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Modeling of a medium speed coal mill

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ABSTRACT

This paper presents a coal mill model that considers the effect of coal moisture on its accuracy. This mathematical model is derived through the analysis of mass flow, heat exchange, and energy transferring balances in which all heat input into or output from the coal mill are calculated quantitatively to reduce the number of unknown parameters that need to be identified. The work presented in this paper focuses on modeling Mill Parter Ship-type coal mills that are widely used in the coal-fired power plants in China. The unknown model parameters are identified using a real-coded genetic algorithm. Simulation results indicate that the model effectively represents the mid-high process of coal mill dynamics and can be used to estimate the key parameters in coal mills, which are difficult to measure or cannot be measured. On this basis, the model can be used for the state monitoring, control optimization, and fault diagnosis of coal mills.

1. Introduction

China's energy structure (coal resources are rich, while oil and natural gas resources are extremely insufficient) indicates that coal will continue to be its largest energy resource for a long time [1,2]. Therefore, the research works of Chinese scientists on the clean and efficient use of coal are extremely important. This energy structure also indicates that coal-fired power is the main component of China's power generation. Thus, the dynamic characteristics of pulverizing equipment in coal-fired power plants should be studied to realize the clean and efficient utilization of coal in thermal power plants.

Coal mills are independent links in pulverizing systems. The sufficient measuring points at the inlet or outlet of a coal mill enables the analysis of the interactions between the control and controlled variables. Consequently, the state estimation signals of key parameters that are difficult to measure or cannot be measured through modeling can be constructed. In recent years, researchers have conducted extensive studies on coal mill models. Tian et al. regarded the milling process as a first-order inertia link with pure delay and established the dynamic fuel model of a pulverizing system; however, it is a single-input, single-output model that does not consider the effect of primary air, thereby resulting in low accuracy [3,4]. Shin et al. established a dynamic model with two kinds of coal particles and a differential coal mill pressure; however, the impact of coal moisture on the coal mill outlet temperature is not considered, thereby resulting in poor accuracy [5]. Liu et al. presented a mathematical model of the coal mill outlet temperature; however, the coefficients of the model need to be re-determined according to different units, which makes the versatility of the model weak [6]. Wei et al. established a multi-stage model for coal mills that covers the multiple working conditions of their start and stop processes. Their model has high precision, but requires the identification of numerous parameters, and it does not consider the impact of raw coal moisture on the energy balance of coal mills [7]. On the basis of the above model, Zeng et al. considered the impact of the moisture of raw coal on the energy balance of coal mills and established a nonlinear dynamic model of coal mills; although the model's outputs are consistent with the actual outputs, the problem of having to identify many parameters remains [8]. Coal mills are regarded as lumped-parameter links, and the calculation methods of the static heat balance in coal mills are provided. This balance indicates that the total energy input into the initial section of the coal mill is equal to the total energy output from the terminal section of the coal mill. This method considers all the energy involved in the coal mill; however, no coal mill model has been established based on the heat balance of coal mills [9–11]. Zeng et al. established an equation with an unknown parameter (coal moisture), which is calculated successfully and has high accuracy in steady-state conditions [12].

On the basis of the literature above, a nonlinear dynamic model of a MPS (Mill Parter Ship)-type medium speed coal mill is proposed in this study based on its mass and energy balance. The effect of raw coal moisture on the energy balance of coal mills is considered to improve the accuracy of the model and all heat inputs into or outputs from the coal mill are calculated quantitatively to reduce the number of parameters that need to be identified. This model can be used to estimate the key parameters that are difficult to measure or cannot be measured: 1) coal powder or raw coal contents in coal mills, which can be used

