RESEARCH REPORT

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Axial fan as a flow monitor in stack

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Summary

A radial fan or an axial fan in a power plant´s stack can, in principle, be used as a volume flow meter. The implementation of a fan for such an operation requires reliable pressure difference measurement over the fan and the monitoring of the fan´s blade angle or rotation speed.

This report deals with practical aspects of the determination of parameters in an axial fan model to be used for volume flow measurements. In power plant conditions it will be difficult to fulfill the requirements of EN ISO 5801 and EN ISO 5802 standards for stable pressure difference measurements. Especially the decision of the location and the type of pressure difference measurement require more experimental work in power plant conditions. Such information is needed to fully estimate the measurement uncertainty related to the use of an axial fan model, and to understand its usability as a backup method for flow measurements.

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1. Introduction

The starting point of this report is the linear model for an axial fan as developed and described in the previous report /1./.

In the utilization of the model it is necessary to determine the volume flow by the tracer method. When determining the model parameters it may also be useful to apply the fan characteristics supplied by the fan manufacturer. With the accurate tracer calibration measurements one can determine the dependency of the volume flow as a function of the blade angle in true process conditions. This function is called the plant´s basic curve and it will be the reference curve during the continuous use of the flow model. During the normal operation of the plant the model gives the flue gas flow rate as a function of the blade angle θ and the difference of the fan pressure to the basic curve´s fan pressure. The fan pressure will be determined by measuring the total pressure difference or the static pressure difference over the fan. A change of the fan pressure value from the basic curve´s fan pressure value at the same blade angle θ is an indication of a change in the plant curve.

According to the standard EN ISO 5801 /2./ the pressure difference of a fan is determined by the difference of the stagnation pressures at the inlet and at the outlet of the fan. If the gas flow velocity is low or Mach-number is less than 0.15 then the stagnation pressure can be replaced by the total pressure. The total pressure can then be measured eg. with a Pitot tube. This study focuses to the axial fan located after the sulphur removal unit in Salmisaari power station. Here the flue gas speed is 30-40 m/s and the Mach-number is about 0.1. Simplified formulas without Mach-corrections can thus be used.

2. Plant curve and basic curve

By using the tracer method the so called basic curve can be determined for the fan. This curve will be the reference curve in the utilization of the fan model during the plant operation. In the case of Salmisaari power station it is advisable to carry out this measurement during November or December as in this period the station´s power will be changed during night and daytime.

The slope parameter $\Delta p_{tf}/\Delta Q$ of the fan model could be determined by artificially changing the plant curve eg. by dropping off scrubbers or electrical precipitators. However, this can hardly be done for calibration purposes. The slope parameter could be determined if the plant curve changes as a consequence of the plant´s normal operation. An alternative method is to use the fan characteristics for the determination of the slope parameter.

3. In-situ fan pressure measurements

The fan manufacturer has given the fan characteristics by using the total pressure difference p_{tF} over the fan /3./. The fan characteristics could be used for the estimation of the parameter $\Delta p_{tf}/\Delta Q$ but this is not straightforward as the fan characteristics are determined in laboratory or it may be based on calculations.

The standard EN ISO 5802 /4./ recommends to use a four-point method for the pressure difference measurement in field conditions as shown in Fig. 1.

