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On the problem of monitoring a technological process based on multipoint spatial measurement of parameters

I V Kovalev^{1,2,3}, V V Losev², M V Saramud², D I Kovalev^{1,2}, M V Karaseva^{2,3} and A S Kuznetsov³

¹ Krasnoyarsk Science and Technology City Hall of the Russian Union of Scientific and Engineering Associations, 61, Uritskogo street, Krasnoyarsk, Russia

² Reshetnev Siberian State University of Science and Technology, 31, Krasnoyarsky Rabochy Av., Krasnoyarsk, Russia

³ Siberian Federal University, 79, Svobodny Av., Krasnoyarsk, Russia

E-mail: basilos@mail.ru

Abstract. The article considers a method for increasing the parameters reliability of a multipoint spatial measurement during the environmental monitoring at thermal power plants. The result is achieved by using functional dependency and applying fuzzy voting by the agreed majority for decision making. The functional dependence is caused by physical processes occurring while the flue gases transformation along the length of the pipe. The proposed approach helps to compare directly the values of the measured parameter obtained at different points in space, due to their reduction using functional dependencies. This approach also can detect the faults in the sensors. The detection of failures occurs by comparing the direct readings at a given point with the readings calculated about other points.

The problems referred to monitoring of the environmental situation are directly related to the production of energy types. Nowadays, the predominant method of obtaining thermal energy is the process of burning hydrocarbons accompanied by significant emissions and further dispersion of thermal energy and combustion products into the atmosphere. The problem of the maximum-efficient use of the potential of side thermal energy is becoming more actual [1].

There exist different ways to use the potential of collateral thermal energy. One of the examples is the operation of scientists in the development of low-grade heat recovery units, as well as the development of steam micro turbine plants [2, 3]. The principle of their operation is to convert low-grade thermal energy into other energy, including electrical one. At the same time, the power of experimental equipment allows using the received energy for its own needs or accumulating it. Thus, there may be experimental problems in addition to the current monitoring of technological parameters associated with the impact on the environment. For example, there may be problems associated with determining the places where it is better to install microturbine units, as well as the problems of their subsequent monitoring, i.e., monitoring their work according to measured indications. Thus, the need for a multi-point spatial changing of the process parameter occurs, e.g., flue gas temperatures at different elevations of the chimney pipe.

The second, important task is to increase the reliability of the obtained data, since high temperatures and the dynamics of heat and mass transferring processes are not normal conditions and environment



for the placement as well as the operation of measuring tools. These circumstances lead to possible distortion of data and untimely failure of sensors. Thus, the need for increasing the resiliency of the measurement system and data reliability appears to ensure objective monitoring of process parameters. One of the methods for increasing data reliability is the multipoint spatial measurement.

The methods that can help to improve data reliability are also reflected in the use of redundancy in measuring tools. Therefore, the multipoint measurement of parameters, according to the method of spatial distribution of sensors on the objects of the technological process of thermal power plants, can be applied to monitoring problems.

As technical measuring tools have been constantly improving [4], they are becoming more intelligent. The change of technology leads to cheaper final cost of products. The conditions and the possibility of using the redundant measuring tools and the development of appropriate methods arise.

Consider a chimney pipe as an object for the formation of a measurement system. Two traditional forms can be distinguished according to the geometric features of structures. They are cylindrical and conical truncated [5].

The distribution of exhaust and chimney gases, and hence the heat and mass transfer processes are difficult to formalize and model subsequently. These processes occur in the space from a boiler to the emission into the atmosphere.

Consider the process of flue gas through the chimney pipe. The pressure difference, as well as the accompanying potential and kinetic energies associated with the presence of temperature and heat of the gases, are changing as they are moving. In the process of the exhaust gases distribution, their natural cooling and heat loss associated with heat exchange with the external environment occurs. This process is influenced by some physical parameters related to the walls' material of the chimney pipe, geometric parameters of its structure, the technological process regulations accompanied by the conversion of thermal energy into a different type (mechanical, steam energy, electrical, etc.) and, accordingly, features heat and mass transferring processes. At the same time, it is possible to neglect the less formalized dependencies and highlight the main parameters of this technological process by idealizing the technological process, under certain constant conditions.

