), 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 available in either graphical or tabular form.

With the adjusted flow rate data in hand, it is a simple matter to select a blower. First, combine standard blower curves with the system resistance curve and select the blower whose curve intersects the SRC at or above the required CFM. 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. 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.

2.2 EXTERNAL COOLING

External cooling of the transmitter consists of two parts, the supply and exhaust air systems (See Figure 2). The supply air system provides fresh unheated air to the transmitter and the exhaust air system removes the heated air from the transmitter room to the outside world. Although identical transmitters may be used by two different stations it can be a safe bet that the system engineer will have to design two different unique systems. Numerous variables such as room size, transmitter position, outside temperature fluctuations, altitude, prevailing wind direction, and budget constraints will dictate different designs.

SUPPLY AIR SYSTEM - The major component of the supply air system is the supply fan and motor assembly. The function of the supply fan is to provide a controlled amount of clean airflow to the transmitter room. The system engineer must size this air mover for adequate airflow at a given static pressure. The amount of airflow in CFM should be 1.5 to 2 times the amount that actually flows through the transmitter. Transmitter airflow data is obtained from the manufacturer and will specify main blower and flushing fan requirements. The selected fan must deliver the required flow rate when used in series with the intake louvers, damper and filter. Each of these devices will cause a resistance to airflow and a corresponding pressure increase. The louvers are designed to weatherproof the wall opening from rain and snow. The damper is used to control the amount of airflow at different conditions. The filter, of course, is needed to keep the intake air as clean as possible. Filter selection by the system engineer is of utmost importance. With the large selection of filter types available, from simple disposables to electrostatic precipitators, a careful analysis of functional requirements is essential. It is strongly recommended that a local engineering consultanting firm be retained for filter selection. A

