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POWER DEPENDENCE ANALYSIS ELECTRIC DRIVES OF DRAFT MACHINES FROM AIR FLOW

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Abstract

The topic of improving the efficiency and quality of the combustion process in heating boiler houses is relevant for heat supply enterprises, in this regard, various methods of automatic regulation of parameters are introduced and applied. The work objective is studying the dependencies of power ratings of forced-draft fan electric drives on air parameters. The research result was the revealing of the dependency of outdoor air temperature and consumed power of forced-draft fans in a heating boiler plant. Its level was 0.85. The research showed that the draft efficiency decreases if air temperature at the inlet of forced-draft mechanisms decreases. We have revealed the regularities of impact of carried medium temperature onto air and gas volumes, and impact of the temperature factor onto determination of draft air flow rate and, consequently, power of forced-draft fan electric drives. The work revealed a correlation relationship between the temperature of the outside air and the power consumption of the draft machines of the heating boiler house. Thus, the performed calculations of dependencies of outdoor air temperature and consumed power of forced-draft fans, regularities of impact of the carried medium temperature on air and gas volumes in the course of operation of forced-draft fans in a heating boiler plant made it possible to draw a conclusion on the need for preheating of the air supplied to boilers, in order to increase operation efficiency of forced-draft fan electric drives, and thus to increase the thermal performance of the heating boiler plant.

Keywords: Mathematical model, heating boiler plant, forced-draft mechanisms, consumed power, recirculation

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1. Introduction

Automatic control of parameters is necessary in order to improve of the combustion process at heating boiler plants. The specific process conditions and parameters can be maintained in several ways, the most popular regulation method is PID-control.

It should be noted that the air mass movement process as such is rather complex and non-linear. Accordingly, the unsteadiness of thermal conditions additionally complicates the development of a control system.

A multi-faceted research is necessary to solve the issue of development of automated gas-air path control systems. At present, works are being actively carried out in the field of identification of the thermal energy production (Gorkavyy et al., 2019) and generation parameters in order to find precise functional schemes for automated control systems and to formulate the optimal control law. Moreover, the involvement of empiric identification based on the use of various professional application software packages is also widespread.

The object of study in this research was forced-draft equipment of the heating boiler plant in Elban Settlement of Amursky District in Khabarovsk Territory. If considered from the viewpoint of automatic control, the said object is interesting because it is a typical solution and the revealed dependencies are characteristic of the whole class of forced-draft fans for heating boiler plants.

2. Problem Statement

Research of the dynamics of power of forced-draft fan electric drives was considered in the papers by Gordin and Zaichenko (2020), Zaychenko et al. (2019), Richter (1962), Sidelkovsky and Yurenev (2009), Fong and Lee (2017), Ibrahim and Kayfeci (2020).

Analysis of the previous works showed the availability of Russian and foreign schemes for automatic control of forced-draft fan electric drive power based on efficient energy plants, which are based on modern commercial equipment, but an integrated study of the dynamics of forced-draft fan electric drive power was not carried out.

The heating boiler plant in Elban Settlement of Amursky District in Khabarovsk Territory does not have a system for automatic control of forced-draft fan electric drive power, so all fans operate with a constant impeller rotation speed.

In the specified conditions the temperature of air, supplied to the forced-draft fan, for most fuels is taken equal to tair= 30 °C (Babichev et al., 1991). Accordingly, the temperature factor in most cases is not essential for determination of draft air flow rate.

However, the situation changes if the conditions of reliable air preheater operation require an increased draft air temperature. This requirement arises when operating with fuels having high humidity and a significant sulphur content. An increased air temperature can be achieved by two methods: by arranging hot air recirculation and by using steam air heaters supplied with turbine bleed steam or steam from boiler gas-heated evaporators. The most widespread method till present is the method of air preheating by recirculating a portion of hot air downstream of the air preheater to the suction pipe of the forced-draft fan. This method is rather simple structurally, since even an additional fan need not be installed. However,

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as seen from Table 1, air flow rate through the forced-draft fan increases rather significantly; it happens due to increase of not only temperature, but the weight amount of carried agent as well.

