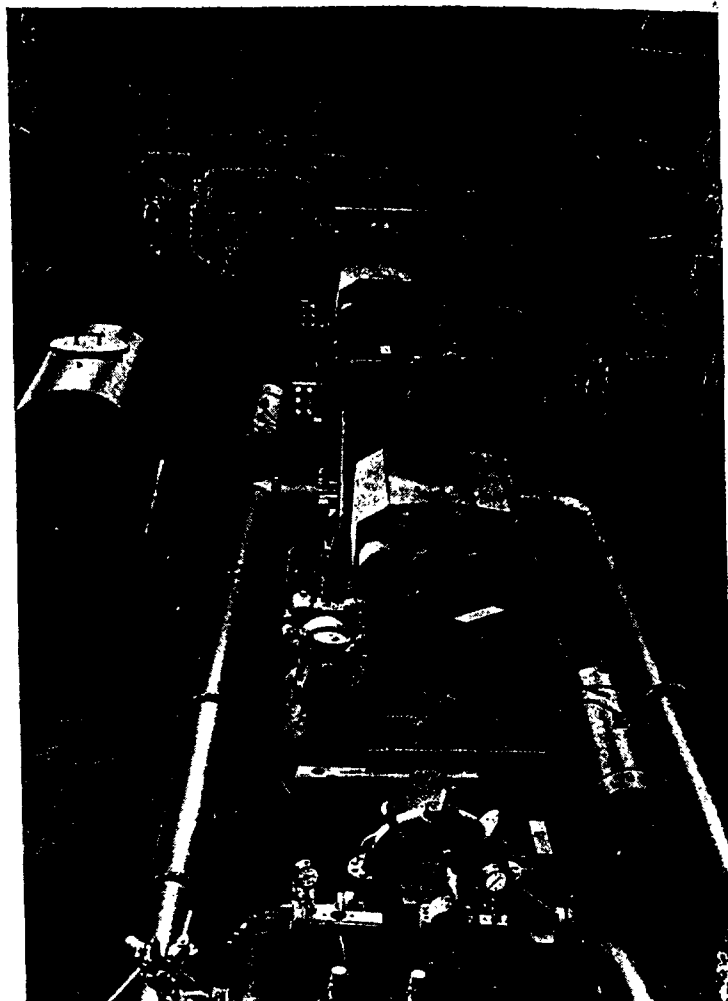


Halliburton ICS Skid Pumps fit nicely into Southern California Edison's pre-operational cleaning plans.



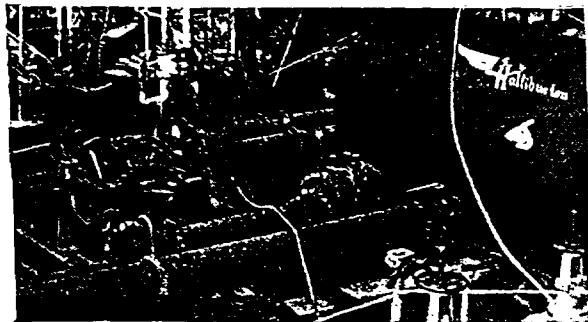
CUSTOMER: Southern California Edison Company
(Alamitos Steam Station near Long Beach).

ASSIGNMENT: Ready new steam generator Unit #5 for start-up by ridding it of iron oxide mill scale deposits.

Halliburton moved its skid mounted pumps, power packs, and temporary piping directly into the heart of the unit. Once the acid cleaning station was set up, a cleaning solution consisting of a mixture of hydroxy acetic formic acids was introduced into the piping systems of the steam plant. This solution,

heated to a temperature of 200° F, was circulated throughout the pre-boiler system, the boiler, the super-heat and re-heat sections at a rate of from 1,000 to 4,000 gallons per minute. After chemical cleaning was completed satisfactorily, the entire system was flushed with high purity water.

POINT TO REMEMBER: What the Halliburton Chemical Cleaning Specialists did for the Southern California Edison Company they can do for your operation — with the best equipment at lowest costs consistent with excellence. Worth investigating, don't you think?



PLAINTIFF'S EXHIBIT

RS-258

INDUSTRIAL CLEANING SERVICES

COMPANY • DUNCAN, OKLAHOMA

COMBUSTION / July 1967

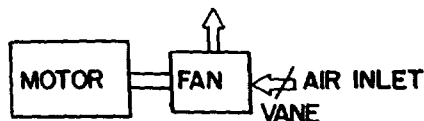
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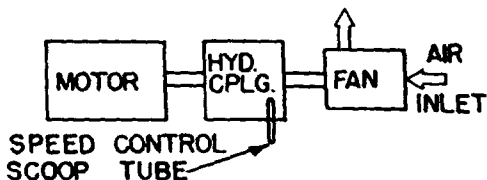
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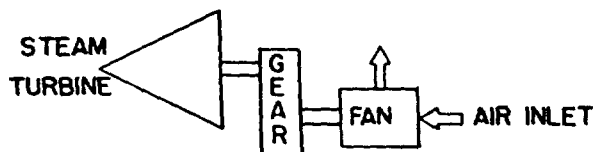
A. CONSTANT SPEED FAN WITH DAMPER CONTROL