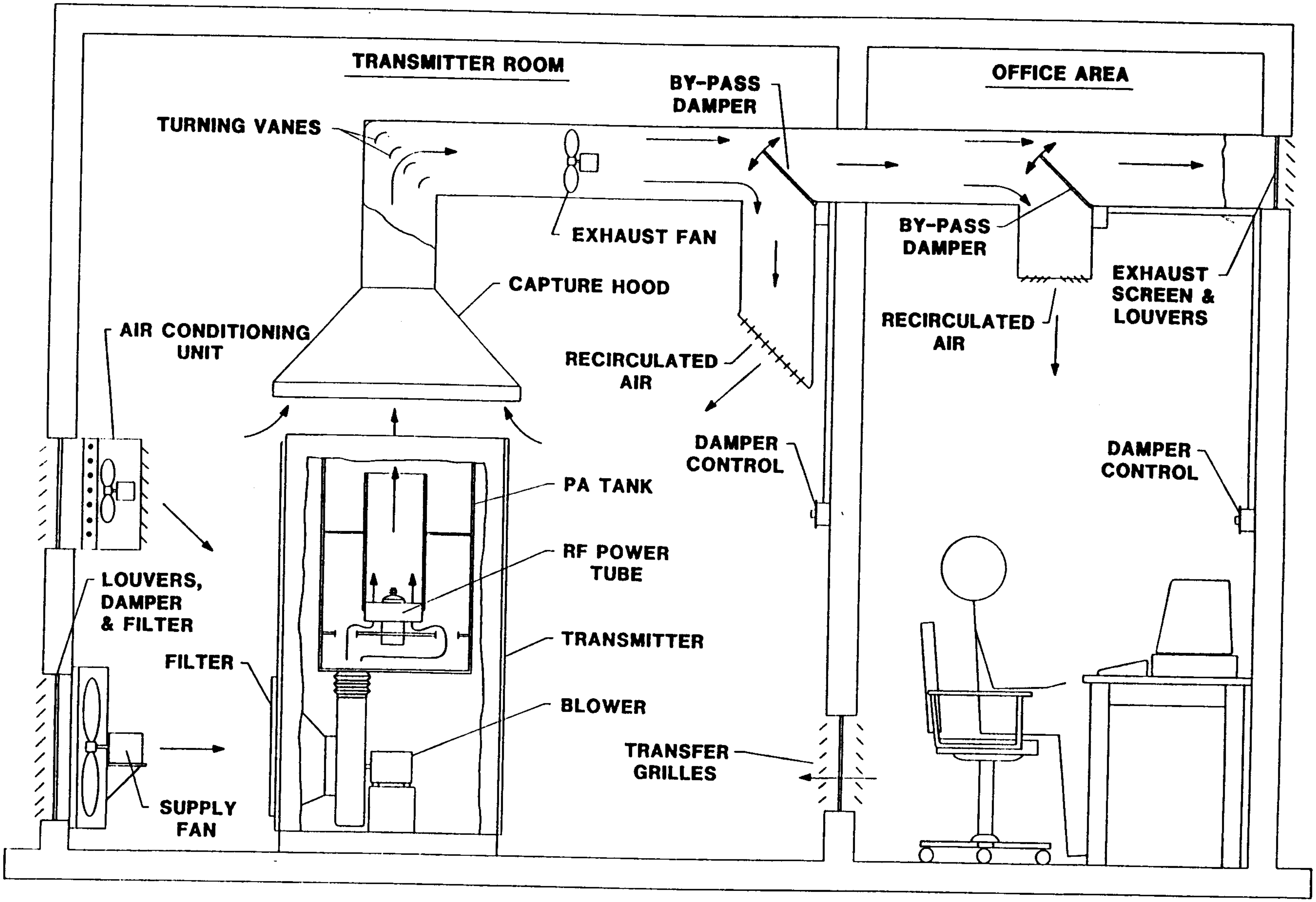

FIG. 2 TYPICAL TRANSMITTER COOLING SYSTEM

consultant that is familiar with the dust and contaminate conditions of your transmitter site will be invaluable to the proper function of your system.

An often needed accessory to the supply air system is an air conditioning (A/C) unit. This air cooler may be as simple as the window mounting type or as complicated as a large multi-tonnage refrigeration unit. When the transmitter room temperature exceeds an acceptable limit, the A/C unit activates and mixes cooled air with the incoming outside air. The A/C device may also be used in a closed loop system where the heated air from the transmitter is not exhausted outside but recirculated through the A/C unit. In this case, the system engineer would size the A/C equipment by determining the total amount of heat produced by the transmitter. This data in BTU's (British Thermal Units) is again available from the manufacturer and would include all of the heat ejected by the transmitter whether it be by conduction, convection or radiation. Also added to this thermal load are other sources of heat such as interior lighting, solar effect, test equipment, station personnel, dummy loads and heat exchanger. With this collected information the system engineer can now select the properly sized air conditioning unit.

EXHAUST AIR SYSTEM - The major components of the exhaust air system are the capture hood, exhaust fan, by-pass dampers and sheetmetal ductwork. Let's investigate the function and design of each of these devices.

Capture Hood - The capture hood is a sheetmetal canopy placed above the transmitter to gather in the heated exhaust air. A properly designed and positioned hood will effectively remove not only the direct air blast from the PA tank but also the radiant heat from the side panels of the transmitter.

Exhaust Fan - The function of the exhaust fan is to remove the heated air from the transmitter to the outside world via the capture hood and associated ductwork. The location of this device is usually as close to the capture hood as possible to keep the ductwork under positive pressure. Positive pressure ductwork prevents dust from infiltrating the system. The fan and motor must be able to withstand elevated temperatures (up to 200°F) so special bearings, windings, and lubricants may be required. The exhaust fan must have the same flow rate as the supply fan in order to maintain a balanced flow in and out of the transmitter room. This flow rate must be provided against the static pressures created by the complete duct system. Typical values for pressure drops through air ducts, elbows, transitions, and diffusers are available to the system engineer from the individual manufacturers.

By-Pass Dampers - The by-pass damper is actually a control gate used to direct airflow in the exhaust air system. Many broadcasting stations now recirculate the heated exhaust air to other rooms of the transmitter building during winter months to reduce energy cost. The movement of this air is regulated by the by-pass dampers. This control may be automatic or manual and the damper may be electrically, mechanically or pneumatically positioned.

Sheetmetal Ductwork - The ductwork used in transmitter cooling systems is the same as used in typical HVAC applications. This sheetmetal, either round, square, or rectangular, is a passageway for airflow from the capture hood to the exhaust louvers. The system engineer must package this duct system into the transmitter building with care and consideration. Always employ competent, skilled craftsmen to fabricate and install this duct system during the construction phase of the project.

III. OPERATION

The operation of the transmitter cooling system is the responsibility of the station engineer. His understanding of the function of each component will allow him to properly and efficiently operate this sometimes complicated system. Let's use the typical cooling system found in Figure 2 and observe this equipment under various operating conditions. Three different outside temperature conditions will be reviewed with the overall goal of maintaining a transmitter room temperature between 60° and 80°F.

CONDITION "A" (OUTSIDE TEMPERATURE RANGE 50°-75°F) - In this condition the intake damper will be fully opened, the supply and exhaust fans will be on, and the A/C unit will be off. Both by-pass dampers will be in the down positions so that all of the heated air will be removed from the building.