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Nomenclature

C_{dc} specific heat capacity of dry-basis coal, kJ/(kg·°C)
C_H specific heat capacity of hot air, kJ/(kg·°C)
C_{H_2O} specific heat capacity of water, kJ/(kg·°C)
C'_{H_2O} average specific heat capacity of vapor at a constant pressure, kJ/(kg·°C)
C_{in} specific heat capacity of primary air, kJ/(kg·°C)
C_L specific heat capacity of cold air, kJ/(kg·°C)
C_{mix} average specific heat capacity of raw coal, coal powder, and the metal involved in heat transfer, kJ/(kg·°C)
C_{out} specific heat capacity of wet air at T_{out}, kJ/(kg·°C)
C_{pf} specific heat capacity of coal powder, kJ/(kg·°C)
C_{rc} specific heat capacity of raw coal, kJ/(kg·°C)
K_c proportion coefficient between the coal feed flow and the coal feeder speed, rpm
K_{conv} conversion coefficient of raw coal to coal powder per unit time, 1/s
K_i model parameters that need to be identified, $i = 1, 2, 3$
K_{loss} coefficient of heat loss through equipment
K_{mac} coefficient of heat generation in milling process
K_{pf} proportion coefficient of coal powder flow
K_{seal} leakage coefficient of sealed air for medium speed coal mill
M_{ar} raw coal moisture, %
M_c raw coal content in coal mill, kg
M_{metal} amount of metal involved in the heat exchange, kg
M_{pc} moisture content in coal powder, %
M_{pf} coal powder content in coal mill, kg
ΔM amount of moisture evaporated in the coal mill, %
ΔP_{pa} differential pressure of primary air, mbar
Q_{air} physical heat input into the coal mill by the primary air per unit time, kJ/s
$Q_{air}\&seal$ physical heat output from the coal mill by primary air and sealing air per unit time, kJ/s
Q_{in} total heat input into the coal mill per unit time, kJ/s
Q_{le} physical heat input into the coal mill by leaking cold air per unit time, kJ/s
Q_{loss} heat loss through the equipment per unit time, kJ/s
Q_{mac} heat produced by the grinding process per unit time, kJ/s
$Q_{\Delta M}$ heat consumed for evaporating raw coal moisture per unit time, kJ/s
Q_{out} total heat output from the coal mill per unit time, kJ/s
Q_{pf} heat consumed for heating fuel per unit time, kJ/s
Q_{rc} physical heat input into the coal mill by raw coal per unit time, kJ/s
Q_{seal} physical heat input into the coal mill by sealing air per unit time, kJ/s
R_{90} coal fineness, %
T_1 inertia time from the air door to the primary air flow, s
T_2 inertia time from the air door to the primary air temperature, s
u_H valve opening of hot air, %
u_L valve opening of cold air, %
W_{air} primary air flow, kg/s
W_c coal feed flow, kg/s
W_H^{max} max-flow of hot air, kg/s
W_L^{max} max-flow of cold air, kg/s
W_{pf} amount of coal powder blown out of the coal mill per unit time, kg/s
θ_H temperature of hot air, °C
θ_{in} primary air temperature, kg/s
θ_L temperature of cold air, °C
θ_{out} coal mill outlet temperature, °C
θ_{rc} temperature of raw coal, °C

as the main basis for coal block and break diagnosis; 2) moisture content in coal powder, which can be used to optimize the outlet temperature of coal mills; and 3) coal powder flow at the outlet of the coal mill, which can be used to optimize the control of the pulverizing system's output.

This paper is organized as follows: section one opens with a brief introduction of coal mills; section two deduces and establishes the nonlinear differential equations of coal mills; section three presents the identification process of model parameters; section four simulates and verifies the model; and the conclusion is provided in the final section.

2. Brief introduction of a coal mill

MPS-type medium speed coal mills are widely used in the thermal power plants in China. They are designed and manufactured by the German company Babcock. This kind of coal mill has the characteristics of low energy consumption and smooth output and has a small effect on abrasive wear and an overhaul period [13,14]. In this study, MPS180-HP-II medium speed coal mill is used as the research object. Its maximum output is 44.496 t/h and the fineness of coal powder R90 is 22% [15] (Fig. 1) (R90 refers to the probability that coal powders cannot pass through a sieve with apertures of 90 μm).

Raw coals fall into the gap between the grinding roller and the grinding disc via a coal chute. Then, the raw coals are crushed into coal powder under the squeezing pressure of the grinding parts. Subsequently, the primary air that enters the coal mill through the air ring dries and brings the coal powders into the coarse coal separator at the upper part of the grinding area for separation. Qualified coal powders are blown out of the coarse coal separator into the boiler while the others fall on the grinding disc for re-grinding.

3. Modeling of the coal mill

In this study, the lumped parameter modeling method is adopted with the following assumptions: 1) the parameters of the medium in the coal mill are uniform; 2) the media in the coal mill are incompressible; 3) the parameters of the medium in the coal mill change along the axial direction only; 4) the change in the flow power in the coal mill is ignored; 5) the coal powder separation process is not considered; 6) only two kinds of coal particles (coal powder and raw coal) exist in the coal mill; 7) the temperatures of the coal powder and the primary air are the same at the outlet of the coal mill.

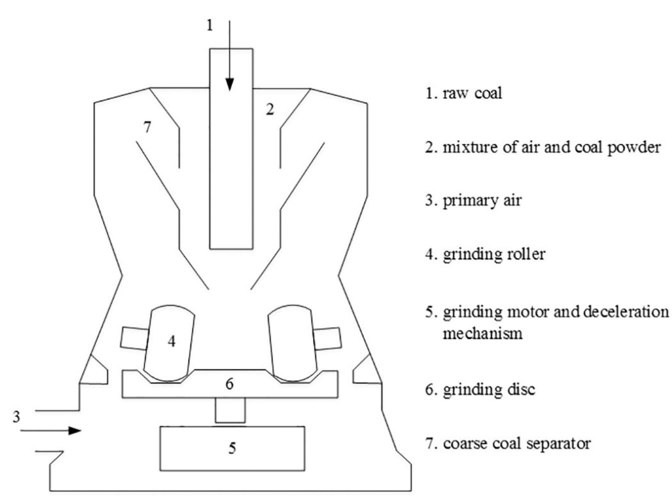

Fig. 1. Schematic of the MPS medium-speed mill.