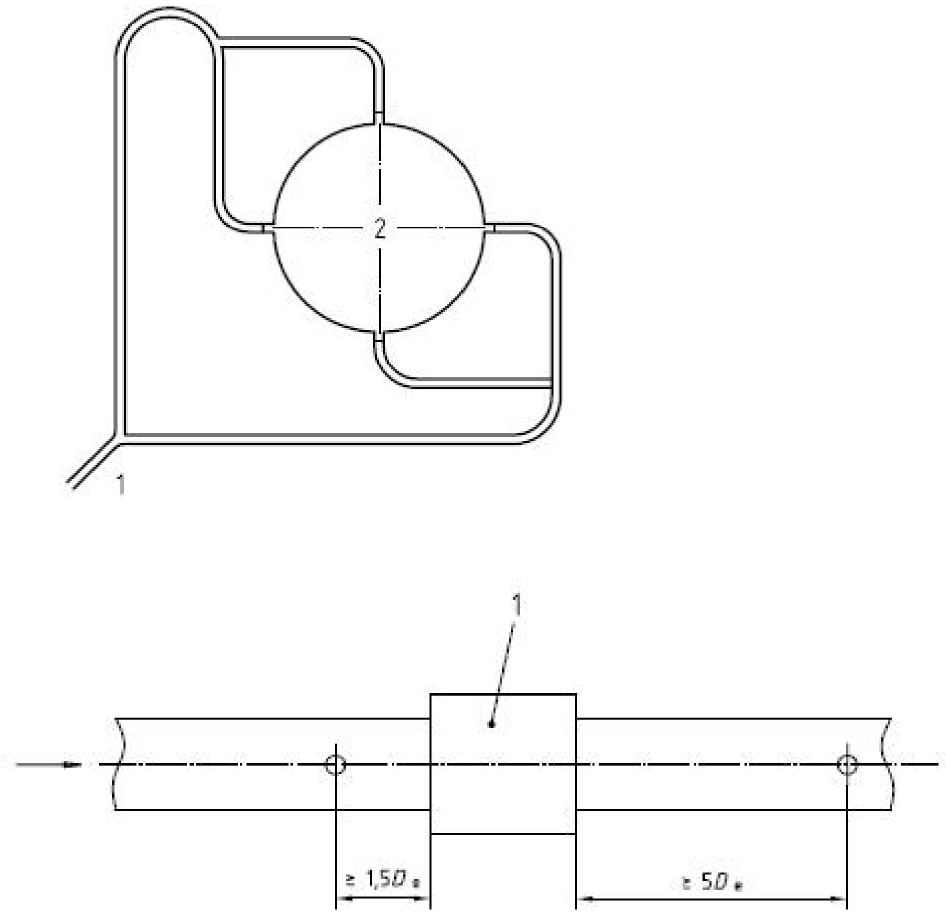

Figure 1. Upper insert: a connection of four pressure sensors for the measurement of the average pressure. Lower insert: the requirements for the location of the pressure measurement planes from the fan according to EN ISO 5802.

The standard EN ISO 5802 discloses also the requirements for acceptable pressure field in pressure measurements. The upper insert in Fig. 2 shows an ideal pressure distribution on the measurement plane, and the lower insert gives an example of a non-ideal pressure distribution. In a measurement of the dynamical pressure the standard accepts the result if more than 75% of pressure readings are larger than 1/10 of the maximum pressure.