Table 1. Air volume increase

Temperature at air preheater inlet, °C	t'_{air}	40	50	60	70
$t_{hot\ air}$=200	r	0,0635	0,133	0,187	0,308
	φ	0,100	0.210	0,305	0,480
$t_{hot\ air}$=250	r	0,0477	0,100	0,158	0,222
	φ	0,081	0,170	0,273	0,385
$t_{hot\ air}$=300	r	0,0385	0,080	0,125	0,174
	φ	0,072	0,150	0,238	0,330
$t_{hot\ air}$=350	r	0,0323	0,0667	0,1035	0,143
	φ	0,065	0,134	0,212	0,295
$t_{hot\ air}$=400	r	0,0278	0,0572	0,0893	0,121
	φ	0,061	0,123	0,197	0,270

Temperature of cold air is taken equal to t=30 °C.

r – increase of weight fraction of air flowing through the fan during recirculation; φ – increase of air volume fraction.

Thus, when it is necessary to increase temperature of the air, supplied to the air heater, from 30 to 60 °C, hot air temperature being 350 °C, the air weight amount will increase by 10.3 %, while volume flow rate through the forced-draft fan, – by 21.2 %. If hot air temperature is lower, more hot air needs to be added, due to which the air volume, carried through the fan, increases still more. Thus, if hot air temperature in the conditions of the previous example is 250 °C, air volume due to recirculation will increase by 27.3 %.

The above-mentioned examples show that recirculation significantly increases the air volume, flowing through the forced-draft fan, which may sometimes require a greater standard size of the fan. Air volume increase is also related to increased electric energy consumption for the fan drive. Energy of the circulating flow is lost upon passing through the throttling gate on the recirculation air duct.

3. Research Questions

The method of air preheating in steam air heaters, which became spread to a certain extent, increases the thermal efficiency of the steam-turbine plant, since it increases the electric/heat output ratio (air is preheated with turbine bled steam). However, the boiler unit efficiency may decrease (Biryukov, 2012; Sokolov, 2012).

From the viewpoint of forced-draft fan operation, this method also has significant advantages. In this preheating method the air volume, flowing through the fan, remains the same as without preheating.

Installation of a hot-air heater entails a certain increase in the resistance of the forced-draft fan path and, consequently, an increased electric energy consumption. However, as compared to the recirculation variant, energy consumption will decrease, since a slightly increased resistance in case of hot-air heater installation is compensated by a significantly decreased volume of air carried through the fan. A scheme

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with a gas-heated evaporator in the end of the boiler unit convection shaft also has the same properties. Installation of a gas-heated evaporator for the PK-47 boiler, intended for combustion of high-sulphur fuel oil, was considered. Steam forms in the evaporator and is directed to a hot-air heater used for air preheating. Then air is directed to the boiler air preheater. Thereat, the risk of its corrosion is virtually eliminated and deep cooling of exit gases is ensured. Other air preheating methods can be also used, e.g. with a recirculation fan. After a check in the operation conditions, some standby lines, shown in the scheme, will probably be unnecessary (Mikhailov, 2016).

Temperature upstream of the exhaust fan depends chiefly on exit gas temperature downstream of the boiler unit. The latter, in its turn, is determined by technical and economic calculation of the whole boiler unit. Consequently, it is determined not only by thermotechnical factors, but also by economic ratios: cost of burned fuel, metal for the heating surface, adopted payback period, amount of depreciation allocations etc. Exit gas temperature for high-power boiler units under construction is usually taken equal to 120-130 °C, i.e. significantly lower than for the previously installed boiler units. Only for fuels having high humidity, temperature has to be increased to 140-160 °C. Due to the temperature factor, gas volume as compared to the blow air volume increases 1.30 times, while for high humidity coals – 1.5-1.6 times (Grinkrug, 2009).

Gas temperature upstream of an exhaust fan usually negligibly differs from the exit gas temperature directly downstream of the boiler unit (it is several degrees lower due to the suction devices on the boiler/exhaust fan section). However, when wet scrubbers are installed as ash separators, gas temperature upstream of the exhaust fan drops by 40-45 °C, causing a relevant decrease of gas volume upstream of the exhaust fan. Thereat, gas is simultaneously humidified and its volume slightly increases (by 1.5-2.0 %). On the whole, gas volume decreases rather significantly (by 8-10%). Volume decrease respectively reduces the power consumption; however, wet rod scrubbers differ by a high hydraulic resistance, so their installation eventually causes not decrease but increase of energy consumption for the exhaust fan drive.

