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***Research paper***

# Hierarchical Neighborhood Models for Ventilation System

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**Abstract**

Considering cement production, we deal with dust, associated with a non-optimal operation of the dust-free ventilation system in the clinker burning department. The optimally organized heating, ventilating, and air conditioning system in any type of production ensures the microclimate of the production premises, corresponding to the sanitary norms and rules, which contribute to the increase of the staff's efficiency. In this paper, the questions of the neighborhood modeling of the heating, ventilating, and air conditioning system in the premises of the cement production shop are considered. A system for minimizing energy costs and reducing dust emission in the clinker burning shop is proposed, which allows increasing the environmental safety of production.

*Keywords*:

## 1. Introduction

In the production of cement, there is a problem of exceeding the allowable concentration of dust in the shop and in the environment, associated with a non-optimal operation of the dust-free ventilation system in the clinker burning department.

The optimally organized heating, ventilating, and air conditioning system ensures the microclimate of the production premises, corresponding to the sanitary norms and rules, which contributes to the increase of the staff's efficiency.

The optimal operating modes of the industrial ventilation system associated with the technological process allow solving energy saving issues in the ventilation section and the maximum productivity of rotary cement kilns.

Let's consider an example of the use of neighborhood hierarchical models for representing the heating, ventilating, and air conditioning system of the cement production.

## 2. Neighborhood Models and Hierarchical Systems

In modern theory of identification and control, considerable attention is paid to discrete models of systems [1], since many objects are purely discrete and finite. However, the existing discrete moels and methods of their analysis do not adequately study objects of complex structure. The problem of modeling and managing such objects is related to the distribution of the system, the complexity of the connections between the subsystems, and the correlation of variables to the components of state or control.

Complex discrete systems have numerous, arbitrary structures of communication between subsystems with an argument of arbitrary nature and dimension. Therefore, classical linear discrete models do not adequately simulate complex discrete systems. They do not provide the necessary flexibility in describing the structure and nature of the relationships of complex object variables. Therefore, new classes of neighborhood models were introduced [1] and investigated [2-8].

Hierarchical control systems [9] have a multilevel structure in functional and organizational terms. Typical examples of technical hierarchical control systems are the integrated power systems, transport systems, industrial complexes of factories and enterprises. Often, hierarchical structures are encountered in solving various computational problems, in graph theory, in mathematical logic, in many other cases.

Thus, the representation of the industrial heating, ventilating, and air conditioning system in the form of a hierarchical bounded neighborhood model, its further structural and parametric identification is an actuary task.

## 3. Neighborhood Model and Structural Identification

Cement production is a system with a complex structure, which includes departments (nodes): "1-Primary processing of raw materials", "2-Grinding of raw materials", "3-Roasting and air purification system", "4-Clinker milling", "5-Cement shipment". Each node is also a complex system.

The dust extraction system is present at all stages of production, as dust is released during the processes of crushing, grinding lime and coal, when unloading the furnace, during subsequent transportation and crushing of cement, its shipment. The three main sources of dust emissions from the chimney are the kiln, clinker cooler and cement mills.

The technological block diagram of the heating, ventilating, and air conditioning system in the roasting shop is shown in Fig. 1.

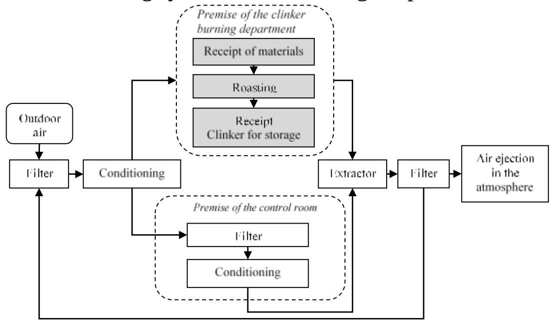


**Fig.1.** Block diagram of the heating, ventilating, and air conditioning system in the firing department

The neighborhood structure [2-4] of the ventilation-filtration system of a production workshop in a simplified basic version is shown in the figure below and consists of the following nodes (vertices): “Ext” - supply air; “Cond” - filtration and thermoregulation (heating or cooling) of supply air; “Plant” - production workshop, heat and dust emission; “Filt” - extraction and filtration of air before ejection and recirculation.