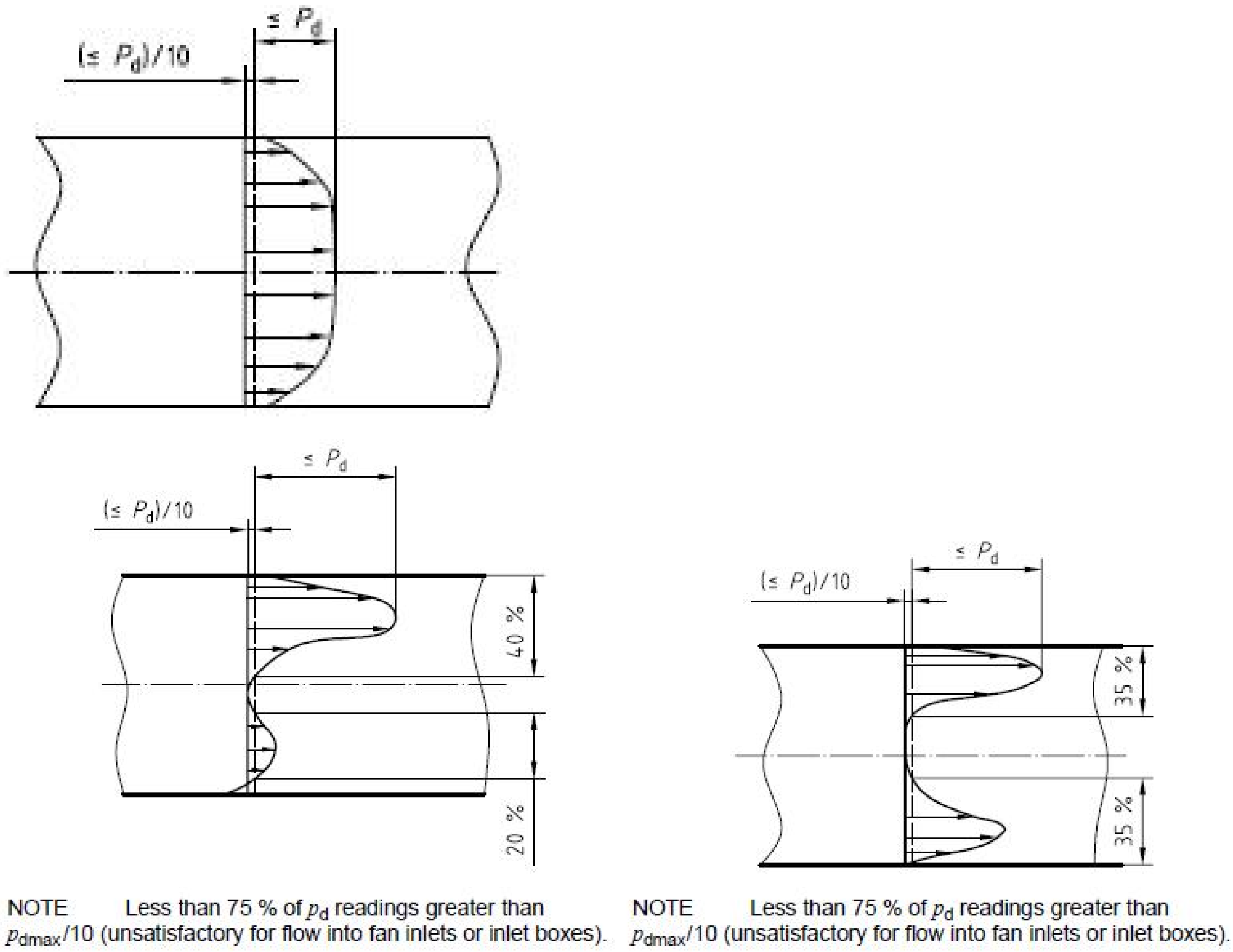

Figure 2. Upper insert: an ideal pressure distribution on the measurement plane. Lower insert: two examples of non-ideal pressure distribution.

Fig. 3 shows the definitions for total pressure difference FTP and for static pressure difference FSP. The dynamical pressure of the fan is defined as the difference of the total pressure on the outlet side and the static pressure (FVP=pt2-ps2).

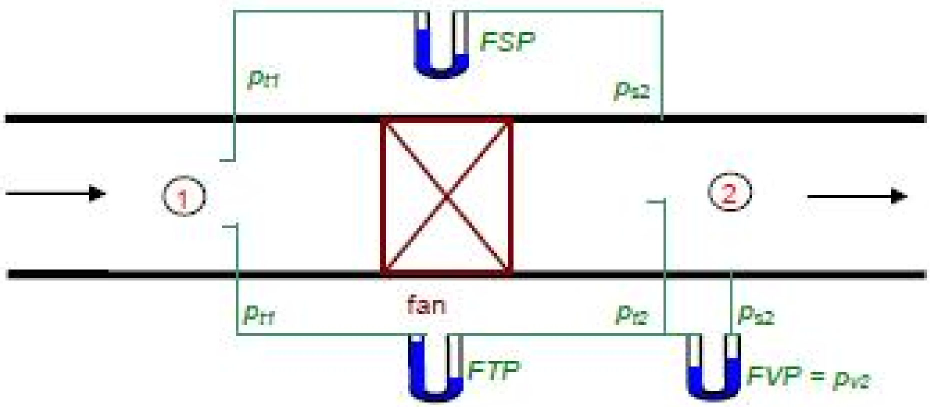

Figure 3. FTP, FSP and FVP for a fan installed in a channel /5./.

