

INCREASING RELIABILITY OF STEAM BOILER BK3 200-100 BY CHECKING THE CHARACTERISTIC OF FRESH AIR FAN

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Abstract: During the operation of both steam boilers of 100 MW block at the Thermal Power Plant "Kostolac A", after the last plant revitalization, there was very often stoppage due to coal dust deposition and the occurrence of fire in the aero-mixture duct sections. Therefore, the reconstruction of the aero-mixtures ducts of the mill plant was necessary. Reconstruction of the aero-mixture ducts demanded the calculation of the required amount of fresh air.

To increase the reliability of mill plant operation and achieve higher availability of the boiler plant as a whole, it was necessary to verify the ability of existing equipment in order to meet demand at the new condition. The paper describes the verification of characteristics of the existing fresh air fan, obtained by comprehensive calculations.

Keywords: Characteristics of the fan, pressure drop, reliability of the boiler plant

1. Introduction

During the last revitalization of the 100 MW unit No.1 at the TPP „Kostolac A“, among other things reconstruction of the aero-mixture conveying ducts systems on all eight mills of this type (the four mills per steam boiler) was carried out, because the installation of new fan mills was planned. Aero-mixture is a mixture of primary hot air, pulverized coal and flue gases recirculated from the top of the furnace, which exit from fan mill. After that, problems in exploitation start, caused by the coal dust deposition and the occurrence of fire in the horizontal aero-mixture duct sections. This led to frequent stoppage of the whole plant facilities. Therefore it was necessary to perform the reconstruction of the aero-mixture ducts of the mill plant.

Steam boilers of unit No.1 at TPP "Kostolac A" was projected for kostolac lignite with lower heating capacity of 7600 kJ/kg, with a moisture content of $W = 38.5\%$, and ash content of $A = 27\%$.

Boilers are Russian (Soviet) production type BK3 200-100 with next characteristics:

Nominal production of fresh steam	$D = 55,55$	kg/s
Superheated steam pressure	$p_s = 99$	bar
Superheated steam temperature	$t_s = 540$	°C
Operating pressure	$p_o = 109,8$	bar
Feed-water pressure	$p_{fw} = 114,7$	bar
Feed-water temperature	$t_{fw} = 215$	°C

Plant for the pulverized coal preparation for two steam boilers of unit No.1 in the TPP "Kostolac A" consists of four fan mill type N 80.75 produced by Minel - Kotlogradnja (EVT), milling capacity of 21 t/h (5.83 kg/s) of kostolac lignite. Mills have been reconstructed several times in previous years in terms of reliable work and raising the capacity of milling.

2. Facility for fresh air supplies

For the burners and furnace supply with air, the two fans VDN 18-II (pos. 1 in Fig. 1) in a parallel relationship is provided. After the fan, the air duct is divided into two parts: one before and another behind convective gas canal.

From them, through four connections, the air reaches steam pre-heaters (2), and then directly into the first package of the first stage of air heater (3). Upon exit from it, the air circulates through the duct in the middle of convective gas canal and reaches wind-dividing box (4), where the air divides into two streams.

The first stream is the primary air. Primary air is pushed into the head of recirculation ducts by the ducts that lead around the boiler (5). Another stream of air, secondary and tertiary air, goes out of the wind box (4) leads to second, two-passage, package of the first

stages of the air heater (6), and then in the second stage of the air heater (7). Immediately at the exit from the second stage of the heater the duct for recirculation of hot air is separated (8), which leads to front of the mouth of the suction fan. It is used to prevent low-temperature corrosion of the heater. Heated air is lead by ducts in front of and behind the convective gas canal into the wind distribution boxes (9). From the right wind distribution box the secondary air is lead to the burners that are placed on the right side, and from left wind box to the burners set on the left side of the furnace. From the wind distribution boxes the tertiary air is also taken away (11). From the tertiary air duct, the separated duct of air for ignitive and supportive liquid fuel air is branched.

As we see from the scheme on Fig. 1, air ducts on the left and right side of the boiler are completely symmetrical and interrelated.

