ALGORITHM FOR CALCULATION OF HEAT TRANSFER COEFFICIENT OF CYLINDRICAL BAR BLOWN BY HOT AIR

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Abstract: *This paper is focused on creation of an algorithm for calculating an envelope boundary condition obtained from experimental measurements performed for calculation of surface heat transfer coefficient of a cylindrical bar installed in a rectangular air channel blown by hot air.*

Keywords: *Heat transfer coefficient, experiment, hot air, ANSYS, boundary condition.*

1. Introduction

Goal of this paper is describing the developing of an algorithm needed for an evaluation of results obtained from the experimental measurements of surface temperatures of a cylindrical bar placed inside an air channel. The measurements were done in order to obtain the data for a determination of heat transfer coefficient between hot air and steel bar.

The heat transfer coefficient will be determined from the following parameters: calculated heat flux, actual temperature of blowing air and surface temperature. The heat flux is computed by a transient analysis using ANSYS. Other values are measured directly. For the most accurate results an envelope boundary condition is required using the ANSYS model including a layout of surface temperatures measured during the experiments.

2. Experimental measuring

The entry point of this task is an experimental measuring. The bar is blown over by hot air in a rectangular channel. The bar is attached to a pivot to keep its position during the measurement performed. The temperature of the bar is measured by 5 thermocouples in five positions on the surface. These 5 thermocouples are on same radial plane. The temperature of blowing air is captured together with each bar measured by the thermocouple placed inside the outlet of the channel. The data from the thermocouples are recorded in a data logger, inside its onboard memory they are downloaded by USB connection into PC after each measurement completed for an upcoming data-processing.

2.1. Description of experimental apparatus

The bar is placed in air channel which is about 0.3 meter long; the outlet holes are installed into the rectangular air channel in a periodical distance of 0.03 meter at the bottom. The sketch of the configuration is shown in Fig. 1. Each channel outlet has the same inlet velocity and air pressure during one experiment. Due to this configuration, an interesting temperature distribution is only in an area between 0 mm to 15 mm from the nozzle outlet. Other temperature distributions are identical (in ideal case) and they are periodically repeated along the total length of the bar. One experiment contains three measurements. The radial plane with installed thermocouples is placed in the distances of 0 mm, 7.5 mm and 15 mm from the hole outlet. This system produces three data sets which are coupled during post processing. The variables of experiments are: air pressure and a distance of bar's axis from the bottom of air channel.

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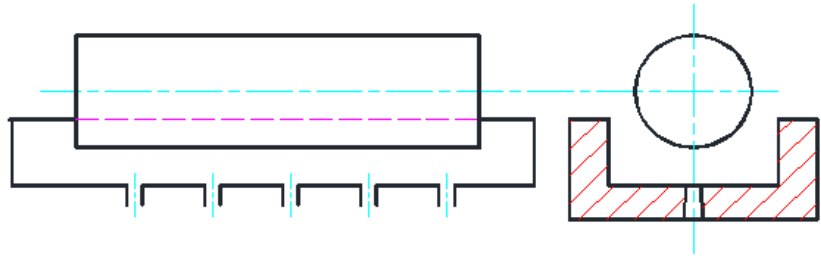
Fig. 1: Sketch of the experimental set-up.