B. CONSTANT SPEED FAN WITH VANE CONTROL



C. VARIABLE SPEED FAN WITH MOTOR & HYDRAULIC COUPLING



D. VARIABLE SPEED FAN WITH VARIABLE SPEED TURBINE DRIVE

Fig. 1—Methods for driving forced-draft fans

By R. H. DUNHAM, ✓

Tennessee Valley Authority,

N. E. NUTTER and R. W. WILLIAMS, ✓

General Electric Company

The Application of Steam Turbines for Driving

THE methods used to drive steam plant auxiliaries can have significant effects on plant performance in the following areas:

1. Over-all heat rate or efficiency.
2. Net output power.
3. Operating flexibility
4. Evaluated investment cost.
5. Dependence on outside power sources for start-up.

As the power requirements for these auxiliaries increase with the use of larger capacity generating units, efficient methods for driving them become more important. Thus, as the rating of turbine-generator units increased above 400,000 kw, separate steam turbines became the predominant method for driving boiler feedpumps. Improvements in plant performance resulting from the application of turbine driven feedpumps have been

studied extensively and treated in other papers. Since the forced-draft fans have power requirements second only to the boiler feedpumps in the typical fossil fueled generating plant, it follows that the effect on plant performance of turbine drives for these fans should be studied.¹

Methods for Driving Forced-Draft Fans

Fig. 1 shows four common methods for driving forced-draft fans and controlling air flow to the boiler. Some of these methods are more efficient than others even when operating at the maximum fan rating or test-block con-

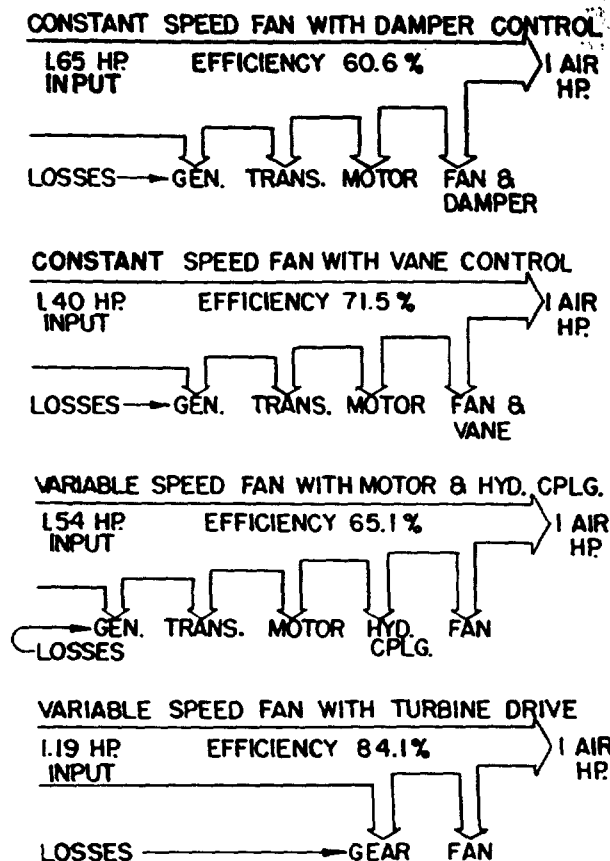
¹ It should be noted that, in addition to the fan-drive turbines for the TVA Paradise 3 Plant which are described in this paper, other applications of steam turbine-driven forced-draft fans for generating plants exist. For example, turbine-driven forced-draft fans have been in successful operation for over five years on the Cleveland Electric Illuminating Company's Lake Shore Unit 18 where two 2500 hp fans are driven in tandem through a reduction gear by a 5000 hp turbine. Also, on the South Carolina Electric and Gas Company's Canaday Unit 3 which is scheduled for operation this year, a single 3700 hp steam turbine will drive two forced-draft fans through a reduction gear having a double ended output shaft.

* Presented at the 29th Annual Meeting of the American Power Conference, April 25-27, 1967, Chicago, Illinois.

Fig. 2—Losses associated with forced-draft fan drive systems operating at the maximum normal plant condition

Notes for Fig. 2:

- Input powers shown are turbine shaft powers required to deliver one air horsepower to the draft system.
- Efficiencies shown are mechanical efficiencies with the illustrated losses considered.
- Data shown are for maximum normal operating condition of the steam plant, with normal fan shaft input power requirements for the variable-speed fans being 69% of the fan test-block rating and proportionally more for the constant-speed fan arrangements due to vane and damper losses.