For purposes of aerodynamic calculation, the air tract is divided into sections, which vary according to temperatures, i.e., air flows in the following way:

section A - suction duct, section B - the duct between the fan and air pre-heater, Section C - steam air pre-heater, section D - the first package of the first stages of air heater, Section E - the duct between the first and second stages of the first package of air heater, section F - duct for primary air, section G - the second package of the first stages and the second stage of air heater, section H - duct for the secondary and tertiary air and section J - ducts that leads to the burners.

Sections and subsections are divided then into the elements according to the the shape and geometry.

3. Calculation of the pressure drop in the air tract

Calculation of the pressure drop in the air tract was performed for all cases for which the calculations of the furnace and mills are done in accordance with methodology given in [1-4], that is for three operating loads of steam boiler: 100, 85 and 70%. Calculations were also carried out for two coal quality: guaranteed quality coal ($H_L = 7600$ kJ/kg, $W = 38.50\%$, $A = 27.50\%$) and coal of better quality with which the plant recently usually works ($H_L = 8142$ kJ/kg, $W = 38.66\%$, $A = 25.31\%$). The calculation is performed in accordance with the recommendations given in [5] and [9], and for some resistance coefficients values were used from [6].

Full pressure drop in air tract is obtained when from the total pressure self-upward pressure of air tract (stack effect) and sub-pressure are subtracted at the place of introduction of air

$$\Delta p_p = \Delta p_u - \Delta p_{su} - \Delta p \quad [Pa] \quad (1)$$

The total pressure drop in air tract (Δp_u) consists of the pressure drop due to resistance to friction and pressure drop due to local resistance.