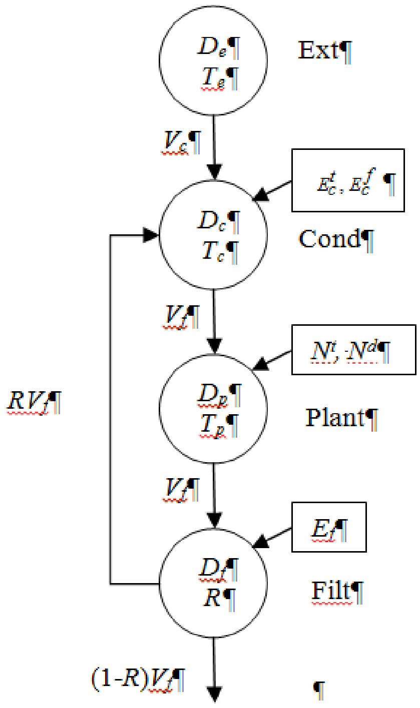


**Fig. 2.** The neighborhood structure of the ventilation-filtration system of a production workshop

In what follows, we will use the mnemonic notation, indexing the variables by letters *e* (for Ext), *c* (for Cond), *p* (for Plant) and *f* (for Filt). The upper *t* and *d* are associated with temperature and dust, the upper *f* is associated with inflow and filtration.

In our basic approximation, the system is described by the following variables:

– Node “Ext” - $D_e$, $T_e$ - dust concentration in the supply air and air temperature.

– Node “Cond” - $V_c$, $D_c$, $T_c$, $E_c^d$, $E_c^t$ - volume of supply air per unit time, maximum dust concentration in the air after filtration, air temperature after thermoregulation, energy consumption for inflow and filtration and thermoregulation per unit time.

– Node “Plant” - $T_p$, $D_p$, $N_t$, $N_d$ - steady temperature and steady dust concentration in the production workshop, the intensities of heat and dust emission.

– Node “Filt” - $V_f$, $D_f$, $E_f$, $R$ - volume of filtered air per unit time, concentration of dust after filtration, energy consumption per unit time for drawing and filtration, coefficient of recirculation.

All values are measured in SI units; $R \in [0,1]$ is the dimensionless coefficient, equal to the ratio of the volume of return air to the entire volume of filtered air [6-7].

The neighborhood model, being formally written, has the form

$$\begin{cases} D_c = F_{cd}\left(D_e, T_e, D_c, T_c, E_c^t, E_c^f, E_f, V_c, V_f, D_f, R\right); \\ T_c = F_{ct}\left(D_e, T_e, D_c, T_c, E_c^t, E_c^f, E_f, V_c, V_f, D_f, R\right); \\ D_p = F_{pd}\left(D_c, T_c, D_p, T_p, V_f, N^t, N^d\right); \\ T_p = F_{pt}\left(D_c, T_c, D_p, T_p, V_f, N^t, N^d\right); \\ D_f = F_f\left(D_p, T_p, V_f, E_f, D_f, R\right). \end{cases} \quad (1)$$

Even in the simplest linear case, these equations contain about fifty parameters.

The first observation that helps simplify the model is that thermoregulation and filtering sub-systems have only two common variables $V_f$ and $R$. Taking into account also the balance equation (2), we can rewrite (1) as

$$\begin{cases} D_c = F_{cd}\left(D_e, D_c, E_c^f, E_f, V_f, D_f, R\right); \\ T_c = F_{ct}\left(T_e, T_c, E_c^t, V_f, R\right); \\ D_p = F_{pd}\left(D_c, D_p, V_f, N^d\right); \\ T_p = F_{pt}\left(T_c, T_p, V_f, N^t\right); \\ D_f = F_f\left(D_p, V_f, E_f, D_f, R\right). \end{cases} \quad (2)$$

Equations for dust filtration, equations for thermoregulation [2] allows to obtain the final system [2,3], which contains only nine coefficients that are subject to further parametric identification.

## 4. Optimization Problems

The aim of our mathematical model is the optimal control of the ventilation-filtration system, see [2-4,10]. This means that the values of all variables must be within the prescribed limits, and energy consumption

$$E = E_c + E_f = E_c^f + E_c^t + E_f. \quad (3)$$

should be minimal. Also, one can consider the minimization problem for the “environmental” functional

$$E^2(k) = (1-k)\left(\frac{E}{E_n}\right)^2 + k\left(\frac{D_f}{D_f^n}\right)^2. \quad (4)$$

where $E_n$ is the nominal value of energy consumption, $D_f^n$ is the nominal intensity of dust emission, and $k \in [0,1]$ is a selectable coefficient. Note that environmental requirements prevail when $k \to 1$.

Now consider, as an example, the following case, which is, in particular, relevant for the model of cement production discussed in [4]. Namely, let $D_e \le D_c \le D_f$, $D_c \le D_p$ and $T_e = T_c$.