Forced-Draft Fans—TVA Paradise 3 Steam Plant*

dition. The differences in efficiency are more pronounced at lower air flow conditions, such as the maximum normal operating condition of the power plant. The draft system air power requirements (proportional to the product of draft system head multiplied by the air flow rate) for the maximum normal plant operating condition are usually only 63 to 76 per cent of the power requirements at the fan test-block condition. This fan air power margin is provided for tolerances in: draft system resistance, air flow requirements, and fan performance. The losses caused by reducing the air flow rate for normal plant operating conditions are significant. In the case of the motor-driven variable-speed fan, these losses result from hydraulic coupling slip introduced to control air flow. With the constant-speed fans, the losses are throttling losses caused by the discharge dampers or inlet vanes. The variable-speed turbine drive arrangement has the advantage of operation over wide ranges of air flow rates with small changes in efficiency.

Fig. 2 shows the variable-speed turbine-drive system to be the most efficient. The next most efficient method,

motor-driven fans with vane control, requires approximately 18 per cent more turbine output power to develop a given amount of air power and the motor-hydraulic coupling arrangement requires approximately 28 per cent more turbine output power. As generating plant load is reduced for part load operation, the efficiency of the auxiliary turbine fan-drive system holds up much better than the other arrangements.

Plant Heat Rate and Kilowatt Gains with Auxiliary Turbine Driven Fans

Since the turbine-driven fan system offers better efficiency than the other arrangements, a comparison of plant thermal performance for this arrangement and the next most efficient system, motor-driven fans with vane control, is warranted. Consider a steam plant cycle having a forced-draft fan with vane control, driven by a motor. Plant-cycle efficiency improvements and increases in net station power output can be obtained by replacing the motor drive and vane control with a variable-speed condensing fan-drive turbine, as shown in Fig. 3.

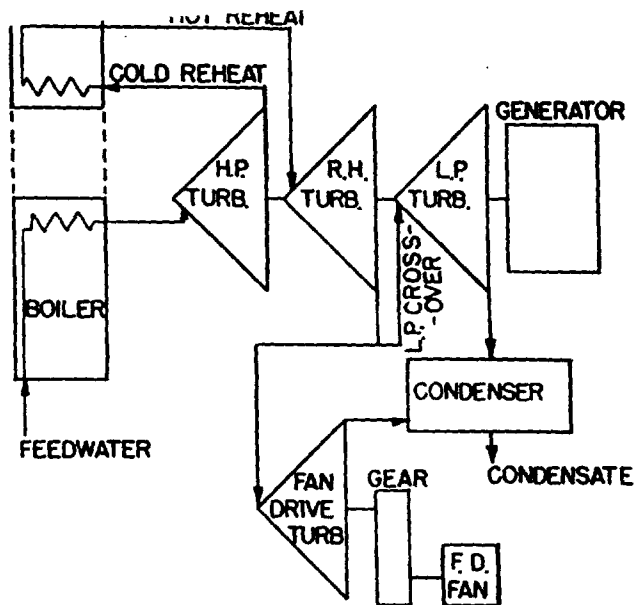


Fig. 3—Steam cycle for a fan drive turbine taking steam from the main turbine low-pressure crossover and exhausting to the main condenser

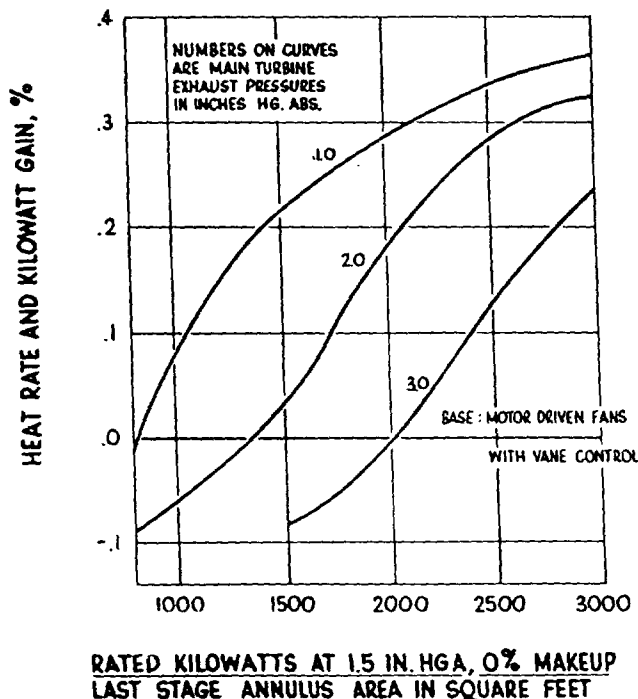


Fig. 4—Heat rate and net plant kilowatt gains for auxiliary turbine-driven forced-draft fans as compared to motor-driven fans with vane control

Notes for Fig. 4:

- Gains shown are for the main turbine valves-wide-open operating condition. Heat rate and kilowatt gains are in percent of the base values with motor-driven fans for this condition.
- Assumed conditions
 - Fan-drive turbine efficiency = 81.5%
 - Fan-drive turbine exhaust pressure = main turbine exhaust pressure + 0.5 in. Hg abs
 - Turbine-driven fan efficiency = 85.0%
 - Turbine-driven fan shaft power required = 1.43% of main unit rating
 - Turbine-drive reduction gear efficiency = 98.5%
 - Motor-driven fan efficiency including vane losses = 76.9%
 - Motor efficiency = 95.0%
 - Transformer efficiency = 99.0%
 - Generator efficiency = 98.5%

HEAT RATE AND KILOWATT GAINS AT CONSTANT MAIN TURBINE THROTTLE FLOW

At constant main turbine throttle flow, the flow to the low-pressure turbine is reduced with the turbine-driven fan arrangement since steam is removed from the low-pressure crossover to supply the fan-drive turbine. This reduces the main turbine exhaust loss which together with the increase in fan-drive system mechanical efficiency results in approximately equal percentage gains in thermal cycle efficiency and net plant power output.

