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A New Measurement Model for Main Steam Flow of Power plants

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Abstract

Accuracy of existing measurement models for main steam flow in power plants is always unsatisfied. In this paper, a model with higher accuracy for main steam flow measurement was proposed. Accurate values of main steam flow can be obtained based on principle of mass balance when unit is at a steady state. Because of volume sections such as cooling wall and super heater, this model isn't suitable for dynamic-state unit. Another measuring model based on Flugel formula can give exact change trends of main steam flow when unit is at a dynamic state. However, its accuracy is unsatisfied. Therefore, this paper took advantages of the two models, fusing them together in frequency domain with complementary filter method. Simulation results show that new model not only gives accurate steam flow when unit is at a steady state but also provides exact change trends of main steam flow.

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Keywords: Main steam flow; Measurement model; Flugel formula; Complementary filter; Fusion

1. Introduction

Main steam flow is one of the most important parameters of power units, of which measuring accuracy is essential for performance monitoring, process control and operation optimization for units [1-2]. Although measuring main steam flow by flow meter is simple and easy to operate, pressure loss caused by flow meter will increase heat consumption of units, especially for high parameter and large capacity unit in which pressure loss is quite great. Moreover, accuracy of flow meter is low when the unit is greatly off design. Therefore, measuring points for main steam flow are always absent in large power units [3]. In this case, main steam flow values are always calculated by models based on Flugel formula in practical engineering. However, Flugel formula contains error. Besides, error of these models will increase if operating conditions of turbine change [3-6]. Therefore, accuracy improvement for main steam flow measurement is very necessary.

So far few studies have been conducted on this work. In this paper, a model with higher accuracy for steam flow measurement is proposed. Section 2 introduces the common model with unsatisfied accuracy based on Flugel formula. Although this model is not so accurate, it can provide change trends of main steam flow exactly. Then, a modified model suitable for large load variation is developed in section 3 on this basis. In section 4, accurate steady-state model is obtained based on mass-balanced equation. Because of their complementarity in frequency domain, these two models are fused together with complementary filter method for a new model. Simulation result shows that new model not only offers accurate steady-state steam flow but also gives exact change trends of steam flow.

2. Measuring model based on Flugel formula

Apply Flugel formula to multistage steam turbine in which steam reaches a critical state both at design and off-design condition, we have,

$$\frac{D_1}{D_0} = \frac{p_1}{p_0} \sqrt{\frac{T_0}{T_1}} \quad (1)$$

Where D denotes steam flow of turbine, t/h ; P denotes pressure of steam after control stage of turbine, MPa ; T denotes absolute temperature of steam after control stage of turbine, K . (Subscript 0 identifies rated values; Subscript 1 identifies actual values).

When steam in multistage steam turbine reaches a critical state neither at design or off-design condition, we have,

$$\frac{D}{D_0} = \sqrt{\frac{T_0}{T}} \sqrt{\frac{p_1^2 - p_2^2}{p_{10}^2 - p_{20}^2}} \quad (2)$$

Where D denotes steam flow of turbine stages, t/h ; p_1 , p_2 denotes pressure of steam before and after turbine stages respectively, MPa ; T denotes absolute temperature of steam before turbine stages, K . (Subscript 0 identifies rated values).

Compared with pressure of steam after control stage of turbine, exhaust steam pressure of low-pressure cylinder is much smaller which can be neglected. Therefore, (2) becomes,

$$\frac{D}{D_0} = \frac{p_1}{p_{10}} \sqrt{\frac{T_0}{T}} \quad (3)$$

Consider that rated values are all constant, Equation (1) and equation (3) can be written as,

$$D_s = k \frac{P_1}{\sqrt{T_1}} \quad (4)$$

Where D_s denotes main steam flow, t/h ; p_1 denotes pressure of steam after control stage of turbine MPa ; T_1 denotes absolute temperature of steam after control stage of turbine, K .

Equation (4) is the common model for main steam flow measurement. This model is simple in form and parameters needed are easy to get. Because turbine is a system doing work fast, change trends of pressure and temperature after control stage of turbine can reflect that of steam flow rapidly. So we can say that (4) has a good dynamic measuring performance.

There are assumptions in derivation process of Flugel formula. Therefore, the model based on Flugel formula is not a precise model. Besides, many factors such as manufacture, installation and long-term operation of turbine will make actual fluxing area and operation parameters of turbine change and therefore cause rated values in (3) change. If not correct coefficient k , measurement error of the model will increase.