Concerning the axial fan PFS-400-236 in Salmisaari power plant there may be an ideal pressure field for total pressure measurement in the inlet side. In the outlet side the straight channel may be stable enough for static pressure measurement but for the dynamic pressure the rotating flow may be too unstable. These arguments are, however, only qualitative. There is no experimental data so far which could be tested according to the criteria shown in Fig. 2.

In these experimental conditions the total pressure difference of the fan could in principle be determined by calculating the dynamic pressure in the outlet side. This could be done by using the information of flow speed /5./: here the dynamic pressure on the outlet side p_{df} is estimated by using the value for mass flow obtained from the dynamic pressure on the inlet side. The average flow speed on the outlet side is determined by using the mass flow q_m, gas density (p_{outlet}, T_{outlet}) and the cross-sectional area. During the measurement of the basic curve it is then necessary to determine volume flow Q, static pressure FSP, and to calculate the dynamic pressure on the outlet side. The total pressure on the outlet side is then the sum of the measured static pressure and the calculated dynamic pressure.

In power plant conditions it may, however, be difficult to get stable experimental results on the outlet side for total pressure or static pressure because of the rotating flow, stack dimensions, pressure losses and the placement of Pitot tubes. In the standard EN ISO 5802 it is simply stated that one can select a measurement plane with common agreement but it has an effect to the accuracy of the measurement.

A schematic picture of the PFS-400-236 axial fan and some pictures of the stack are shown in Fig. 4.

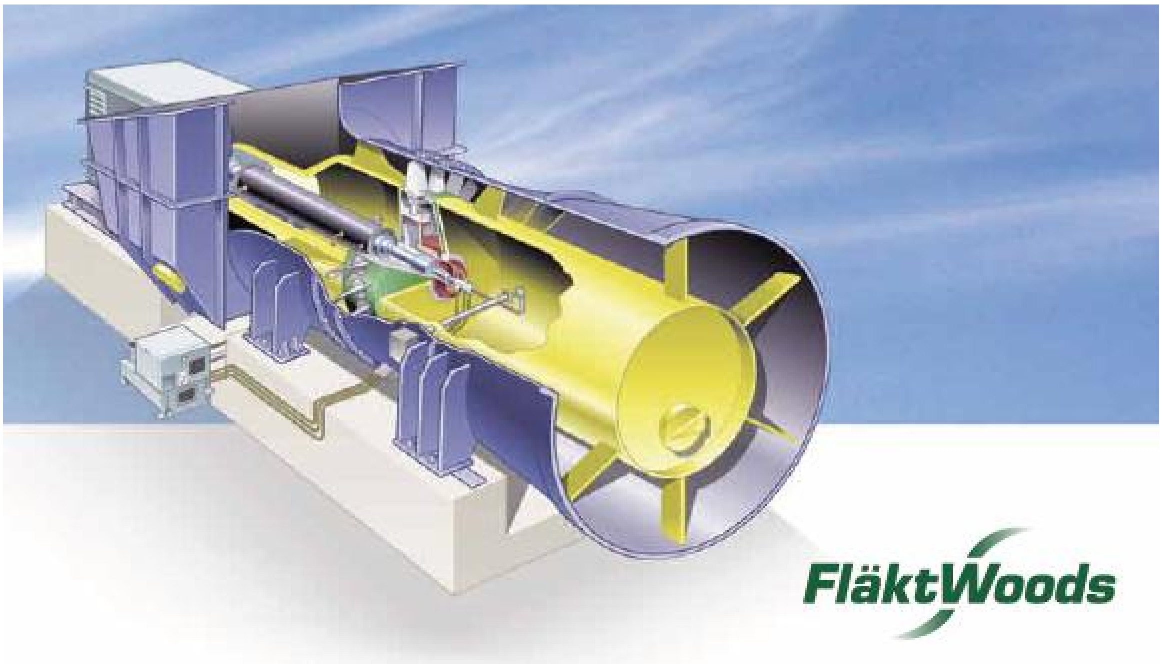

Figure 4. Axial fan and its connection to the process.