The approximate heat rate and net power gains are shown in Fig. 4 plotted as functions of main turbine parameters which are indicators of exhaust loading and exhaust loss. Fig. 4 shows the heat rate and net kilowatt gains to be greatest when fan-drive turbines are applied to cycles using main turbines with highly loaded exhaust sections operating at low exhaust pressures. Fan system efficiencies and power requirements used for the development of Fig. 4 are average values for systems where turbine drives have been studied by the authors. For a particular application these values may vary, depending on the fan test-block rating as compared to the maximum normal operating condition, the type of boiler firing, and other variables. Fig. 5 and 6 have been included to allow correction of the heat rate and kilowatt gains for differences in fan system efficiencies and power requirements.

The method for using the presented curves is illustrated by this example. Consider a turbine-generator rated 600,000 kw at 1.5 in. Hg abs and 0 per cent makeup in a plant with a motor-driven forced-draft fan and vane control of air flow to the boiler. The effect of replacing the motor-driven fan with a turbine-driven fan would be as follows:

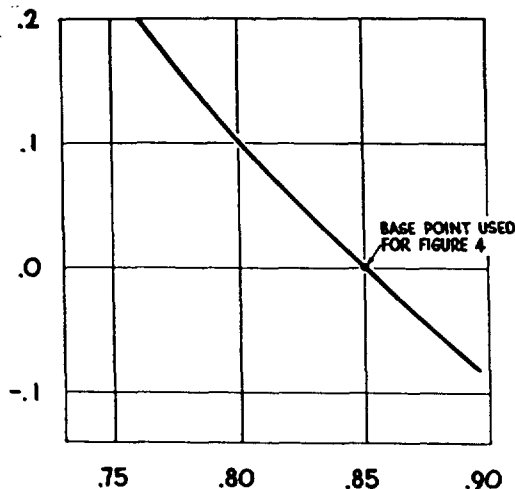
A. Basic Data

- Main Turbine Type and Performance: Tandem-compound steam turbine with four exhaust ends having 222.5 sq ft of total exhaust annulus area, operating at valves wide open and with motor-driven fans to deliver 619,248 net kw (fan and feedpump power considered) at a net heat rate of 7724 Btu/Kw hr with 1.5 ins. Hg abs exhaust pressure.
- The forced-draft fan shaft power required for the valves wide open condition with a turbine-driven fan is 12,190 hp and the fan efficiency at this condition is 85 per cent. The fan turbine has an efficiency of 81.5 per cent and its exhaust pressure is 2.0 ins. Hg abs. The reduction gear efficiency is 98.5 per cent.
- The motor-driven fan with vane control has an efficiency of 75.0 per cent at this condition and the motor, transformer, and main generator efficiencies are 94.5, 99.2 and 98.2 per cent, respectively.

B. Calculated Heat Rate and Kilowatt Gains with Turbine-Driven Fans

- The basic gain is read from Figure 4 at the parameters: rated generator output/last-stage annulus area = $600,000/222.5 = 2690$ and operating turbine-exhaust pressure = 1.5 ins. Hg abs. The basic gain = +0.33 per cent (interpolated).

HEAT RATE AND KILOWATT GAIN, %



$$R = \frac{\epsilon \text{ MOTOR DRIVE}}{\epsilon \text{ TURBINE DRIVE}}$$

Fig. 5—Effect of fan-system efficiency on heat rate and kilowatt gains with turbine-driven fans

Notes for Fig. 5:

- A. ϵ motor drive = fan eff (includes effect of vane or damper) X motor eff X transformer eff X generator eff.
- B. ϵ turbine drive = fan eff X gear eff.

2. The correction for fan-system efficiency is read from Figure 5 at the parameter $R = (.75)(.945) - (.992)(.982)/(.85)(.985) = 0.824$. The gain correction for efficiency is +0.05 per cent.
3. The correction for fan power requirements is read from Figure 6 at the parameter, $(\text{kw})/(\text{sq ft})(\text{in. Hg abs}) = (600,000)/(222.5)(1.5) = 1790$. The gain correction for a 5 per cent increase in fan power is +0.0183 per cent. The base fan power is $(0.0143)(600,000)(1.34) = 11,500$ hp. The per cent increase in fan power is $(12190-11500)(100)/11500 = 6.0$ per cent. The gain correction for fan power = $(0.0183)(6.0)/(5.0) = +0.022$ per cent.
4. The total heat rate and kilowatt gain factor (in per cent) = $0.33 + 0.05 + 0.022 = +0.402$. Therefore the heat rate and net kilowatt gains at main unit valves wide open are as follows: Heat Rate Gain (Reduction) = $(7724) \times (0.00402) = 31$ Btu/Kw hr. Net Kilowatt Gain (Increase) = $(619,248) \times (0.00402) = 2489$ Kw.