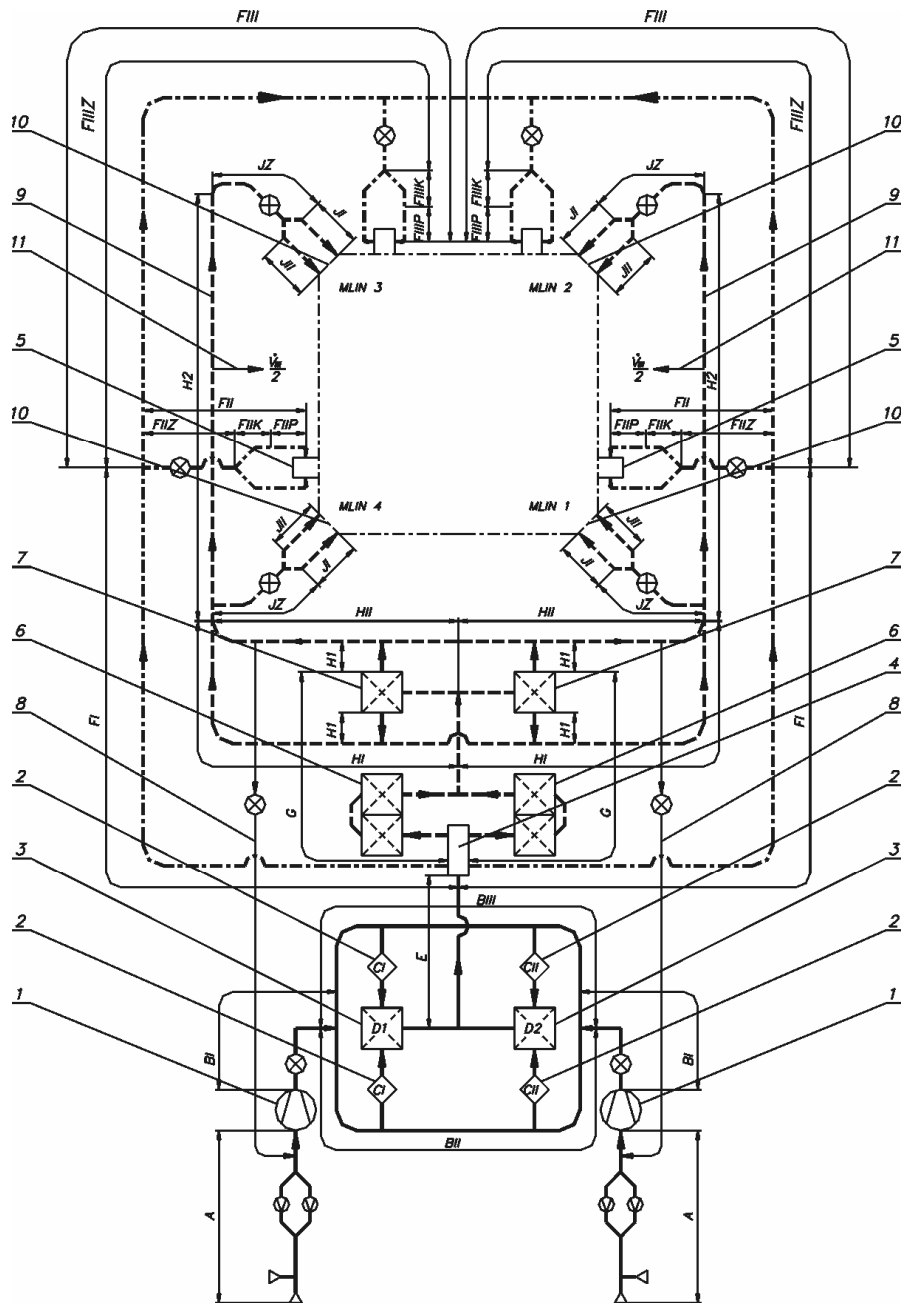


Figure 1. Schematic of the air tract

1. Centrifugal fan; 2. Steam air pre-heater; 3. First package of the first stage of air heater; 4. Wind dividing box; 5. Head of recirculation duct; 6. Second package of the first stage of air heater; 7. The second stage of the air heater; 8. Hot air recirculation duct; 9. Wind dividing boxes; 10. Burners; 11. Tertiary air.

Since the left and right sides of the air tract are completely symmetric and interconnected, their calculations when operating with four mills and when operating with three mills are somewhat different. Namely, with the exclusion of a mill, mentioned symmetry of airflow through individual ducts is lost, and in some ducts flow occurs in the opposite direction compared to the case of four mills operation. Operation with three mills occurs at 70% load of steam boiler.

The scheme of the primary and secondary air tract is shown in Fig. 2 in the case when the mill no. 3 is turned off.

To show the difference in pressure drops when system operates with three and four mills, calculation of the pressure drops for both examined fuels with three loads under the assumption that in each case the number of mills in operation is four are done, and then pressure drop for 70% load with three mills in operation is also calculated. Coefficient of friction of relative unit length of the duct was determined by the next formula

$$\lambda = \frac{1}{\left(2 \log \frac{3,6}{\bar{\Delta}}\right)^2} \quad (2)$$

where is $\bar{\Delta}$ - relative roughness, i.e., the ratio of absolute roughness and equivalent diameter of the duct. The value of absolute roughness was adopted $\Delta = 0.00018$ m, which according to [6] corresponds to the old (used) ducts of the steel plate. Coefficient of friction was determined by the formula

$$\zeta_i = \lambda \frac{l}{D_e} \quad (3)$$

where l [m] - the total length of the straight duct part with constant cross section, and D_e [m] - equivalent diameter of the duct. Coefficients of local resistance were adopted or calculated based on the shape and dimensions of individual elements.

In the considered air tract, the total air is divided into several streams, which are:

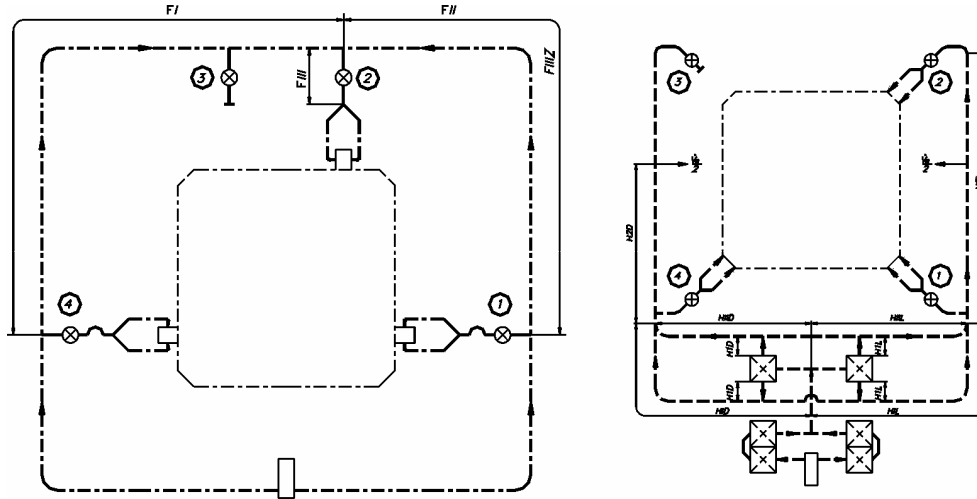


Figure 2. Schematic of the primary and secondary air tract when the mill No. 3 is turned off

- primary air,
- secondary air,
- tertiary air
- air for cooling burners that do not work,
- air for ignitive and supportive liquid fuel combustion, and
- sealing air for the mills.

Primary air is, as already mentioned, introduced in the head of recirculation ducts by the ducts that lead around the boiler, for regulation of temperature of aero-mixtures.

Secondary air is lead by the ducts in front and behind convective gas canal into wind distribution boxes. From the distribution box on the right it is lead in the burners that are placed on the right, and from left into the burners set on the left side of the furnace. The distribution of secondary air into the lower and upper burner is adjusted to amounts of pulverized coal, which, also on the lower and upper burner, is distributed by aero-mixture splitter. From the wind distribution box tertiary air is also lead away.

Tertiary air flow according to the designer data is 15,0 % of the total theoretical amount of air flow ($B_r V^0$), which is taken into account when defining the flow. Pressure drop in the tertiary air duct was not determined. Because of the large complexity of the air tract, the air flow for cooling the pulverized coal burner, which is not in the operation, is neglected in the calculation. This has influence on calculation results because the calculation is done with slightly larger air flows, so the pressure drops are also larger. However, these differences are small and are included in the tolerance of accuracy of calculation. Since the calculations were performed for the operation in the stationary conditions without adding liquid fuel, calculations for this air duct were not carried out. In these calculations is assumed that there was no air recirculation of heated air in the suction mouth of the fan.

Pressure drop due to resistance of friction and local resistance with the operation with the four mills is:

- a) Primary air
- Mills no. 1 and 4
- $$\Delta p_{ul} = \Delta p_{A-E} + \Delta p_{FI} + \Delta p_{FII} \text{ [Pa]}$$
- Mills no. 2 and 3

$$\Delta p_{ul} = \Delta p_{A-E} + \Delta p_{FI} + \Delta p_{FIII} \text{ [Pa]}$$

Pressure drop in sections from A to E is:

$$\Delta p_{A-E} = \Delta p_A + \Delta p_{BI} + \Delta p_{BII} + \Delta p_{CI} + \Delta p_{DI} + \Delta p_E \text{ [Pa]}$$

or, as the $\Delta p_{BII} = \Delta p_{BIII}$; $\Delta p_{CI} = \Delta p_{CII}$ and $\Delta p_{DI} = \Delta p_{DII}$

$$\Delta p_{A-E} = \Delta p_A + \Delta p_{BI} + \Delta p_{BIII} + \Delta p_{CII} + \Delta p_{DII} + \Delta p_E \text{ [Pa]}$$

Pressure drop in subsection FII is

$$\Delta p_{FII} = \Delta p_{FIIZ} + \Delta p_{FIIIK} + \Delta p_{FIIIP} \text{ [Pa]}$$

and in subsection FIII

$$\Delta p_{FIII} = \Delta p_{FIIIZ} + \Delta p_{FIIIK} + \Delta p_{FIIIP} \text{ [Pa]}$$

b) Secondary air

- Lower burner stage

$$\Delta p_{ulld} = \Delta p_{A-E} + \Delta p_G + \Delta p_{HI} + \Delta p_{HII} + \Delta p_{H2} + \Delta p_{JZ} + \Delta p_{JI} \text{ [Pa]}$$

or, as the $\Delta p_{HI} = \Delta p_{HII}$

$$\Delta p_{ulld} = \Delta p_{A-E} + \Delta p_G + \Delta p_{HI} + \Delta p_{HII} + \Delta p_{H2} + \Delta p_{JZ} + \Delta p_{JI} \text{ [Pa]}$$