Point out the main parameters for the development of a measurement system that have an impact having a functional dependence for the stage of the technological process i.e., removal, distribution and dispersion of flue gases and combustion products, and therefore for the accompanying thermal energy (1). Further, we express the functional dependence of the main parameter describing this technological process i.e., the temperature of the exhaust gases, and which is the main parameter of monitoring the installation sites of microturbine units.

$$T_i = f(\lambda, S_{outer}, S_{inner}, V, T_0, \Delta L), \quad (1)$$

where T_i is exhaust gas temperature at the i -th mark, C^0

λ is thermal conductivity of the pipe material, $W/m \cdot K$

S_{outer} is outer surface of the pipe in contact with the atmosphere, m^2

S_{inner} is space of the inner surface of the pipe in contact with the exhaust gases, m^2

V is rate of the flow of exhaust gases, m / s

t_{ij} is the value of the temperature of the exhaust gases at the i -th mark, obtained from the j -th sensor, C^0

ΔL is distance between the sites (marks) of monitoring the installation sites of microturbine units, m .

This relationship can help to express the expected temperature at any of the measurement points relative to any other point. At the most critical points, it is possible to use a group of sensors and a multiversion approach [6] to increase the reliability of measurements at a particular point, as a rule, at the output of the boiler. Thus, for example, we have a deliberately reliable value T_1 obtained by direct measurement at a given point., It is possible to express this value based on the temperature values at the other points, $T_1 = f(\dots, T_2, \dots)$, $T_1 = f(\dots, T_3, \dots)$, $T_1 = f(\dots, T_4, \dots)$ etc using the formulated functional dependence.

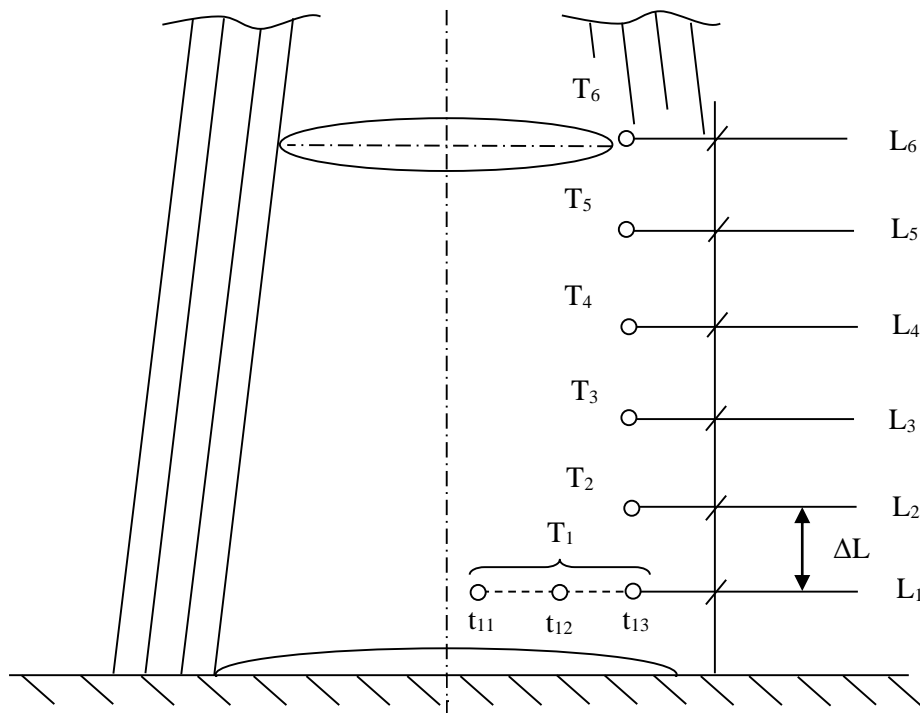


Figure 1. Schematic representation of process monitoring sites for multipoint spatial temperature measurement of exhaust gases in a chimney.