After the outlet of the fan there is a 6-7 m long rectangular channel, then a 90° angle rotating the flow upwards, and then a 15 m long channel up to direction of the chimney. The requirements of EN ISO 5802 are not fulfilled because of these channel dimensions (Fig. 1, lower insert).

Concerning the possible future measurements of dynamic and static pressure in this outlet channel one should note that the gas flow is possibly swirling and turbulent in spite of the straightening blades (Fig. 4). An access door is available in the wall of the outlet side. Pressure measurement connections could be constructed to the outlet side through this door.

A picture of the inlet channel of the fan is shown in Fig. 5.

Figure 5. A picture of the inlet side of the axial fan.

Fig. 6 shows the characteristics of the axial fan in Salmisaari power plant. The curves show the dependence of volume flow as a function of blade angle and the total pressure increase.

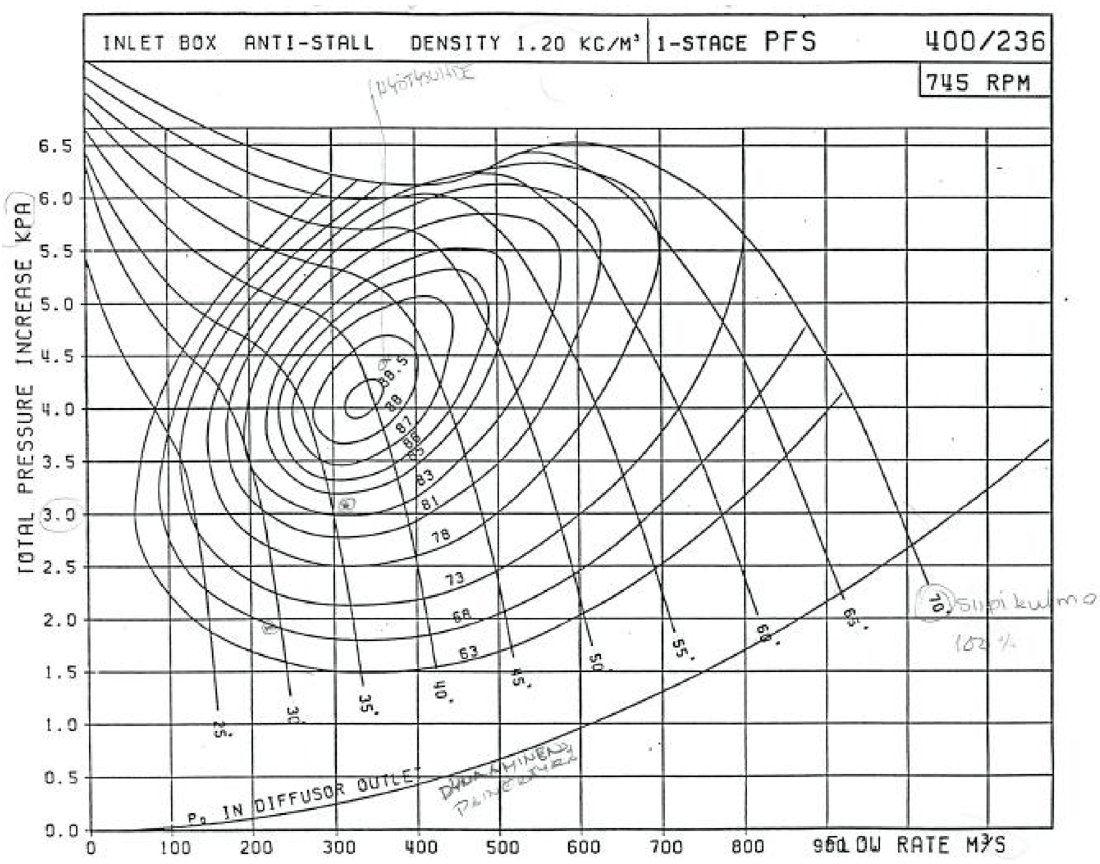

Figure 6. The fan characteristics of PFS-400-236 axial fan.