This method for calculating heat rate and kilowatt gains for fan-drive turbines is similar to a method for predicting the effect of auxiliary turbine-driven boiler feedpumps on plant performance which was presented in a 1966 American Power Conference Paper. See Ref. (1).

HEAT RATE AND KILOWATT GAINS AT CONSTANT LOW PRESSURE TURBINE FLOW

When replacing the motor-driven fan with a turbine-driven fan receiving steam from the main turbine low-pressure crossover, as shown in Fig. 3, it may be desir-

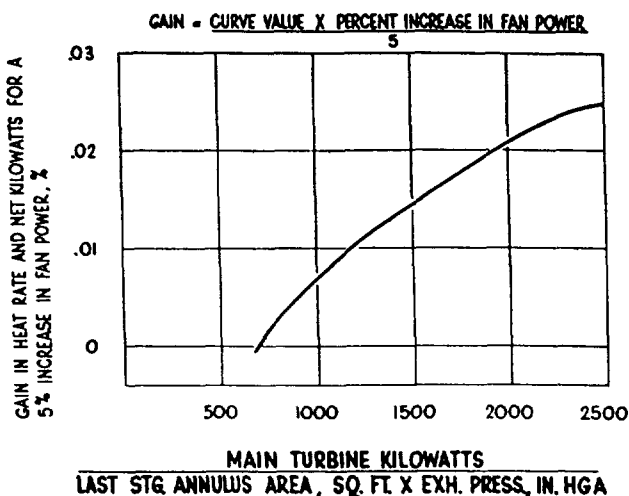


Fig. 6—Effect of fan-power requirements on heat rate and kilowatt gains with turbine-driven fans

Notes for Fig. 6:

- A. Power corrections should be made on the basis of turbine-driven fan power requirement using a fan efficiency of 85%.
- B. The base turbine-driven fan shaft horsepower is 1.43% of the main turbine rating.

able to increase the main turbine throttle flow and re-heat turbine flows to bring the low-pressure turbine flow up to its original flow with motor-driven fans. In this manner, the main turbine output can be increased by much more than in the constant throttle flow case, although the heat rate improvements will be less. This arrangement can be very attractive for units which are load limited by the flow to the last stage of the low-pressure turbine since it provides more net kilowatts for a given main turbine size. However, this increased turbine capability may require increased ratings of the boiler, generator, and other station equipment. The increase in net kilowatt capability by this method would be approximately three times the fan power requirements at the main turbine valves wide open condition.

Extracting Steam for Air Preheating from Fan-Drive Turbines

If analysis of the power plant heat cycle indicates that steam coil air preheaters are desirable to preheat the air entering the gas-to-gas air preheater, fan drive turbines offer another possibility for gains in station thermal performance. Extraction steam for air preheating should ideally pass from the source (turbine) to the air preheater with minimum pressure drop to avoid throttling losses which degrade plant heat rate. However, when steam is extracted from the main turbine for air preheating, consideration must be given to the lowest main turbine load at which the air preheater must function on this steam source, since the extraction pressure decreases with main turbine load. Design of the steam-coil air preheater for this minimum main turbine load condition requires that throttling of the air preheating steam be tolerated for high main-turbine loads; the extraction pressure being high. An alternative is the use of a controlled-pressure extraction on the fan-drive turbine to furnish steam for the air preheater. The controlled-extraction pressure fan-drive turbine maintains constant extraction pressure without introducing large throttling losses. The method by which this is ac-

complished is discussed later in this paper. Expansion of steam in a turbine to a lower extraction pressure and enthalpy before using it to heat combustion air will result in over-all heat-cycle efficiency improvements; the degree of improvement depending on the quantity of extraction steam required and other characteristics of the thermal cycle.

Steam Sources for Fan-Drive Turbines

If a separate steam turbine is used to drive the forced-draft fans, a logical question is where should steam be taken to supply the fan turbine for optimum cycle efficiency. Because of the large throttle flow requirements of the fan-drive turbine, the choices considered will be restricted to the major steam lines in the cycle: the superheater outlet, cold reheat, hot reheat, and low-pressure crossover lines. While the data required to prove the following is too extensive to present here, the general conclusion reached is that gains in station thermal performance will be greatest with the fan-drive turbine receiving steam from the low-pressure crossover line, as shown in Fig. 3, particularly if the main turbine has a low-pressure section which is highly loaded. However, if the low-pressure section is not highly loaded and if the air preheating steam requirements are large enough to justify a controlled extraction on the fan-drive turbine for air preheating, cold reheat steam may be the best source for the fan-drive turbine.