These conditions imply the absence of filtration and thermoregulation for the supply air in “Cond”. Moreover, here the recirculation does not make sense in connection with the purpose of our optimization, and hence *R*=0. Then the system (7) can be rewritten as:

$$\begin{cases} E_c^f = \beta_c^f V_f; \\ D_p = \beta_p^d N^d - \beta_p^f V_f; \\ E_f = \beta_f^d V_f (D_p - D_f) + \beta_f^f V_f; \\ E_c^t = 0; \\ T_p = T_c + \gamma_p^t N^t - \gamma_p^f V_f. \end{cases} \quad (5)$$

Thus, for minimization of energy consumption $E(V_f, D_f) = E_c^f + E_f$ we have the linearly constrained two-dimensional quadratic optimization problem:

$$(\beta_c^f + \beta_c^d)((\beta_p^d N^d - \beta_p^f V_f) - D_f) + \beta_f^f)V_f \longrightarrow \min . \quad (6)$$

$$\begin{cases} \beta_p^d N^d - \beta_p^f V_f \le D_p^{\max} \\ T_e + \gamma_p^t N^t - \gamma_p^f V_f \le T_p^{\max}; \\ D_f \le D_f^{\max}. \end{cases} \quad (7)$$

## 5. Hierarchical Neighborhood Model

Consider the neighborhood structure (Figure 2) from the point of view of the hierarchic connections, shown on the block diagram of the technological process (Figure 1).

We construct a neighborhood model [2-4] of node 3, "Roasting and air purification system" consisting of subsystems 1 (Roasting) and 2 (Air purification system), shown in Fig. 3.

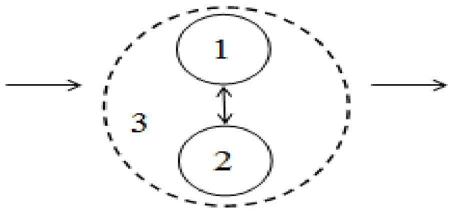


**Fig.3.** Enlarged diagram of the node "Roasting and air purification system"

In compartment 1 there are three rotary cement kilns, a clinker warehouse, as well as a control panel for a rotary kiln, on which the operator-type works are carried out. At the same time, the greatest amount of cement dust is released from the drying zones, calcination and exothermic reactions. Clinker dust is also formed at the end of the sintering and cooling zones.

The air ventilation system should also address the issues of reducing heat losses from the rotary cement kiln head and normalizing the air humidity.

Let's imagine a ventilation system in the form of a neighborhood system, including nodes (Figure 4): "4-Input", "5-Filter1", "6-Conditioning1", "7- Filter2", "8-Conditioning2", "9- Control panel premise"," 10-Extractor "," 11-Filter3 "," 12-Ejection".

**Fig.4.** Detailed scheme of the node "Roasting and air purification system"

Figure 4 shows a ventilation system as a hierarchically subordinate subsystem, located in the enlarged schema node 2.

The node 4 supplies external air to the room, then the air is cleared of dust in the node 5, brought to the desired temperature and humidity in the node 6. Since the requirements for the air environment in the control room are more stringent than in the workshop room, the air must be further processed (node 7, 8) to achieve the necessary parameters of the microclimate. Then the prepared air enters the room of the control panel (node 9) and in the workshop (node 3), from which it is removed by exhaust ventilation node 10. Then it passes filtration (node 11) and is recycled to the atmosphere (node 12). In order to save energy, air recirculation is carried out - the transfer of part of the air flow after the filters to the node 5. In addition, one must take into account the dust and heat entering the shop from the rotary kiln.

Modeling a complex system because of the hierarchical structure of models, the output values of higher-level models are used as parameters of lower-level models. The output of node 1 is the arrival of clinker dust and heat input from the rotary kiln. In this consideration of the system, the task is to identify the models of a complex system under the conditions of parametric coupling of models that describe the incompleteness of the initial data.

Let's highlight the main advantages of using hierarchical models:

1. Freedom of local actions (during the intervals of time, due to the moments of receipt of control actions from the higher level on the hierarchical ladder);
2. The possibility of expediently combining different for each level of the system local optimality criteria and a global criterion for optimality of the system as a whole;
3. The flexibility of the management system and its wide possibilities to adapt it to changing conditions;
4. Universality in the solution of similar in general, but different in detail management problems.

## 6. Conclusion

Thus, to optimize the environmental safety of production, it is proposed to optimize the ventilation system in the room of the clinker kiln, which allows to clean incoming air, remove excess heat, moisture, dust, harmful gases, purify gassed and dusty air before it is released into the atmosphere.

It is of further interest to study the structural identification of neighborhood hierarchical models using the example of a ventilation system for cement production.

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