4. Alternative ways to measure fan pressure

In the following section three alternatives for the pressure measurements of the fan are described:

A. Total pressure difference measurement with Pitot tubes on inlet and on outlet sides, Fig. 7. The selection of measurement planes and the checking of the pressure distribution require Pitot measurements on the measurement planes. The coefficient $\Delta p_{tf}/\Delta Q$ is estimated by using the fan characteristics.

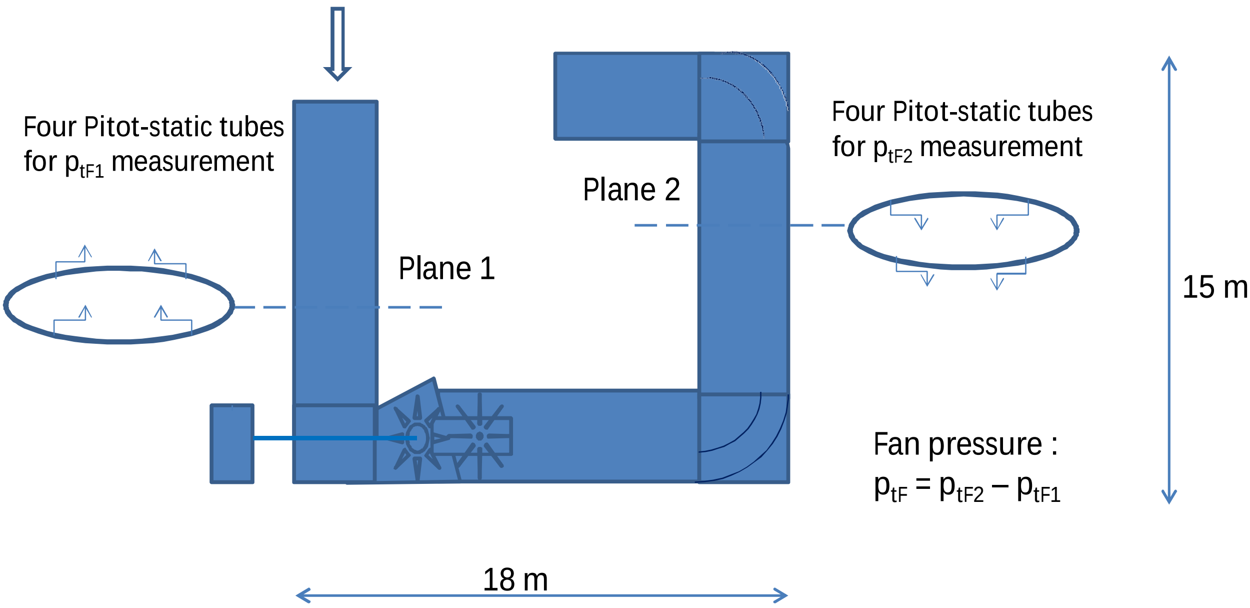

Figure 7. p_{tF} –measurements with Pitot tubes in stack.

B. Total pressure measurement with Pitot tubes in the inlet side over 1.5 D distance from the fan´s inbox, p_{tF2} will be estimated by calculating it with static pressure and volume flow in outlet side, Fig. 8. In this method the pressure and temperature readings from inlet and outlet sides are needed, and $\Delta p_{tf}/\Delta Q$ is determined from the fan characteristics.