Startup and Light-Load Operation of Fan-Drive Turbines

The use of fan-drive turbines taking steam from either the main turbine low-pressure crossover or the cold reheat for normal operation requires that an auxiliary steam source be provided for these turbines during plant startup and light-load operation of the main turbine, since the steam pressure at the normal source on the main turbine will not be sufficient to meet the fan-power requirements under these conditions. Steam from a station auxiliary boiler can be used to supply the fan turbine during startup and light-load operation. For some applications the fan drive turbines have been provided with second inlets which receive steam directly from the main boiler superheater outlet. In these cases, the turbine control valves are arranged so that main boiler steam is used only when the normal supply from the main turbine is insufficient to meet the fan-power requirements. For these applications, a steam line tie to the station auxiliary boiler is also required to supply fan power for starting the main boiler. The secondary high-pressure steam inlet is very similar to that provided on dual inlet boiler-feedpump-drive turbines and allows the auxiliary turbines to operate independent of the main turbine.

Operating Flexibility of Turbine-Driven Forced-Draft Fans

The provision of a secondary inlet on the fan-drive turbine increases its operating flexibility. For example, should the main turbine be tripped from operation, the fan turbine with a high pressure inlet will automatically take steam directly from the superheater outlet of the boiler to maintain fan power which will allow the boiler to continue to operate. If the boiler fires must be tripped under this condition, the fan turbine can operate on steam stored in the boiler drum or superheater to

provide fan power for boiler purging. During a hot restart of the turbine-generator, it may be possible to operate the fans on stored boiler steam and deliver sufficient air flow to allow re-firing of the boiler; otherwise it would be necessary to start the auxiliary boiler to supply steam for the fan turbine. Turbine-driven fans, like turbine-driven boiler feedpumps, reduce the dependence of the generating plant on outside sources of electric power for startup and increase its potential for getting on the line, delivering power, during emergency situations.

The use of steam turbines to drive forced-draft fans helps to provide automatic fast response of the air supply system to flow change demands without causing fluctuations in station auxiliary electric power requirements. The steam turbine, having an oil-relayed speed control system, can change power levels rapidly to accelerate the fan, a high inertia load, and meet air flow demands. The turbine control system can be designed to set turbine speed in response to an input signal proportional to air flow requirements; thus allowing the supply of air to the boiler to be an automated subloop in the plant control system.

Effect of Turbine Drives for Forced-Draft Fans on Evaluated Plant Investment Costs

Turbine drives for forced-draft fans can result in a lower evaluated investment cost on a dollars per kilowatt of station capability basis. The improvement in evaluated cost depends on the kilowatt and heat rate gains for the particular application. Generally, the improvement will be greatest for tandem-compound main turbines having highly loaded low-pressure sections and boilers having large fan-power requirements, such as coal-fired types using cyclone burners.

For most applications of turbine-driven fans, the reduction in evaluated investment cost does not result from a lower total equipment cost but from the increase in plant capability and improvement in plant heat rate. These additional kilowatts of capability can be added at a lower cost per kilowatt than that of the base-plant kilowatts.

Forced-Draft Fan-Drive Turbines for TVA's Paradise 3 Steam Plant

For the TVA Paradise 3 steam plant, three turbines, each driving a one-third-size forced-draft fan, were applied to the heat cycle as shown in Fig. 7; taking steam from the cold reheat line and exhausting to condensers. A constant-pressure extraction for feeding air preheaters was provided on each fan-drive turbine.

This arrangement provides heat rate gains as shown in Fig. 8, at the maximum normal main turbine operating condition. Since the low-pressure turbine sections of the main turbine were not highly loaded, and since large quantities of air preheating steam were required, fan turbines receiving steam from the cold reheat and having controlled extractions for air preheating yielded better performance characteristics than straight condensing turbines receiving steam from the low-pressure crossover. The heat rate gains vary inversely with the air preheating requirements, and for a mean air temperature of 57.3 F resulted in a heat rate improvement of approximately 0.3 per cent for this application.

The three fans are driven through reduction gears by steam turbines rated 11,750 hp each. The expected fan-