3. Correction of common model

When unit load changes in a large scale, D_s is not in a linear relation with $p_1 / \sqrt{T_1}$ any more that is because coefficient k will change when working condition changes. Table 1 shows calculation errors of (4) at different working conditions in which k is constant and given by rated values at 100% working condition of a 600MW unit. We can see that calculation error of (4) increases with deviation degree of actual operating condition from rated condition. If we could correct (4) based on data at different conditions, accuracy of this model will improve. For a 600MW unit, the corrected relation between D_s and $\frac{p_1}{\sqrt{T_1}}$ is,

$$D_s = a * \frac{p_1}{\sqrt{T_1}} + b \tag{5}$$

Although the relationship is not so accurate and different units at different operation period will have different relationships, the magnitude of flow changes given by the relationship is meaningful to our research work, and we call it dynamic model.

4. Research on new model for main steam flow measurement

4.1 The new model

According to principle of mass balance, when unit is at a steady state [7-8],

Table 1 Calculation errors of Eq. (4) at different working conditions with constant $k=4191.8$.

Parameters	Load				
	100%	75%	50%	40%	30%
Actual values (t/h)	1801.33	1304.38	901.92	748.56	590.74
Calculation values by Eq. (4) (t/h)	1801.33	1323.32	929.3	774.58	593.97
Errors	0%	1.5%	3%	3.5%	5.5%

$$D_s = D_{fw} - D_{bl} - D_l + D_{ss} \tag{6}$$

Where D_{fw} denotes feed water, t/h; D_{bl} denotes sewerage flow of boiler, t/h; D_l denotes the amount of steam used by boiler itself, t/h; D_{ss} denotes desuperheating water, t/h.

Accurate steady-state steam flow could be obtained by this model theoretically and we call it steady-state model. For units without D_{bl} and D_{ss} measuring points, design values can be used because D_{bl} and D_{ss} share a very small part of D_{fw} and effect of their fluctuations can be neglected.

Steady-state model gives accurate steam flow when unit is at a steady state while dynamic model provides exact change trends of steam flow which means that these two models have good performances in low frequency band and high frequency band respectively. These two frequency bands are quite different, so we could make use of their informational complementarity, fuse accurate information from different models in frequency domain and therefore obtain a new model with good performance in the entire frequency band [9-10].

Steam values calculated by steady-state model can be written as,

$$D_{sj}(t) = D_{sf}(t) + N(t) \quad (7)$$

Where $D_{sj}(t)$, $D_{sf}(t)$ denote calculation values of the steady-state model and that of the dynamic model respectively. $N(t)$ denotes difference values between calculation values of the steady-state model and that of the dynamic model.

Equation (7) shows that information in high frequency band of $N(t)$ is a kind of noise to $D_{sj}(t)$. If we can reduce the noise, a satisfied model will be gotten. Pass $N(t)$ to a low pass filter L so that information in high frequency band of $N(t)$ can be removed. And the new model is

$$\begin{aligned} D_s(t) &= D_{sf}(t) + L(N(t)) \\ &= D_{sf}(t) + L((D_{sj}(t) - D_{sf}(t))) \\ &= (1 - L)(D_{sf}(t)) + L(D_{sj}(t)) \end{aligned} \quad (8)$$

Equation (8) shows that calculation values of the steady-state model passed through low pass filter added to calculation values of dynamic model passed through high pass filter makes high-quality flow values. And the low pass filter plus the high pass filter equals one. Filter L and filter $1-L$ are called complementary filters. The method that utilizes complementarity of information in frequency domain of multi-sensor signals of same kind and design complementary filters to get high-quality information is called complementary filter method.

Low pass filter L should satisfy

$$\begin{cases} \lim_{w \rightarrow 0} |L(jw)| = 1 \\ \lim_{w \rightarrow w_0} |L(jw)| = 0 \end{cases}$$

Where $|L(jw)|$ is amplitude frequency characteristics of L , $w_0 \gg w_c$, w_c is the cutoff frequency of L .

L is various in forms. We choose a simple form easy to apply in engineering in the following simulation,

$$L = \frac{1}{Ts + 1} \quad (9)$$

The bandwidth of L is $1/T$, and it should guarantee that low frequency band of signals calculated by steady-state model and high frequency band of signals calculated by dynamic model are all with little noise. In Fig.1, when design complementary filters for two signals which have noises in different frequency bands, the bandwidth of low pass filter should be in the range of $w_1 - w_2$.