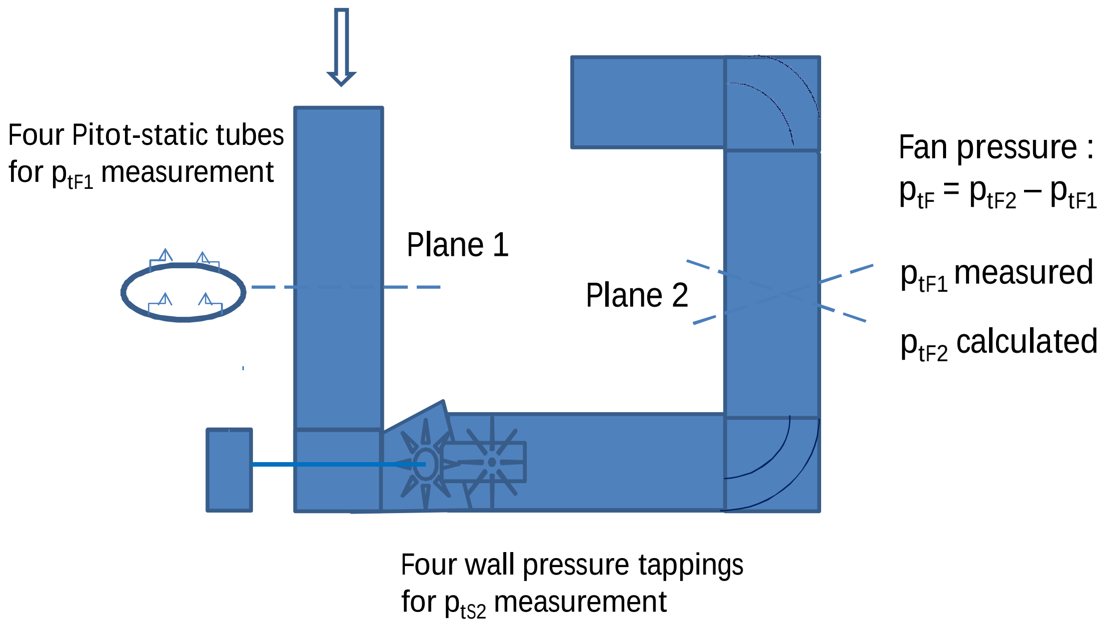

Figure 8. A combination of total pressure and static pressure measurements.

C. Measurements of static pressures in inlet and outlet sides, Fig. 9. In this method the fan characteristics is not used, but by using tracer method one determines Q vs. θ when the power plant´s load changes and $\Delta p_{tf}/\Delta Q$ is determined when the plant curve changes. A minimum of three tracer measurements are needed for the determination of the model parameters.

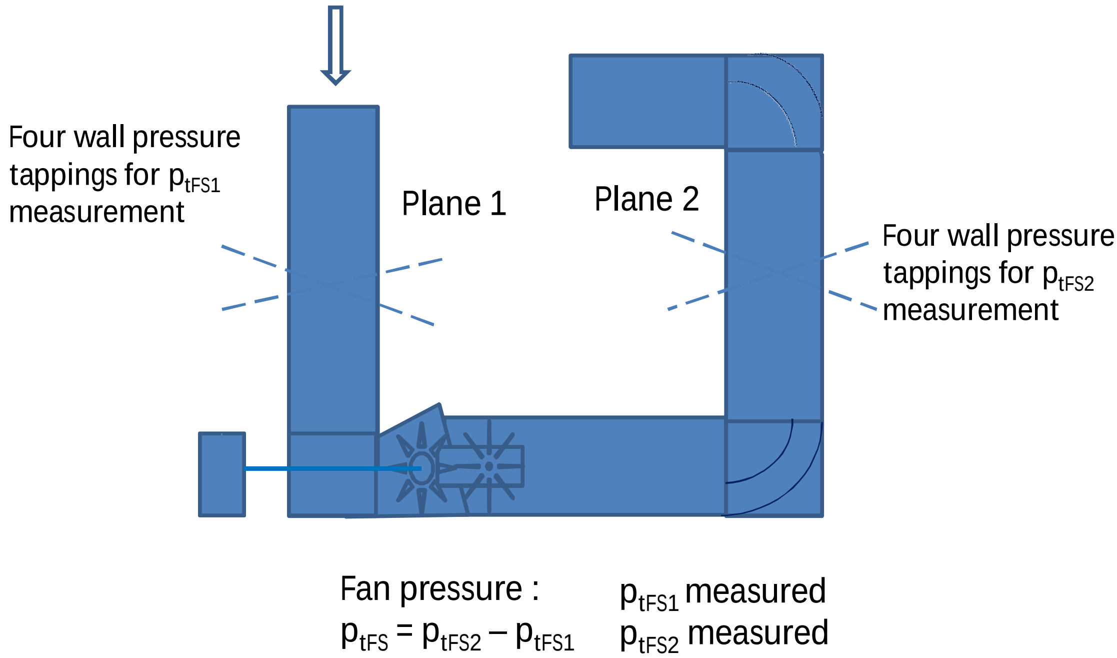

Figure 9. The determination of the fan model with static pressure measurements and with tracer method