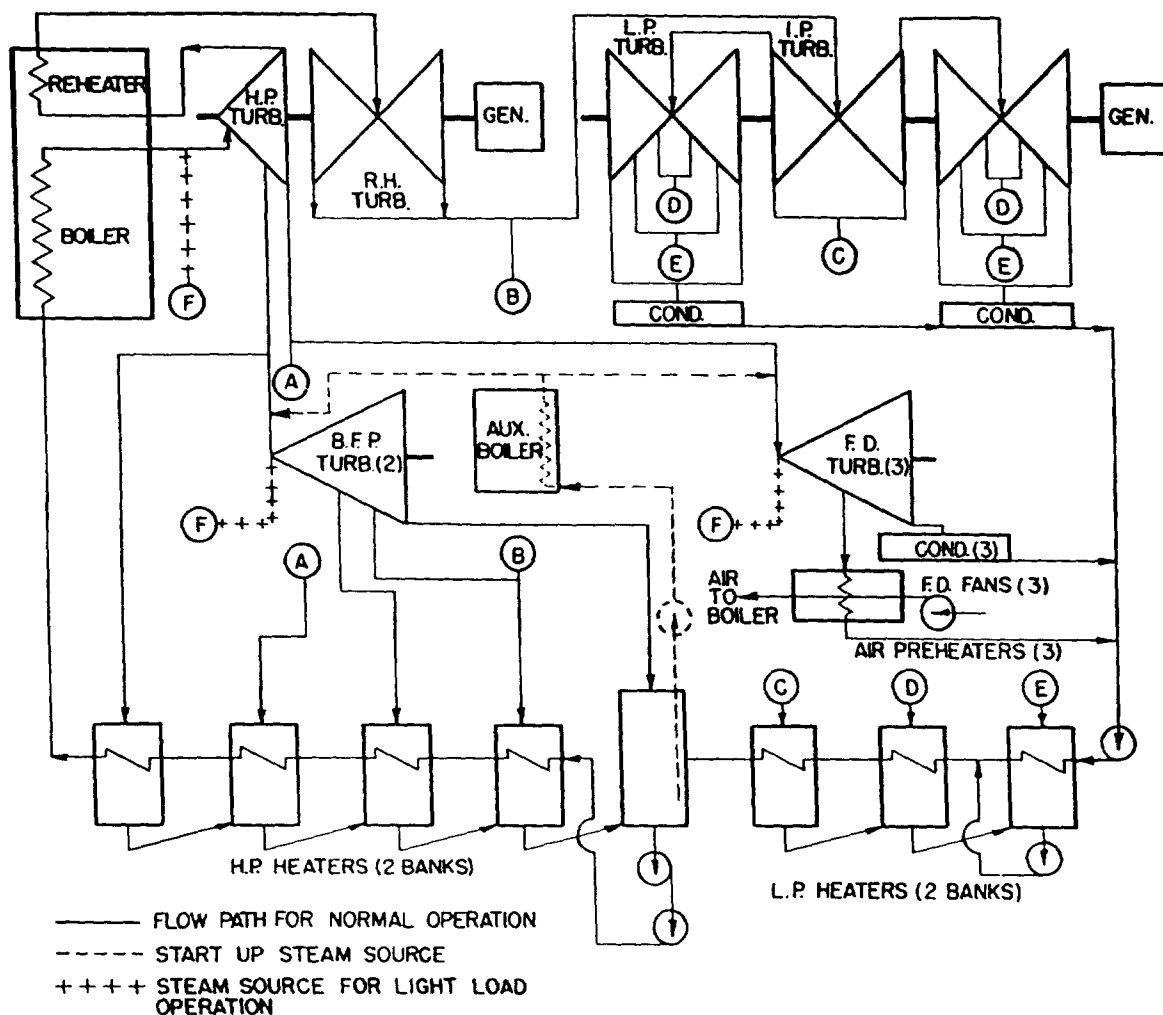


Fig. 7—TVA Paradise 3 steam plant heat cycle

requirement at the maximum normal operating condition of the main turbine is 22,800 hp, or approximately 1.6 per cent of the main turbine rating. The test-block fan-power requirement is 34,731 hp. The normal steam supply to the fan-drive turbines is from the old reheat line; however, a supplementary source is added from the high-pressure steam line for light-load operation and furnace purging after trip-out of the main turbine. Auxiliary boilers supply steam to the turbine-driven fans and boiler feedpumps for startup. The fan-drive turbines exhaust to individual condensers which connect to the main condenser and individual air preheaters supplied by the controlled-pressure extraction on each turbine. Each air preheater is divided into two operations; one section receiving steam through a temperature-controlled valve to maintain constant air inlet temperature, and the other coming into service automatically, and operating at constant pressure, when inlet air temperature is so low that additional air heat-transfer surface is required. Turbine speeds are adjusted automatically to meet the draft system flow demands, independent of the extraction flow for air preheating.

Fig. 9 is an elementary schematic of the Paradise 3 fan-drive turbine. The turbine is divided into two sections by an extraction valve gear which controls the extraction pressure by regulating steam flow to the exhaust section. The turbine control system sets speed in re-

sponse to an electrical air flow demand signal and maintains constant extraction pressure. These control functions operate simultaneously as in the following examples:

1. If the turbine speed is below that necessary to meet the air flow requirements, the speed governor opens both the extraction and inlet control valves to allow more steam to pass through the turbine to increase speed but not affect extraction pressure.
2. If the extraction pressure is below the set value, the pressure governor opens the inlet valves but closes the extraction valves to increase the extraction pressure while maintaining constant speed.

The low-pressure inlet and extraction control valves are multiple valves feeding sectionalized nozzle plates, although for simplicity, they have been shown as single valves. Each fan drive turbine has five stages ahead of the extraction and four stages in the exhaust section. The turbines have rating of 11,750 hp at 5000 rpm and drive the fans at a maximum speed of 1308 rpm through single-step reduction gears.