3. Data processing

The measured data are in a raw unfiltered text form, which is needed to be processed for creation of the envelope boundary condition. This process contains filtering, data minding, interpolation, coupling and output formatting. At the beginning of the process there are 3 sets of the measured (pink planes in Fig. 2) surface temperatures in our area of interest (gray cylinder in Fig. 2) and at the end there should be a smooth temperature layout on the cylinder surface in every time step.
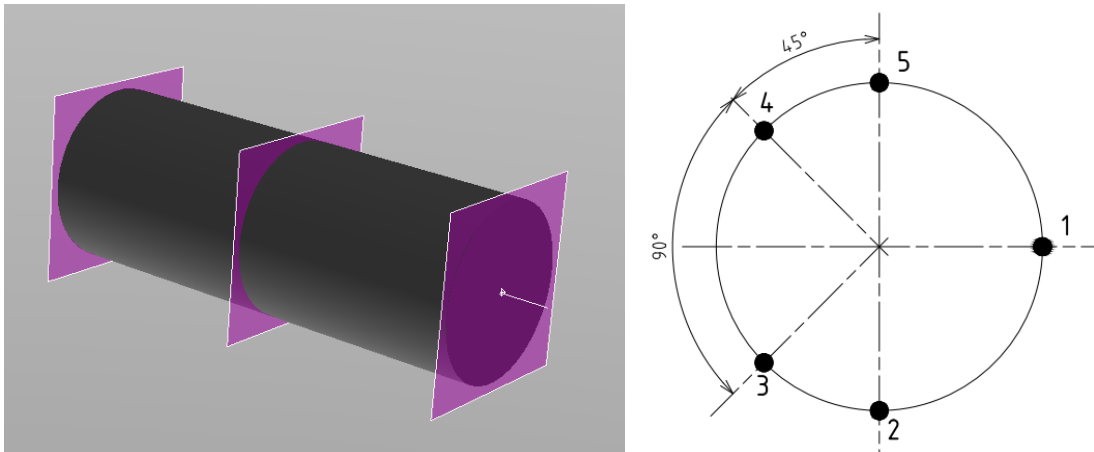

Fig. 2: Illustrations of planes where the surface temperatures were taken (on the left side) and position of thermocouples (on the right side).

3.1. Data filtering

The raw data which is downloaded into PC needs to be filtered to reduce noise which is naturally created in the experiment apparatus. The Gauss filter with a convolute mask was chosen as filtering method. Filtration was performed with the help of the software developed at the Heat Transfer and Fluid Flow Laboratory. Each data set was filtered by the same filtration method. The next operation is data coupling. Due to the fact that each set is actually different measurement, each data set has different lengths and time when the bar starts to heat its self. The different time starting point is solved manually during filtration. The length of data is solved in a MATLAB's script.

3.2. Developing envelope boundary condition

Merit of case is how to handle a 5D matrix (position of point in 3D space, time and its temperature) in a way that is easy to program and that is natural for human mind. ANSYS supports 5D arrays (tables) but in this particular case this is not the way how to do it. Author decided to use the cylindrical coordinate system (ρ, φ, Z) together with the 3D table together in ANSYS to apply boundary condition. This boundary condition will be placed on the cylindrical area, thus one coordinate (ρ axis) will be constant and there is no need to consider it. 3D table in ANSYS has possible 3 variables (X, Y, Z) which can be override by global ANSYS variables, in this case X by TIME, Y by φ. Z coordinate in the 3D table has the same meaning like the global variable Z axis. The temperature of the point in an exact location and time is stored in a cell; and each point is fully described in 3D space and time with its own temperature.

The other thing is a filling of table for the boundary condition. The internal ANSYS algorithm for degrees of freedom value assignment (nodal temperatures in this case) requires having all temperatures across time and position for whole model in one table. Filling such a large table is possible only by an automatic internal file input algorithm. The ANSYS will allocate enough memory space for a required table but allocating the memory for the data is a separated task from reading data. ANSYS reads the data from input file and fills the cells of the table until it finds the end of a file marker or it has space for storing data. By the time when ANSYS allocates its memory for the table, it needs to know the table dimensions. Because of that there must be a link between data size and ANSYS table before reading the data from the text file and all data must be in one text file, written sequentially plane by plane.

3.3. Developing envelope boundary condition

MATLAB was selected for developing specific algorithm for its strong orientation on matrix computing and capability for handling a large set of data. MATLAB's script was created with its own programming language for creating the envelope boundary condition. The script is handling all the obstacles discussed in the previous chapter. The runtime diagram is presented in Fig. 3.