5. Calibration and the use of fan model

In a calibration experiment one uses the tracer method and measures eg. three volume flow values with different θ values and simultaneously the fan´s pressure difference (total pressure difference or static pressure difference) is determined. In this way the plant´s basic curve will be determined with the parameter θ and the measurement results p_{tF} and Q. The value of volume flow Q and $\Delta p/\Delta Q$ can be found by changing the plant curve and by doing the calibration measurement with the tracer method.

If the plant curve cannot be changed for the calibration (eg. by temporarily shutting down a purification unit) then the fan characteristics must be used. One should note that the fan characteristics may be based on calculations and not on measurements.

The parameters A, B and C of the axial fan model can then be determined with the calibration measurement results.

$$Q = A \cdot \Theta + B \cdot \Theta \cdot \left(p_{tF}^{\exp} \cdot \frac{\rho_0}{\rho_{\exp}} - p_{tF}^{0} \right) + C \text{, where} \qquad [2]$$

p_{tF}^{0} is the total pressure difference in the reference plant curve measurement,

$p_{tF}^{\exp}$ is the total pressure difference during the actual use of the fan as flow meter. The gas density ratio $\frac{\rho_0}{\rho_{\exp}}$ corrects the possible change in gas density caused by changes in gas composition, absolute pressure or in temperature.

During the normal operation of the plant one can calculate the volume flow Q with the blade angle and the fan pressure difference $\left(p_{tF}^{\exp} \cdot \frac{\rho_0}{\rho_{\exp}} - p_{tF}^{0} \right)$ which changes if the plant curve changes. If the pressure difference measurement is based on static pressure measurement (case c, Fig. 9) then p_{tF} is replaced by p_{tSF}.

6. Estimation of total measurement uncertainty

The total measurement uncertainty of the volume flow given in the formula 2 is determined by using the uncertainties of the parameters A, B and C, and the uncertainties the measured variables $p_{tF}^{\exp}$, p_{tF}^{0}, $\frac{\rho_0}{\rho_{\exp}}$, and θ.

The experimental uncertainty of the pressure difference can be determined by measuring it with different blade angle. The standard deviation can be calculated from this data. This standard deviation contains the repeatability of the measurement device and the possible variations in the flow field which may occur at different power levels of the fan. It is, of course, necessary that the plant curve is constant during this experiment.

The measurement uncertainty of the blade angle can be estimated by the data supplied by the fan manufacturer and by annual calibrations.

The parameters A and C and their uncertainties are based on experiments with the tracer method. Parameter B ($\Delta p_{tf}/\Delta Q$) can be estimated by using the fan characteristics, or by an experiment where the blade angle is kept constant and the plant curve is momentarily changed.

7. Conclusions

In power plant conditions an accurate measurement of pressure difference is difficult because of fixed geometry and dimensions of flue gas ducts and possible variations in the flow field at different power level of the plant. The stability of the flow field and proper locations of pressure sensors could be determined by Pitot measurements. So far these Pitot measurements have not been carried out in this project.

In previous paragraphs three alternative methods have been discussed for the implementation of a pressure difference measurement in a stack. Probably the simplest method is the static pressure measurement over the fan with four point setup (case c, Fig. 9). Qualitatively this method can be justified as it may provide a measurement setup which is less sensitive to whirling flow than the total pressure measurement with Pitot tubes.

The parameters of the volume flow model will be determined with the tracer method. Here, a minimum of three measurements points are needed and the plant curve must be momentarily changed in order to determine the parameter B. In this way one can avoid the inaccuracies connected to the use of a calculated fan characteristics.

In plant conditions the pressure measurement setup needs a heating system, pressurized air for cleaning the pressure tubes, and it must be constructed to prohibit the accumulation of condensed water.

The use of an axial fan as a volume flow meter is probably best suited for a backup method of a primary flow meter. In such a usage somewhat larger measurement uncertainties could be accepted.

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