Methodology of Visualization of non-Isothermal Mixing Processes Under the Influence of External Dynamic Forces

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Abstract

This article considers the problem of taking into account the influence of a change in spatial orientation on thermal-hydraulic processes. To obtain the parameters of non-isothermal mixing and create a database of these processes, first of all, an experimental method was used to study these processes on a small-scale model. The obtained parameters were visualized and further graphic images were analyzed using the OpenCV library (Open Source Computer Vision Library - an open source computer vision library). A new approach to visualization of mixing processes of non-isothermal flows is proposed. The result of this analysis was the integral and local characteristics of the process of non-isothermal mixing of flows. To assess the degree of influence of a change in the nature of the problem on the integral characteristics of the process of mixing of non-isothermal flows, a series of experiments was carried out for various types of problems. The research is limited by the scale of the model, and there is also a need to develop other criteria for assessing the nonisothermal mixing of flows under the influence of external forces. The value of the article is a new approach to the evaluation of non-isothermal mixing processes. The analysis of the obtained images makes it possible to study the process of non-stationary heat transfer under the conditions of external dynamic influences and to identify areas of non-uniform mixing.

Keywords

Ship nuclear power plant, OpenCV, dynamic mode, visualization, non-isothermal flow.

1. Introduction

The creation of complex thermohydraulic systems used in nuclear power and marine engineering is impossible without comprehensive analysis, complex tests and studies of finished samples on ground-based prototype stands, principle models, both when making decisions about implementation and during their operation as part of transport and stationary facilities.

In the field of thermal hydraulics, there are only two reasonable ways to study the processes of non–isothermal mixing and natural circulation - experimental and computational, which still requires validation on experimental models [1], [2].

However, simply obtaining data is often not enough, their complex analysis with the help of visualization tools, correlation analysis, as well as their subsequent interpretation is necessary. Only such an integrated approach with the use of applied software, as well as our own developments, including the use of computer vision technologies, allows us to obtain visual information about thermohydraulic processes and identify new types of connections between elements. For example, the works [3], [4], [5] describe the application of these approaches to the analysis of such processes.

2. Materials and methods

As mentioned above, the use of visualization methods seems promising in the analysis of thermohydraulic processes in various industries. As an object of research, we selected the lowering ring

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section of the circulation path of the hydraulic model of a ship's nuclear power plant, as well as the entrance to the core simulator [7], [8]. The method of temperature sensing was used as a research method, which was implemented by installing a grid of thermistors directly on the wall of the model along the lowering ring section, as well as directly in the simulator tubes. For the annular gap: each thermistor is directly hermetically sealed into the wall of the model along the circumference and together they make up 5 belts of 8 sensors with a step between the belts of 50 mm. However, I would like to clarify that the stability of the experimental results obtained is confirmed by the repeatability of the key results under various boundary conditions and their non-distortion when checking at intermediate points, which was studied for some modes. A general view of the experimental stand and a local view of the contact groups of thermosondes is shown in Figure 1. The system for collecting experimental data allows receiving signals both from a separate thermal sensor belt and from all channels in combination with high sampling.

To obtain and process experimental data, the program "Program for collecting, processing and analyzing data from an experimental stand for modeling thermohydraulic processes under the influence of external dynamic forces" was created [9].

The program is designed to collect and process experimental data [10] on the temperature distribution of characteristic flow areas in the model of the hydraulic tract of a ship's nuclear power plant, as well as on the position of the model in space relative to the laboratory coordinate system.

The program can be used in experimental studies and their subsequent analysis.

The experiment consisted in the following: a preheated coolant was injected into one or more circulation loops using a pump, a relatively cold coolant was injected into another circulation loop, also using a pump. This paper describes the processes of non-isothermal mixing when injecting streams into circulation loops located opposite.

To initiate vibrations in one or two planes, the model is placed on a swinging platform made in the form of a cruciform suspension [11]. The choice of parameters for dynamic testing of the model in pitching conditions is justified by the Maritime Register. In addition, it is necessary to separate the oscillations by amplitude: with a large amplitude (>15 °) and a small amplitude (<15°), as well as by period: with a large period (>10 seconds) and a small period (<10 seconds) [12]. It is obvious that the effect of these fluctuations on the described thermohydraulic processes is different.

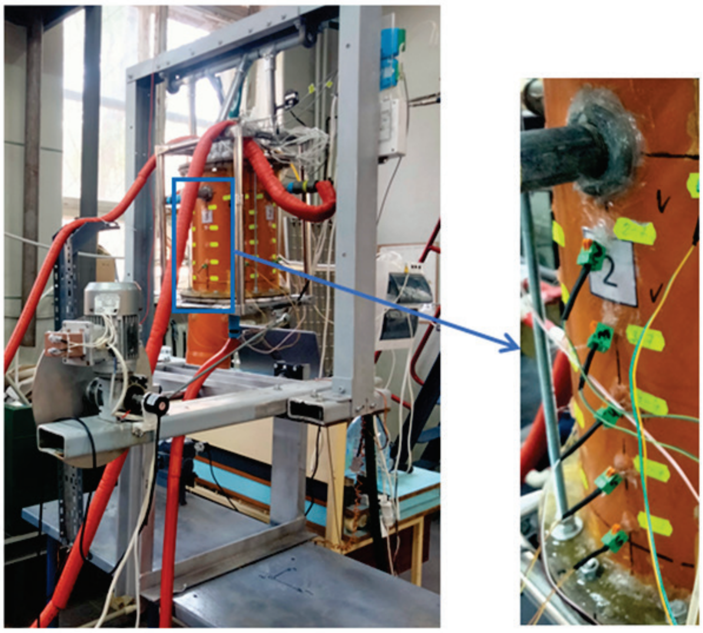

Figure 1: General view of the experimental stand and a local view of the contact groups of thermosondes