In the course of the forced-draft fan-drive study for Paradise Unit 3, several arrangements were considered; for example: four fans with individual motor drives, four fans with individual turbine drives, two turbines each driving two fans, extraction turbines integrated into

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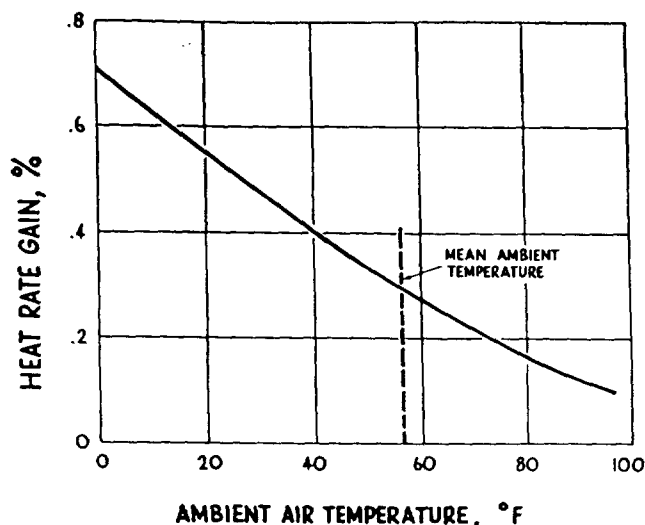


Fig. 8—TVA Paradise 3: heat rate gains for fan-drive turbines with controlled extraction for air preheating, as compared to motor-driven fans with air preheating steam taken from the main turbine low-pressure crossover

the feedwater cycle, and straight condensing turbines with various methods of air preheating. From the viewpoint of plant performance factors such as thermal efficiency, net station power output capability, operating flexibility, and plant evaluated investment cost, the three fans with individual turbine drives having controlled extractions for air preheating proved to be the most attractive arrangement.

Conclusions

Steam-turbine drives for forced-draft fans can offer improvements in power plant performance in the areas of: (1) thermal cycle efficiency, (2) net station output power, (3) operating flexibility, (4) evaluated investment cost and (5) reduction of station dependence on outside power sources for startup power.

The extent of heat rate and kilowatt gains and reduction in evaluated equipment cost depends on the power requirements of the fans and will be greatest for plants using coal-fired boilers with cyclone burners since this arrangement requires large quantities of fan power. Also, the use of main turbines having highly loaded low-pressure sections operating at low exhaust pressures will increase the heat rate and kilowatt gains to the range of $\frac{1}{4}$ to $\frac{1}{2}$ per cent on a constant throttle flow basis. On a constant low-pressure turbine flow basis, the heat rate gains will be less, but the kilowatt gains will be approximately three times the fan power. The above gains are on the basis of straight condensing fan-drive turbines taking steam from the low-pressure crossover as compared to motor-driven fans with vane control.

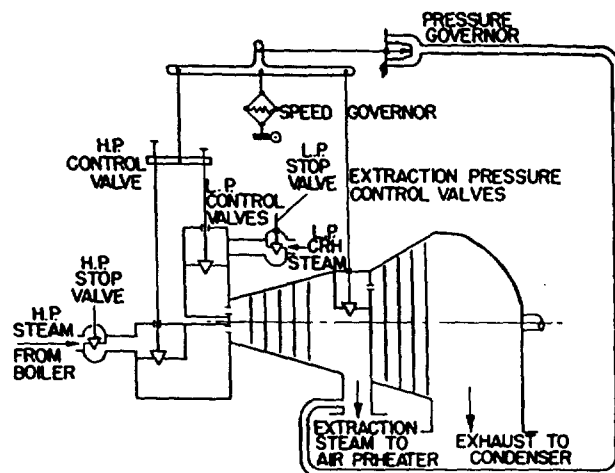


Fig. 9—Schematic of forced-draft fan-drive turbine with controlled extraction for air preheating

For some main turbines where the low pressure sections are not highly loaded, condensing fan drive turbines taking steam from the cold reheat line and supplying air preheating steam from a constant pressure extraction may offer better heat rate gains than straight condensing turbines taking steam from the low-pressure crossover line. The effect of the fan drive turbine's location in the steam cycle should be investigated for each application to assure optimum performance gains.

The use of turbines to drive fans reduces the dependence of the power plant on outside sources of power for plant startup and together with turbine-driven boiler feedpumps can affect major reductions in outside power requirements.

In a similar manner, its ability to maintain fan operation for boiler purging after trip-out of the main turbine is another step toward reducing station dependence on outside power sources.

It is not the intent of this paper to imply that turbines will be the best method for driving forced draft fans in all generating stations, but is to show that, when fan power requirements are large, considerations should be given to turbine drives for these auxiliaries.

REFERENCE

- (1) "Heat Rate Gains in Utility Power Plants with Condensing Auxiliary Turbine Drives." R. C. Spencer, H. A. Mayor and S. Styra, The American Power Conference, April 1966, Chicago, Illinois.

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