4.2 Application and Simulation

The new model was applied to a 600MW unit in this paper. Fig.2 shows load change of the unit. There are main steam flow curves calculated by the three models in Fig.3 for this load change process. Fig.3 shows that steam flow curve calculated by (6) fluctuates dramatically when unit is at a dynamic state. That's because feed water flow is easily affected by regulation and pressure change when load changes. Practice has shown that main steam flow is approximately proportional to unit power. Fig.2 and Fig.3 show that the curve calculated by (5) reflects change trends of steam flow much better. Although (5) is a correction equation, it still can't give exact flow values and the steady-state values calculated by it have a deviation from that calculated by (6) because of long-term operation of units. However, the new model,

expression of which is (8), takes advantages of former two models. When unit is at a steady state, calculated values of new model are close to that of

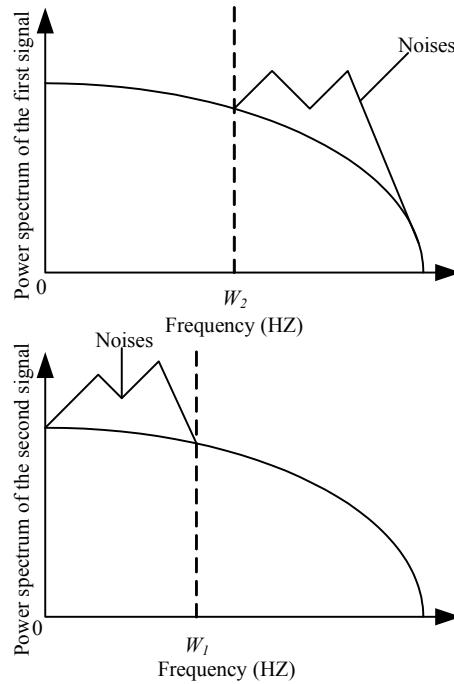


figure 1 Sketch map of two signals with noises at different frequency bands

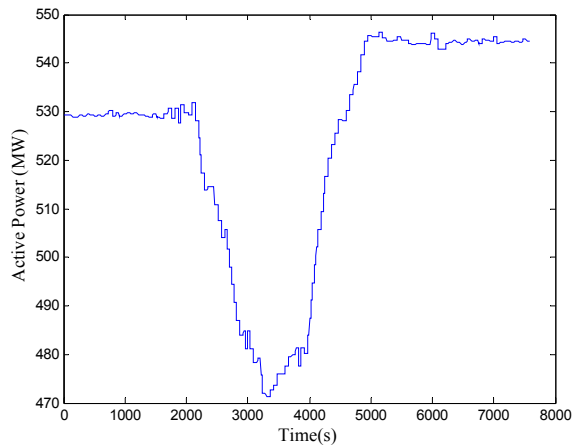


Figure. 2. Load change of the unit

steady-state model which also removes high frequency noises brought by instability of feed water flow. And when load changes, calculated values of new model are close to that of dynamic model which offers real dynamics of main steam flow.

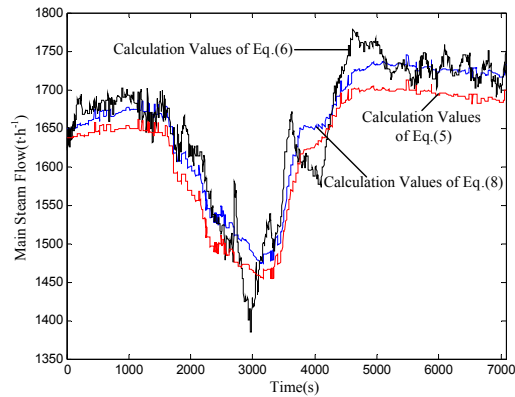


Figure 3. Main steam flow curves calculated by the three models

5. Conclusions

Aiming at lack of precision of main steam flow measurement models, a model with higher precision was proposed. Following conclusions could be drawn:

1) Accurate measurement of main steam flow is very important to power units. However, in order to decrease pressure lose, measuring points for steam flow are always

absent in large power plants. In this case, steam flow values can be calculated by measuring models.

2) The existing model in practical engineering is based on Flugel formula. Because of the inherent problems of Flugel formula, accuracy of the model are not satisfied, especially when unit changes load in a large range or has operated for a long time. However, it can give exact change trends of main steam flow.

3) Accurate steady-state model for main steam flow can be obtained according to principle of mass balance which is not suitable for dynamic-state measurement.

4) Complementary filter method can help extract useful message from different signals of same kind for a higher quality signal. Take values calculated by those two models (dynamic model and steady-state model) as the different signals of same kind, design complementary filters for them and a new model with higher accuracy is obtained.

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