The first step is a data input obtained from three measurements. Eat measurements have different length and a moment when air stars heat the bar. Based on the shortest measurement, the other 2 are cropped to the same length and to have the same moment of heating. Their time values are rewritten. This assures that the moment of heating will be at same time point. The second step is data interpolations of every three temperatures from each set of measurements from the same thermocouple and same time. These interpolations make additional data at Z axis between planes of the measurements. The third step is interpolations of temperatures in each time in each plane along Z axis. These interpolations make additional data along φ axis. All interpolations use the same method, an embedded cubic spline interpolation with a prescribed end slopes to enforce smooth distribution. Last step is storing all data on hard drive.

3.4. Calculation of heat flux and heat transfer coefficient

The heat transfer coefficient is calculated from the measured air and surface temperature and computed heat flux. Two APDL macros were used, the first one for automatic creation of geometry, mesh etc., and the second one for automatic calculation of the heat transfer coefficient at the specific points on the surface where the thermocouples are solder to the steel bar. Both macros read the lengths of data, the temperatures of hot air and time duration from the determined files produced by MATLAB script.
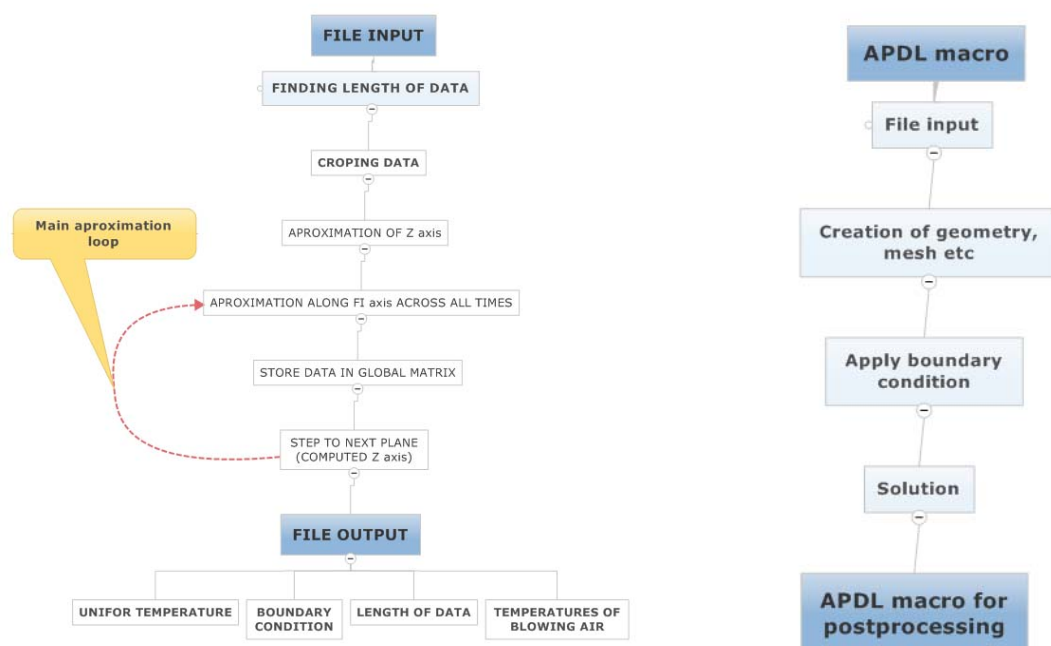

Fig. 3: The runtime diagrams of MATLAB script on the left side and ANSYS on the right side.

4. Conclusions

The algorithm for the calculation of the smooth envelope boundary condition has been provided. The algorithm requires only a manually filtered input data. The rest of the process is fully automatic and it doesn't require any special knowledge. The algorithm is fully adjustable for different computational demands.

