

Soft-sensing and Error Analysis of Air Flow

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Abstract. To measure air flow in the power plant, regression models are set up with variables according to mechanical analysis and data mining technique, and the results are verified by goodness of fit, F-test and deviance. It is proved that the results using multi-sensor data fusion is more reliable and accurate than the single ones or the arithmetic average value, and based on that, a principle is presented to ensure the data with smaller error is selected. The soft-sensing model of air flow is established by the experiment in a power plant.

Introduction

The main air measuring points in the power plant boiler include the outlet hot primary and secondary and the cold primary air flow of the air preheater, the mixed cold airflow in the mill's entrance. There are mainly two methods for the air flow measurement: according to differential pressure and heat diffusion. The flowmeters of differential pressure type calculate the flow via measuring the differential pressure of the throttling element based on the Bernouli Equation and Continuity Equation of Fluid. There are errors due to its non standard measuring device, the flow coefficient changes influenced by the flow field, the limitation of installation, fly ash and fluctuations, etc. The ones of heat diffusion type calculate the flow by measuring the temperature change of two thermal resistances, without pressure loss and temperature compensation. They are stable with small pressure loss and no blockage, but lag because of the process of heating and cooling of the thermal resistances and easily affected by the pulsating flow [1-4].

According to the problems, on the one hand, engineers upgrade the existing devices to reduce errors, such as using double Venturi tubes to increase the pressure signal, improving the type to reduce the pressure loss and straight pipe section and cleaning automatically. On the other hand, researchers found that the air flow can be calculated through the performance monitoring and soft-sensing using some auxiliary variables [5-6]. In recent years, the soft measurement technology has been widely used in the research of thermal power plant.

Soft-sensing Modeling

The application of the air flow soft measurement methods include artificial intelligence techniques and fitting method based on the performance curve and operation data, having different calculation, fitting accuracy and applicable scope.

Auxiliary Variables. The selection of secondary variables is critical for the soft measurement results. The auxiliary variables must first have a close relationship with the measured variable and every single one should be easily measured and have high accuracy. The number and position of the auxiliary variables are also important.

A soft measurement model was proposed in [4] based on the theory of coal combustion applies coal quality, coal quantity and oxygen content in the flue gas to calculate the total amount of air. The calculation formula is

$$V_a = \frac{0.266K_{c1}Q_B(w(O_2)\phi K_{c2} - 1) + w_{O_2}}{w_{O_2} - w(O_2)\phi} \quad (1)$$

where K_{c1} and K_{c2} are coal quality coefficient, $w(O_2)\%$ is oxygen content in dry flue gas, w_{O_2} is oxygen content in dry air, and Q_B is total heat generated by coal.

The method of performance curve in [5] treats the fan as a part of pressure, so the parameters can be attributed to the flow, pressure, temperature and density. By the way the changes of temperature and density can be ignored with the assumption that the pressure and power are not affected by the effects of transient phenomena. Thus the flow model can be achieved by the total pressure of the fan, deflector opening and power coefficient.

It is found in [6] that there is a strong correlation among the motor current, blower opening, pressure difference and air volume.

It gives the calculation of current and power in [7] as:

$$I = \frac{N \times 1000}{U \times \cos j \times h_e \times \sqrt{3}} \text{ A} \quad (2)$$

$$N = \frac{Q \times p}{3600 \times 1000 \times h} \text{ kW} \quad (3)$$

where U is the voltage [V], $\cos j$ is the motor power coefficient, h_e is the motor efficient, Q is the flow [m^3/h], p is the total pressure [Pa], and h is the air efficient [%].

Model Test. We always test the validation of models after they are established. The goodness of fit is calculated by the correlation coefficient between the measurement and the estimate

$$r = \frac{\sum_{i=1}^N (y_i - \bar{y})(\hat{y}_i - \bar{\hat{y}})}{\sqrt{\sum_{i=1}^N (y_i - \bar{y})^2} \sqrt{\sum_{i=1}^N (\hat{y}_i - \bar{\hat{y}})^2}} \quad (4)$$

Significance test uses the F statistical value which can be written as

$$F = \frac{\sum_{i=1}^N (\hat{y}_i - \bar{\hat{y}})^2 / M}{\sum_{i=1}^N (y_i - \hat{y}_i)^2 / (N - M - 1)} \quad (5)$$

where M is the number of auxiliary variables.