- Upper burner stage

$$\Delta p_{ullg} = \Delta p_{A-E} + \Delta p_G + \Delta p_{HI} + \Delta p_{HII} + \Delta p_{H2} + \Delta p_{JZ} + \Delta p_{JI} \text{ [Pa]}$$

or,

$$\Delta p_{ullg} = \Delta p_{A-E} + \Delta p_G + \Delta p_{HI} + \Delta p_{HII} + \Delta p_{H2} + \Delta p_{JZ} + \Delta p_{JI} \text{ [Pa]}$$

Self-upward pressure occurs in inclined and vertical ducts due to density differences of hot and ambient air, the acceleration due to gravity and the height difference from entrance to exit of the duct

$$\Delta p_s = \pm \Delta \rho g h \text{ [Pa]} \quad (4)$$

and is taken with a positive sign for upwards flow, and with the negative sign for downwards flow. Heights of parts of the duct where the temperature is higher than the surrounding air are shown in Fig. 3.

Self-upward pressure in the primary air tract is

$$\Delta p_{sl} = \Delta p_{sE} + \Delta p_{sF} \text{ [Pa]}$$

and in a tract of secondary air

a) for the lower burner stage

$$\Delta p_{slll} = \Delta p_{sGI} + \Delta p_{sGII} + \Delta p_{sH} + \Delta p_{sJI} \text{ [Pa]}$$

b) for the upper burner stage

$$\Delta p_{sllg} = \Delta p_{sGI} + \Delta p_{sGII} + \Delta p_{sH} + \Delta p_{sJI} \text{ [Pa]}$$

Sub-pressure in the area of introducing primary air consists of self-upward pressure from that point to exit from the furnace and sub-pressure at the end of the furnace

$$\Delta p_l = \Delta p_{lls} + \Delta p_l^* \text{ [Pa]}$$

and sub-pressure in the places of introducing secondary air from self-upward pressure from that point to exit from the furnace and under-pressure at the end of the furnace, so that

- for the lower burner stage

$$\Delta p_{lld} = \Delta p_{llsd} + \Delta p_l^* \text{ [Pa]}$$

- for the upper burner stage

$$\Delta p_{llg} = \Delta p_{llsg} + \Delta p_l^* \text{ [Pa]}$$

Sub-pressure at the end of the furnace was adopted as $\Delta p_l^* = 20 \text{ Pa}$.

Change in the flow rate of secondary air through the bottom and the top stage of burner occurs in accordance with the new distribution of pulverized coal. Table 1 shows the recapitulation of the results, shown in detail in [10], of aerodynamic calculation for secondary air ducts and full pressure drop in air tract for guarantee fuel, for the operation with four and three mills and three different loads.