Examples of results are shown in Figs. 4, 5. Fig. 4 shows the temperature distribution within the model at the end of calculation. The hottest area is above the nozzle outlet and the coldest one is in the area furthermost from the nozzle outlet. Fig. 5 shows the heat flux distribution at the end of calculation. The right side of Fig. 5 shows heat flux trends of the thermocouples points in time.
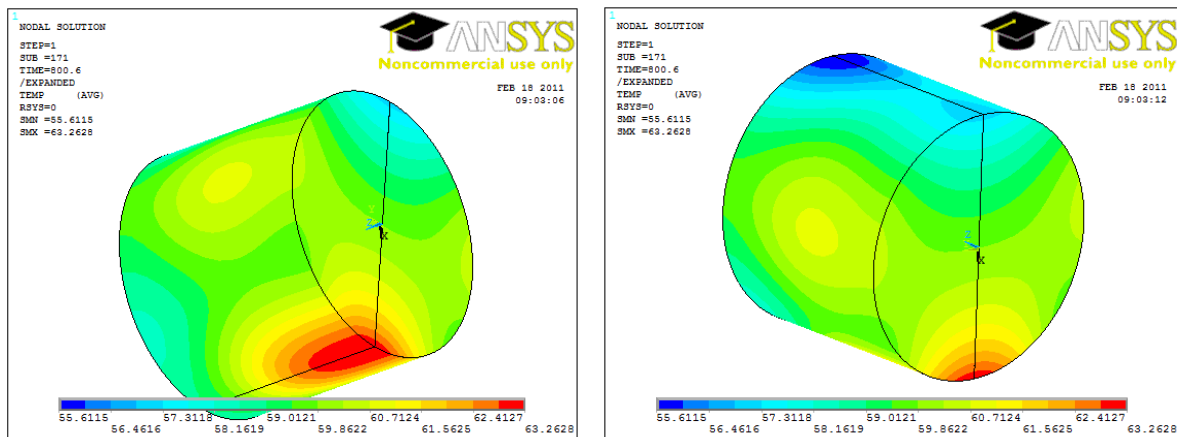

Fig. 4: The temperature distribution at the ANSYS model, isometric view of the hottest and the coldest area. Their locations are in expected places.
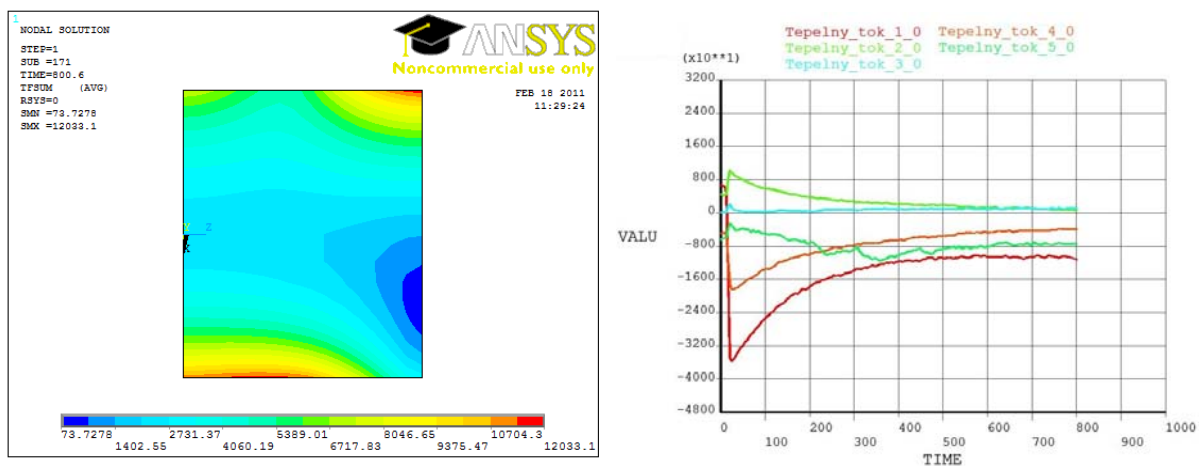

Fig. 5: Heat flux distribution in XZ plane on the left side and on the right side heat flux distribution [W·m^{-2}] at surface points where thermocouples were attached.

References

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