4. Purpose of the Study

The work objective is studying the dependencies of power ratings of forced-draft fan electric drives on air parameters. Revealing the dependence of the outside air temperature and the power consumption of the draft machines of the heating boiler house will make it possible to conclude that additional measures are needed to increase the efficiency of the operation of the electric drives of the draft machines, as a result of which the increase in the thermal operation of the heating boiler house.

5. Research Methods

Analysis is performed by revealing the correlation one-factor dependencies which link the outdoor air temperature and consumed electric power of exhaust fans in a heating boiler plant.

$$N = \frac{\overline{N} \cdot p \cdot \dfrac{\pi \cdot D_2^2}{4} \cdot u_2^2 \cdot z_2}{102} \quad (1)$$

where $\overline{N}$ - power factor which depends on fan type;

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ρ – density of carried gas, kg·s^2/m^4;

D_2– impeller outer diameter, m;

u_2– circumferential speed on the outer diameter, m/s;

z_2– number of suction holes.

The given formula shows that with continuous speed of the fan impeller, forced-draft fan consumed power will be directly proportional to the density of carried gas.

Actual power of the forced-draft fan was measured for 12 hours (from 19:00 till 07:00), then the indicators were taken and statistical data of air temperature and consumed power change was drawn up. Charts of air temperature and consumed power change were obtained as result of statistical observation. The charts are given in Figure 1.

Since air density is applied in the given formula (1), the dependence on change of forced-draft fan consumed power (in fractions of the rated one) and air density was plotted using the reference data on air from the reference book.

Power fan was measured and air density was determined. The revealed correlation dependence and measurement results are given in Figure 2.

The result of the actual measurements showed the actually existing linear dependence on air density and actual power of the forced-draft fan: change of air density linearly impacts the actual forced-draft fan power, nevertheless, this impact was significantly lower than assumed by formula 1.

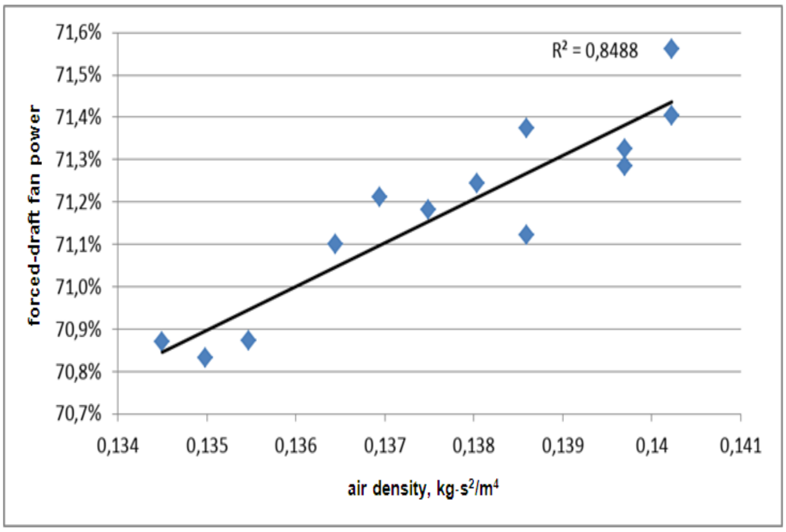

Figure 1. Correlation dependence of fan power on air density

Air density parameters within the observation time changed from 0.1345 to 0.1402 kg·s2/m4, which was equal to 4.3%. At the same time, the actual forced-draft fan power changed by 0.8% only. It means that, in the observation period, when air temperature and density change, air circumferential speed on the outer diameter of the forced-draft fan also decreases at the same time.

Decrease of air circumferential speed on the outer diameter of the forced-draft fan facilitates the growth in decrease of air flow rate and increase of draft channel pressure.

Pressure rise can be calculated using formula [3]:

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$$H = \overline{H} \cdot \rho \cdot u_2^2 \quad (2)$$

where $\overline{H}$ – pressure factor which depends on fan type;

The pressure rise calculation showed than pressure rise during the observation period was 0.08%, which actually matches the change in the actual power. Therefore, decrease of air temperature at the forced-draft fan inlet negatively affects the forced-draft fan efficiency, thus reducing the total efficiency of the heating boiler plant.