3. Results and discussion

Figure 2 shows a diagram of information flows. After receiving the archive with the experimental data (.xlsx), the procedure for preparing an executable file with the initial data (.dat) was carried out in which the coordinate grid is aligned with the experimental data according to the modes.

Then, to obtain a graphical visualization, this file was executed in the 3DFieldPro program, where a color scale was set to match the temperature data and the coordinates of the model. The Kriging function was used to interpolate the obtained values at other points (Gaussian process regression is an interpolation method for which the interpolated values are modeled by a Gaussian process).

The graphic images obtained in this way (.jpg) were processed using the OpenCV library (Open Source Computer Vision Library) [13], which contains computer vision algorithms, image processing and general-purpose numerical algorithms with open source implemented in C++. The result of this analysis was the integral and local characteristics of the process of non-isothermal mixing of flows.

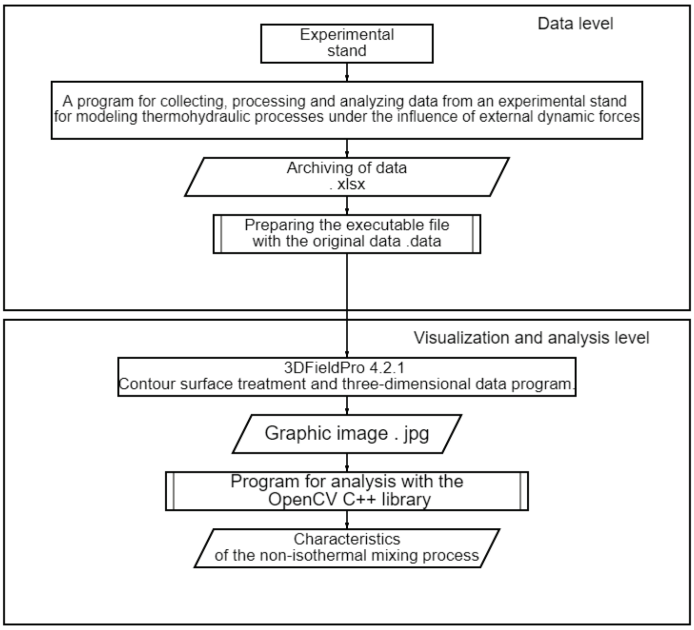

Figure 2: Information flow diagram

In the course of the work, an experimental database of temperatures for characteristic modes was obtained, as well as a database on the position of the experimental model in space obtained from the angular position sensor. Figure 3 shows an example of scanning the cylindrical wall of the model together with the coordinate grid, as well as visualization of the obtained experimental values. The purpose of further investigation of the obtained images is to analyze the characteristic hot/cold vortices (spots), visualization of the boundary of the mixing process, its nature.

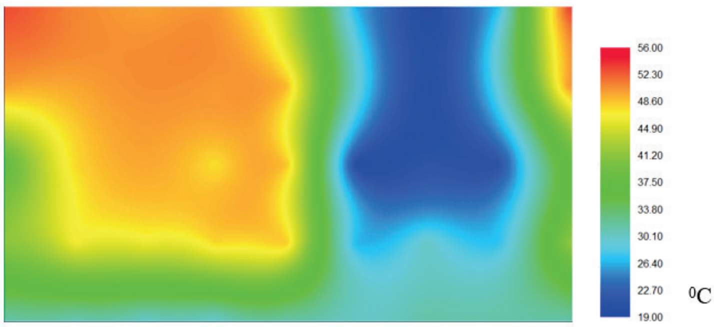

Figure 3: Visualization of the obtained experimental data in the 3DfieldPro program in the dynamic mode (pitching T = 4 sec, 150)

Figure 4 shows the algorithm for analyzing the mixing mode (frame). An example of visualization of the boundaries of cold and hot regions using the library of computer vision algorithms, image processing – OpenCV is also shown. After preprocessing the image, the Canny operator was used to highlight the boundaries of the hot/cold vortex region. Then, by identifying the boundaries of the characteristic areas of mixing, their areas and geometric dimensions can be found.