CONDITION "B" (OUTSIDE TEMPERATURE LESS THAN 50°F) - At this range of operation the intake damper begins to close as temperatures decrease and thus restricts airflow into the building. Both the supply and exhaust fans are operating. To compensate for the restricted intake airflow, the transmitter room by-pass damper will begin to rise and allow recirculated air to flow back into the room. The office area damper will also divert some of the heated air into that space. Some of the exhaust air will still leave the building until very low outside temperatures will cause the by-pass dampers to utilize all of the heated air. At this point, the intake damper will fully close and the supply fan will be turned off. The operation is now a closed loop system that uses no outside air. The transfer grilles allow a balance of pressure between the two rooms and provides a flow path for the return air.

CONDITION "C" (OUTSIDE TEMPERATURE GREATER THAN 75°F) - In this "hot" condition the intake damper will be fully opened and both the supply and exhaust fans are operating. The A/C unit will be on and is now mixing cooled air with the intake air before it is drawn into the transmitter. Both of the by-pass dampers will be positioned to allow all of the exhaust air to exit the building. Cooling of the office area must be accomplished by other means and equipment.

The control and functional interaction between the fans, dampers and A/C unit can be as simple as manually operated or automatically activated by a microprocessor. In any case, the station engineer must keep this system in "tune" and properly maintained for reliable performance.

IV. MAINTENANCE

Maintenance of the transmitter cooling system by the station engineer is a very important responsibility. An aggressive overall maintenance program is the foundation for a dependable, first class quality transmission system. The benefits of proper maintenance are knowing that the equipment will function when needed and in the manner in which it is required. Preventive maintenance consists of those precautionary measures applied to equipment to forestall future failures rather than to eliminate failures after they have occurred. These procedures are performed on a regularly scheduled periodic basis, and the results recorded in a maintenance log. Maintenance of a cooling system falls predominantly into the category of good housekeeping by cleaning and occasional lubrication of moving parts. Below is a checklist of maintenance procedures that should be applied to various key components of the cooling system:

FANS & BLOWERS - Clean dirt and dust from fan blades and blower impellers as required to prevent reduced airflow performance and unbalanced conditions that may cause bearing damage to this equipment. If belt driven, check the system for belt tightness, wear and alignment. Lubricate all fan and blower motors in accordance with the manufacturer's instructions and use a high quality lubricant. Motors are cooled by air passing through and around them. If airflow is restricted because of accumulated dust, internal failure may result from overheating. Mounting bolts should be checked for tightness.

FILTERS - Air filters should be checked once every week and replaced or cleaned as required. Make certain that disposable type filters are positioned correctly according to airflow direction and never reverse a dirty filter. Use only the filter type and quantity suggested by the equipment manufacturer. The practice of stacking filters does not improve air cleanliness but will restrict airflow and may cause overheating problems.

DAMPERS - Check dampers for accumulated dust and dirt that would restrict airflow or impair movement of the louvers. Lubricate all mechanical linkages and solenoids as recommended by the manufacturer.

POWER TUBE - Visually inspect the power tube for blocked air passages through the fin area. Use a shop vacuum cleaner or high pressure air hose to remove the obstructions. During routine maintenance it is very important to look for tube and socket discoloration, either of which can indicate overheating.

CONTROL SYSTEM - The control system of a transmitter cooling operation can be the most "touchy" component that the station engineer must deal with. A typical system may consist of thermostats, logic boxes, flow sensors, and servo mechanisms. Consultation with the system engineer is essential for proper performance of this system. Adjustments to thermostat settings and flow control should be in accordance with the system engineers instructions and guidance.

V. CONCLUSIONS

Proper design, operation and maintenance of a transmitter cooling system is critical to a successful broadcasting organization. The transmitter designer must empirically test the internal cooling system with a competent and logical engineering approach. The system engineer must provide an external cooling system that will produce a proper environment to the transmitter, regardless of outside temperature changes. The station engineer must understand the operation and maintenance requirements of his own unique system in order to have a cost effective and quality transmission signal. And finally, the major purpose of this paper is to sensitize the broadcast station management to the importance of a properly designed, operated and maintained transmitter cooling system.

For Further Information On Transmitter Cooling Systems

Chiarulli, M., "Common Pitfalls in Designing Transmitter Cooling and Ventilation Systems", ABC Television, New York, NY

Shulz, W., "Process Cooling System For High-Rise Building Transmitter Installations", WFYR Radio, Chicago, IL

Stanley, H., "Guidelines for Transmitter Plant Installation and Maintenance", Harris Corp., Quincy, IL

Steinkamp, J., "Air Flow Measurements Using A Variable Frequency AC Generator", Broadcast Electronics, Inc., Quincy, IL

Whitaker, J., "Maintenance: Staying on the Air", Broadcast Engineering, November 1984

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