6. Findings

Analysis of dynamics requires the calculation of forced-draft fan consumed power in certain modes. The known formula for calculation of forced-draft fan consumed power in different modes:

$$N = \frac{\overline{N} \cdot p \cdot \frac{\pi \cdot D_2^2}{4} \cdot u_2^2 \cdot z_2}{102} \quad (1)$$

where $\overline{N}$ - power factor which depends on fan type;

ρ – density of carried gas, kg·s^2/m^4;

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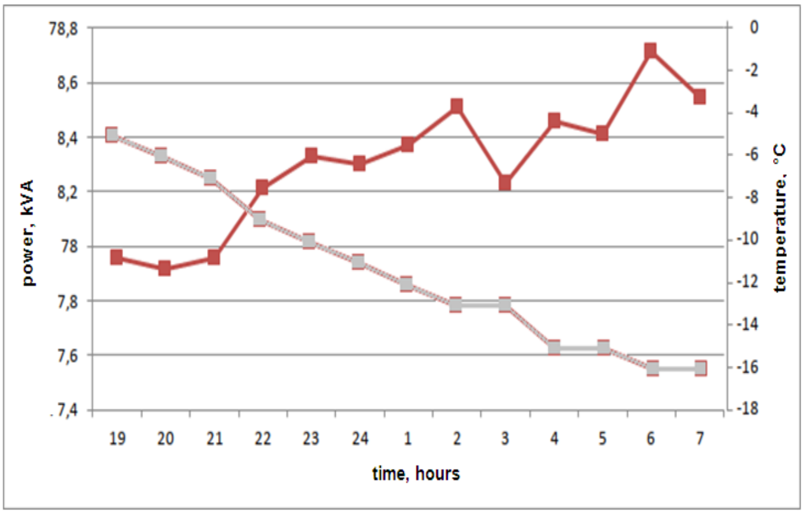

Figure 2. Charts of air temperature and consumed power change for the forced-draft fan of boiler plant

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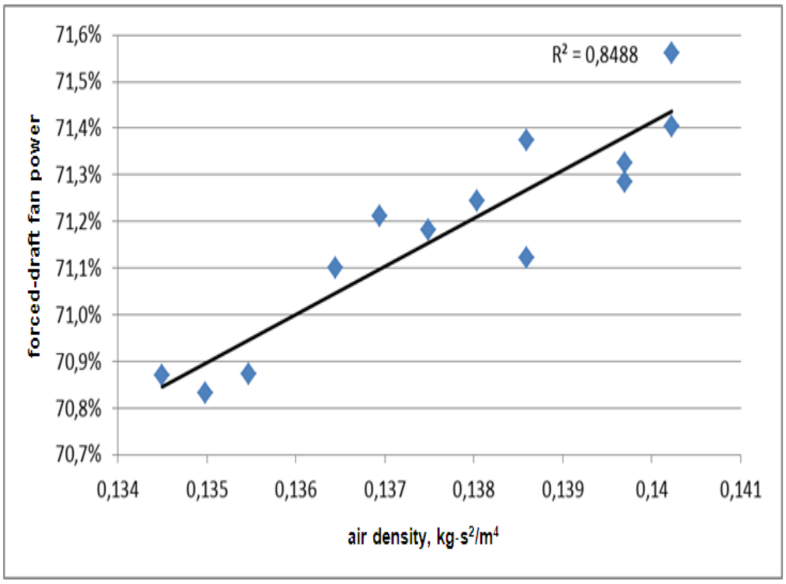

Figure 3. Correlation dependence of fan power on air density

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Decrease of air circumferential speed on the outer diameter of the forced-draft fan facilitates the growth in decrease of air flow rate and increase of draft channel pressure.

Pressure rise can be calculated using formula [3]:

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7. Conclusion

The following conclusions were made as a result of research.

1. There is marked correlation dependence between outdoor air temperature and consumed power of forced-draft fans in a heating boiler plant equal to 0.85.

2. When air temperature at the forced-draft fan inlet decreases, the blowing efficiency of the heating boiler plant decreases.

3. Increase of forced-draft fan energy efficiency requires preheating of the air which is supplied to the heating boiler. This solution can be implemented, for instance, using the flue gas heat.

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