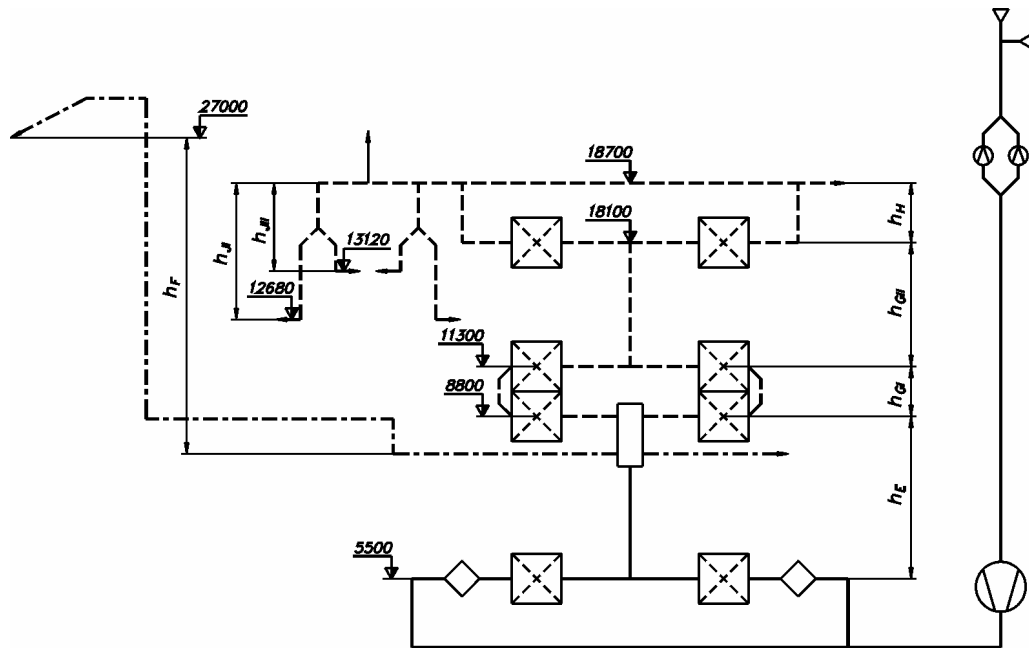


Figure 3. Ducts height for stack effect calculation

Table 1. Recapitulation of the results of aerodynamic calculation of the secondary air ducts and the full pressure drop in air tract for guaranteed quality coal

Number	Label	Sign	Unit	Boiler load D			
				1,0	0,85	0,7	
				Number of mills in operation			
				4	4	4	3
1	Lower burner level						
1.1	Pressure drop from section A to section E	ΔP_{A-E}	Pa	681,1	493,9	336,2	336,2
1.2	Pressure drop in subsection G	ΔP_G	Pa	336,6	251,1	177,4	164,8
1.3	Pressure drop in subsection H	ΔP_H	Pa	315,3	221,8	146,1	75,6
1.4	Pressure drop in subsection JZ	ΔP_{JZ}	Pa	34,3	24,1	15,9	163,4
1.5	Pressure drop in subsection JI	ΔP_{JI}	Pa	2060,0	1447,9	954,9	1518,9
1.6	The total pressure drop due to friction resistance and local resistance	ΔP_{il}	Pa	3427,3	2438,7	1630,5	2258,9
1.7	Stack effect in the secondary air tract	ΔP_{sS}	Pa	9,9	10,5	11,4	11,4
1.8	Stack effect in the furnace	ΔP_{plS}	Pa	129,8	129,0	127,8	128,0
1.9	Sub-pressure at the end of the furnace	$\Delta P_l''$	Pa	20	20	20	20
1.10	Full pressure drop in the secondary air tract	ΔP_p	Pa	3267,6	2279,2	1471,3	2099,5
2	Upper burner level						
2.1	Pressure drop from section A to section E	ΔP_{A-E}	Pa	681,1	493,9	336,2	336,2
2.2	Pressure drop in subsection G	ΔP_G	Pa	336,6	251,1	177,4	164,8
2.3	Pressure drop in subsection H	ΔP_H	Pa	315,3	221,8	146,1	75,6
2.4	Pressure drop in subsection JZ	ΔP_{JZ}	Pa	34,3	24,1	15,9	163,4
2.5	Pressure drop in subsection JII	ΔP_{JII}	Pa	2058,5	1446,4	953,3	1517,1
2.6	The total pressure drop due to friction resistance and local resistance	ΔP_{il}	Pa	3425,8	2437,3	1628,9	2257,1
2.7	Stack effect in the secondary air tract	ΔP_{sS}	Pa	12,4	12,9	13,8	13,8
2.8	Stack effect in the furnace	ΔP_{plS}	Pa	125,8	125,2	123,8	123,8
2.9	Sub-pressure at the end of the furnace	$\Delta P_l'$	Pa	20	20	20	20
2.10	Full pressure drop in the secondary air tract	ΔP_p	Pa	3267,6	2279,2	1471,3	2099,5

4. Verification of the fresh air fan characteristics

As stated, for the air transport two fans VDN 18-II were chosen. These fans are two-speed ($N_1 = 980$ rpm, and $N_2 = 740$ rpm) with the stator regulation. Characteristics of the fan are given for temperatures of 20 °C. Unfortunately, its characteristics for different vanes angle for stator regulations are not given.

The values of calculated capacity of one fan and his head reduced to the conditions for which its characteristics are given, for different boiler load and different number of mills in operation, are given in Table 2.