Residual variance is calculated as follows

$$s^2 = \frac{\sum_{i=1}^N (y_i - \hat{y}_i)^2}{N - M - 1} \quad (6)$$

Data Fusion. When there are a few measuring sensors or models, we can combine them using weighted fusion algorithm to obtain a more reliable result.

$$Y = a_1 Y_1 + a_2 Y_2 + \dots + a_n Y_n \quad (7)$$

where the weight is defined as

$$a_i = \frac{1/s_i^2}{\sum_{i=1}^n 1/s_i^2} \quad (8)$$

and the variance is given by

$$s = \sqrt{\sum_{i=1}^n \left(\frac{Y_i}{\sum_{i=1}^n Y_i} \right)^2 s_i^2} = \frac{1}{\sqrt{\sum_{i=1}^n 1/s_i^2}} \quad (9)$$

As shown above, the more measurements we have the higher accuracy the fusion result has. However, if the measurement's weight is quite small while its variance is big, it is unnecessary to put it in the fusion. A measurement is selected which satisfies the following criteria:

$$s_i \leq t s_{\min} \quad (10)$$

where t is a confidence coefficient determined by error distribution.

Illustrative Case

Data from a 1000MW power plant in China is used, whose boiler type is SG3040-27.56-M538 and fan blower is ANN-3120/1600N.

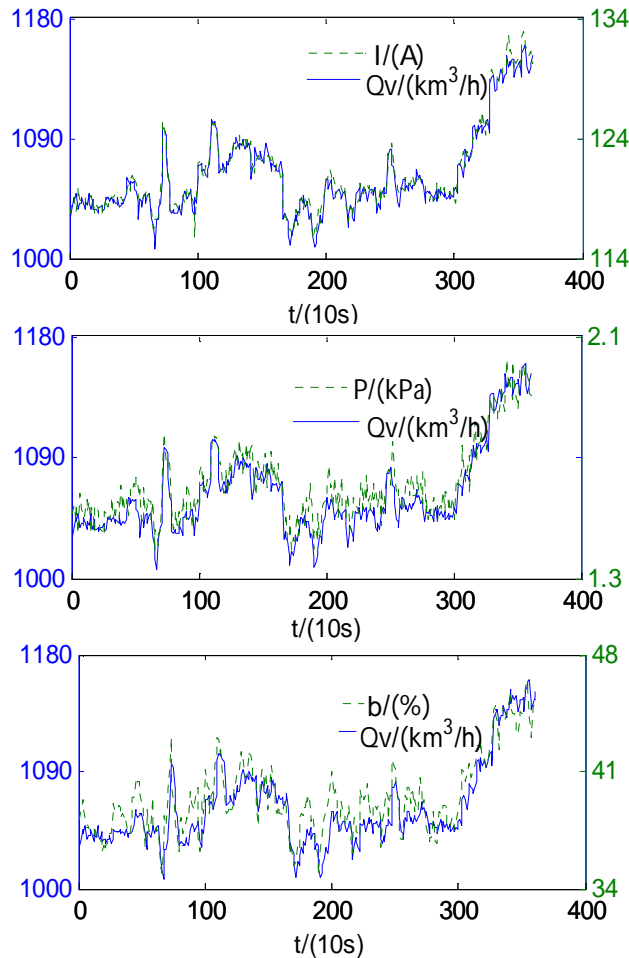


Fig. 1 The Comparison between I , P , b and Q_v

The trend chart (Fig. 1) shows flow changes as current I , pressure P and opening b , so these three variables are selected as inputs of soft-sensing models.

We use the auxiliary variables to establish single equation econometric models of airflow which can be shown as:

Table 1 Model Test Result

Model	Goodness of Fit	F	Standard Deviation
$\hat{Q}_{v1} = 8.6176I + 18.5526$	0.9791	8317.38	6.5547
$\hat{Q}_{v2} = 12.7394b + 560.035$	0.9119	1772.30	13.2251
$\hat{Q}_{v3} = 230.4319P + 690.7904$	0.9230	2064.73	12.4016

All three models pass the goodness of fit and F test. The minimum standard deviation of them is 6.5547, and its confidence coefficient can be calculated as 1.96. So the model \hat{Q}_{v1} and \hat{Q}_{v3} are proposed to put in the fusion process while they satisfy Eq. 10.

Summary

Soft-sensing models for air flow in power plant has been designed, established and evaluated, which can be an effective reference. It can work instead for a short period while the measuring devices are in the fault diagnosis because of its accuracy and response speed. The fusion theory proves that it has a more accurate result than any original sensor and arithmetic mean value of them, and a selecting principle has been presented to ensure that the sensors with smaller error will be put in.

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