Firstly, we get the opportunity to compare directly the obtained indicators of the measured indicators using this approach, we should get the same values (with a certain tolerance) using functional dependency. Secondly, we can obtain the value of the parameter being measured by multiversion voting, comparing both the directly measured value and the one calculated relative to neighboring points. This approach will also allow detecting failures in the readings measured by the sensors. For example, if the direct readings of the measuring system return data that are not consistent with those calculated relative to other points, but the calculated values agree, then the calculated values will go to the output of the multiversion system, and the sensor at this point will be recognized as failed, the system will report.

It is necessary to apply fuzzy voting algorithms, for example, fuzzy voting by agreed majority to make a decision in the multiversion system [7]. Since the calculated values may not take into account minor changes in the process due to external factors (wind gusts around a pipe, precipitation, heat from the sun cure), they are not perfectly accurate, but have certain dispersion.

Therefore, the decision-making algorithm should take into account possible small differences in the value of the calculated parameter values. Fuzzy voting algorithms can do this. When they are applied, the indicators close in value will vote for the same class (with a different input coefficient). This eliminates the situation in which the values as close as possible to the correct are considered incorrect.

As for the choice of the basic voting algorithm, the most common ones at the moment are voting by absolute majority, voting by agreed majority and median voting [8]. It is necessary for this that the answers of more than half of the voters coincide voting by an absolute majority is the least suitable option, since in order to make a decision. In the case of 4 sensors, in case of failure of two of them, the voting algorithm with an absolute majority will not be able to make a decision, since there are no 3 matching answers. In turn, the algorithm of the agreed majority in this situation will be able to eliminate 2 incorrect answers and decide on the remaining two correct values.

The median vote is of great interest. But there exist a lot of its implementations. The simplest calculation of the arithmetic average does not suit us, since a failed sensor can transmit values that differ from the real ones by orders of magnitude, which will substantially distort the answer. It is possible to

apply modifications when the highest and lowest values are excluded from the calculation. However, in the considered example, with two failed sensors out of four, we can get a set of answers of the form (83; 83; 6800; 9300), of which the last two are erroneous. In this case, the algorithm will discard the extreme values and calculate the arithmetic average $(83 + 6800) / 2 = 3441.5$, while the real value is 83. In this situation, the voting algorithm by an agreed majority will make the right decision, since it will score 2 votes for 83 and 6800 and 9300 one by one. Therefore, it is preferable to use a fuzzy voting algorithm by an agreed majority to implement the proposed system.

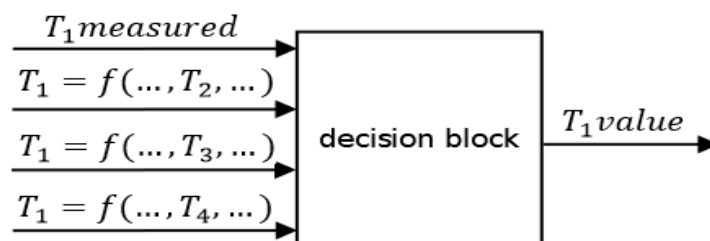


Figure2. Diagram of decision making.

Figure 2 presents the diagram of decision making. The input is received as a value directly measured at a given point, and calculated relative to other points. Decision blocks based on a fuzzy majority vote make a decision based on the obtained data.

Moreover, the proposed method allows obtaining values not only at the points of direct location of the sensors, but also at any arbitrary point, setting the required value of ΔL relative to any of the sensors. This feature is used in the development of the production modernization. The values calculated for all points will help to select the optimal place more accurately to accommodate the various equipment planned for the unit. It can be microturbine units, various production components, filtering systems, additional sensors and monitoring systems.

The article presents a method for increasing the reliability of parameters of a multipoint spatial measurement. The result is an approach that allows both to increase the reliability of the monitoring parameters, and to obtain the value of the measured values at any free point, and not only at the points where the sensors are located directly. The approach is based on the existing functional dependence of the distribution of the magnitude in space and the application of the multiversion approach using fuzzy voting for decision making by the agreed majority. The proposed approach helps to compare the values of the measured parameter directly. They are obtained at different points in space, thanks to their reduction using functional dependencies. This approach also makes it possible to detect faults in the sensors by comparing direct readings at a given point with the readings calculated about other points. If it is impossible to measure the value at a certain point directly, one can get its calculated value about the neighboring points. This feature will also help to determine the optimal place to determine various devices such as microturbine installations, filter elements, etc.

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