Characteristic curves of the fan and air tract during combustion of guaranteed quality coal are shown in Fig. 4.

Table 2. Computed fan capacity and reduced fan head

Number	Label	Sign	Unit	Boiler load D			
				1,0	0,85	0,7	
				Number of mills in operation			
			4	4	4	3	
1.	Ambient air temperature	t_{HV}	°C	30	30	30	30
2.	Number of fans in operation	z	-	2	2	2	2
3.	Air flow per fan under normal conditions	\dot{V}_o	m ³ /s	20,880	17,688	14,575	14,496
4.	Air flow in the ambient air temperature	\dot{V}_t	m ³ /s	23,175	19,631	16,176	16,089
5.	The coefficient of flow reserve	β_1	-	1,1	1,1	1,1	1,1
6.	Calculated fan capacity	Q_r	m ³ /s	25,493	21,594	17,794	17,698
7.	Full pressure drop in the secondary air tract	ΔP_p	Pa	3267,6	2279,2	1471,3	2099,5
8.	The coefficient of pressure reserve	β_2	-	1,2	1,2	1,2	1,2
9.	Calculated fan head	H_r	Pa	3921,1	2735,0	1765,6	2519,4
10.	Coefficient characteristics of the fan	K	-	1,07	1,07	1,07	1,07
11.	Fan head reduced to its characteristic	H_{rk}	Pa	4195,6	2926,5	1889,1	2695,8

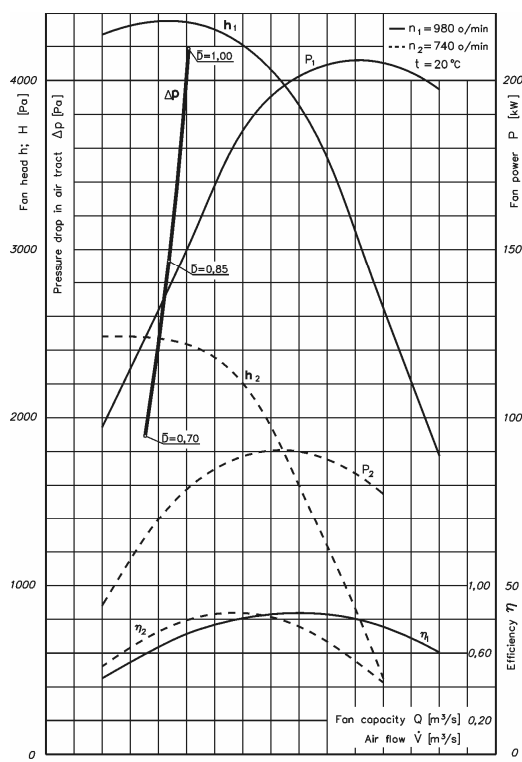


Figure 4. The characteristic of the fan and air tract for variable fan speed in operation with a guaranteed quality coal

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According to position of the operating point in the fan aerodynamic operation diagram, we have concluded that the existing fan is able to meet demands at considered condition. If we compare the results of calculation of the designer [2] and the calculation results from this project we can see that the designer performed calculations with greater air flow, while in this project pressure drop is significantly increased due to the redistribution of secondary air to the quantities of pulverized coal behind the aero-mixture splitter. Regardless of these differences can be said that the selected fan can satisfy all operating conditions.

5. Conclusion

After a comprehensive calculation for the different loads and the different quality of coal the optimal solution for the reconstruction of the aero-mixture ducts of pulverized coal plant of 100 MW steam unit No.1 at at TPP „Kostolac A“ is proposed. The proposed reconstruction required and verification of existing equipment characteristics in order to operate in new conditions. After extensive calculations it was concluded that the existing fresh air fans can meet demand to operate in all operating conditions of the boiler plant. Reconstruction of the aero-mixture ducts of pulverized coal system, according to the proposed solution, was made at the end of 2008 year. Transport of aero-mixture to the burner works perfectly. To date, no malfunction of the plant due to pulverized coal deposition and the occurrence of fire in the horizontal sections was not noticed, which previously was often the case. In this way, the reliability of pulverized coal plant is maximized and higher availability of the boiler plant as a whole is achieved.

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