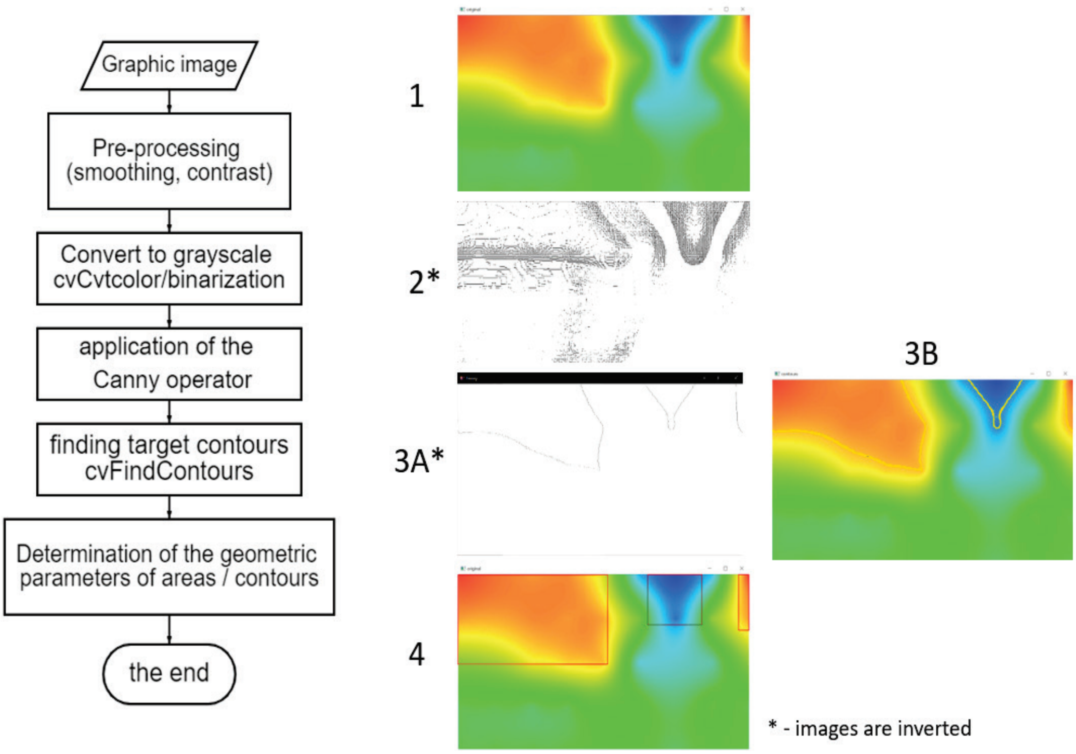

Figure 4: Algorithm for analyzing the mode (frame) of mixing

Table 1 shows the results for different types of tasks, as well as a comparison of the results obtained by the average temperature along the mixing axis and by the areas of the "hot" and "cold" sectors.

It can be seen from the results obtained that static roll and pitching in the same plane have the greatest influence on the processes of non-isothermal mixing. This is explained by the fact that there is a strong concentration of hot/cold flow relative to one of the walls of the model, causing a local maximum/minimum in this area.

Table 1

Comparison of the results obtained for different types of tasks

Task type	Average temperature along the mixing axis	The area of the "hot" sector in relation to the area of the "cold" sector - S1/S2
Statics	41,76	2,467
Roll	29,76	3,258
Pitching is a big period	44,42	4,832
Pitching small period	46,26	1,87
Pitching in two planes	40,04	3,1

When exposed to the pitching model in two planes, a slightly different picture is observed. There is no clear and unambiguous dependence of finding areas with high/low temperature on the position of the model in space (at least for oscillations with low amplitude). In addition, it is noticeable that there are practically no large areas of unevenness and the amplitude of pulsations of temperature parameters is lower than when pitching in the same plane.

4. Conclusion

Visualization of the processes of mixing of non-isothermal flows in the model of a ship nuclear power plant in static and dynamic modes was carried out. The analysis of the obtained images makes it possible to study the process of non-stationary heat transfer under the conditions of external dynamic influences and to identify areas of non-uniform mixing.

The experimental data obtained were visualized using modern software packages - OpenCV with implementation in high-level C++ and 3DFieldPro. A visual and convenient tool for visualization and analysis of these processes was obtained. In the future, a more detailed experimental study is planned (with an extensive variation of input conditions) in order to obtain a database of non-isothermal mixing processes under the influence of external forces.

Based on the obtained images, areas of uneven mixing were identified. In the static mode, there is a concentration of hot and cold vortices in the upper part of the model wall, for a hot flow, a displacement of the flow (twist) of the flow by an angle of about 50 degrees is noticeable. In the dynamic mode, there is a concentration (not mixing) of cold and hot flow directly under the inlet pipe, which is expressed in vast areas with high/low temperature.

Based on the experimentally revealed unevenness of the mixing process, it is concluded that it is necessary to take more accurate account of dynamic effects when modeling the processes of non-isothermal mixing of coolant flows in the case of irregular agitation. Taking into account the fluctuations of the system in one plane gives an inaccurate result, requiring a more thorough approach to the selection of simulated conditions. Only the possibility of modeling vibrations in two planes with careful selection of the input parameters of the oscillatory process allows us to obtain reliable results of modeling non-isothermal mixing processes in the case of external dynamic influences.

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