COMPARISON OF THE TEMPERATURE DISTRIBUTION IN THE DRY AND WET CYLINDER SLEEVE IN UNSTEADY STATE

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Abstract

This paper presents the modelling of the heat loads in the dry and wet cylinder sleeve in unsteady state. Next compared the results obtained temperature distribution on the individual surfaces of the dry and wet cylinder from the moment of starting the turbocharged Diesel engine to the moment when the distribution of the temperature changed in a small range. Modelling was conducted based on the boundary conditions III kind as a function of time, which describes the convective heat transfer coefficient and the temperature of the surrounding surfaces of cylinder sleeve, appointed on the basis of the bizonal model. The thesis used the finite elements method (FEM). The calculations show that top parts of the cylinder sleeve near of the mount flange heat up the fastest however the temperature in the bottom parts below the 3rd ring in the piston is the lowest. Higher temperature of the dry cylinder sleeve in relation to the wet is caused by the fact that different convective heat transfer coefficients on the side of the liquid coolant were assumed. The highest difference of average temperature occurs in the initial phase of heating up of the dry and wet cylinder sleeve between 5 and 15 second. In the result of carried out calculations it was stated that the cylinder sleeve fastest heats up during first 20 second of the engine work then the temperature starts to stabilize and in 40 second it changes in a small range.

Keywords: *numerical techniques, analysis and modelling of the heat loads, cylinder sleeve, FEM*

1. Introduction

This paper is an attempt to answer concerning the influence of cooling on the change of temperature distributions in the cylinder sleeve. The analysis issue was conducted on example of the loads of heat in the dry and wet cylinder sleeve in the turbo Diesel engine with direct injection to the combustion chamber. The analysis was carried out from the moment of starting the engine to the moment when the distribution of temperatures changed in a small range.

2. Modeling of the heat loads

Modelling of thermal loads of the dry and wet cylinder sleeve was carried out on the basis of periodically changing boundary conditions of type III which describe the surface film conductance α as well as the temperature T of the working medium surrounding the surfaces of the funnel [2], appointed on the basis of the bizonal model [1].

3. Explicitness conditions

In the case of analysing the unsteady flow of heat in a cylindrical funnel, among others the unambiguity conditions should be taken into consideration [3], to which belong: geometrical conditions, physical conditions as well as initial conditions.

3.1. Geometrical conditions

Geometrical conditions define the shape and sizes of the considered body. The geometrical models (Fig. 1) of the analysed funnel were made by means of solid tetrahedral three-dimensional elements of 4 nodes (TETRA 4) and dimensions of 3 mm accessible in Cosmos/M system [4]. The model consists of: 169.513 elements, 42.648 nodes, 325 curves, 150 surfaces.

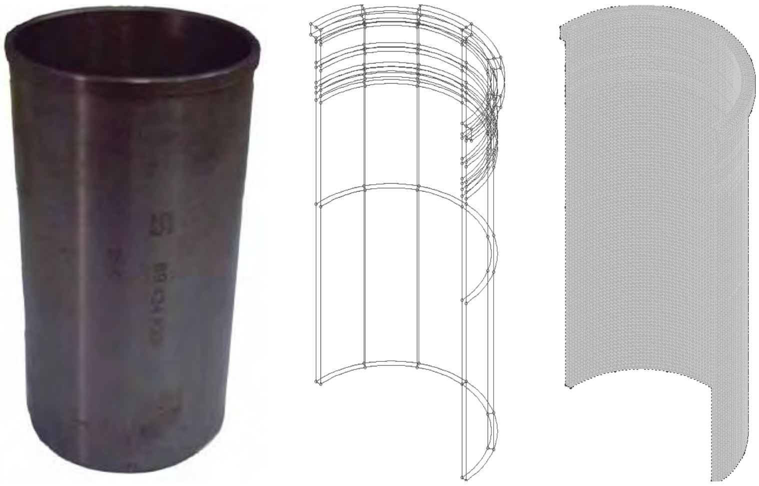


Fig. 1. The next stages of building a model of discrete cylinder sleeve

3.2. The physical conditions

While modelling the thermal loads of the wet and dry cylinder sleeve, it was assumed that it is made from alloy cast iron with small additions of Cr (about 0.5%) and Mo (about 0.2%), with large content of phosphorus (0.4-0.7%) . Because the calculations of the heat flow in the sleeve concerned unsteady state, three basic physical properties of the used material were necessary – density *p*, specific heat capacity c_p and thermal conductivity λ (Fig. 2) (changes of this coefficient in the temperature function were taken into consideration).

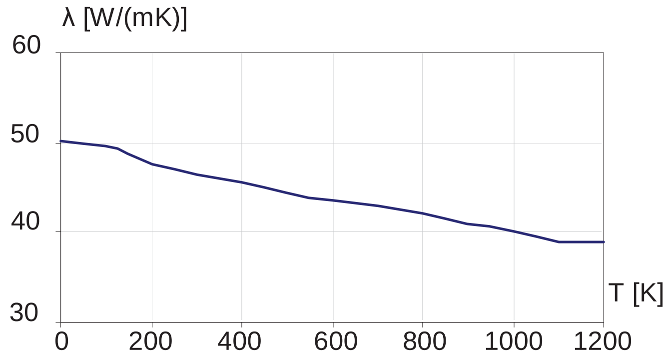


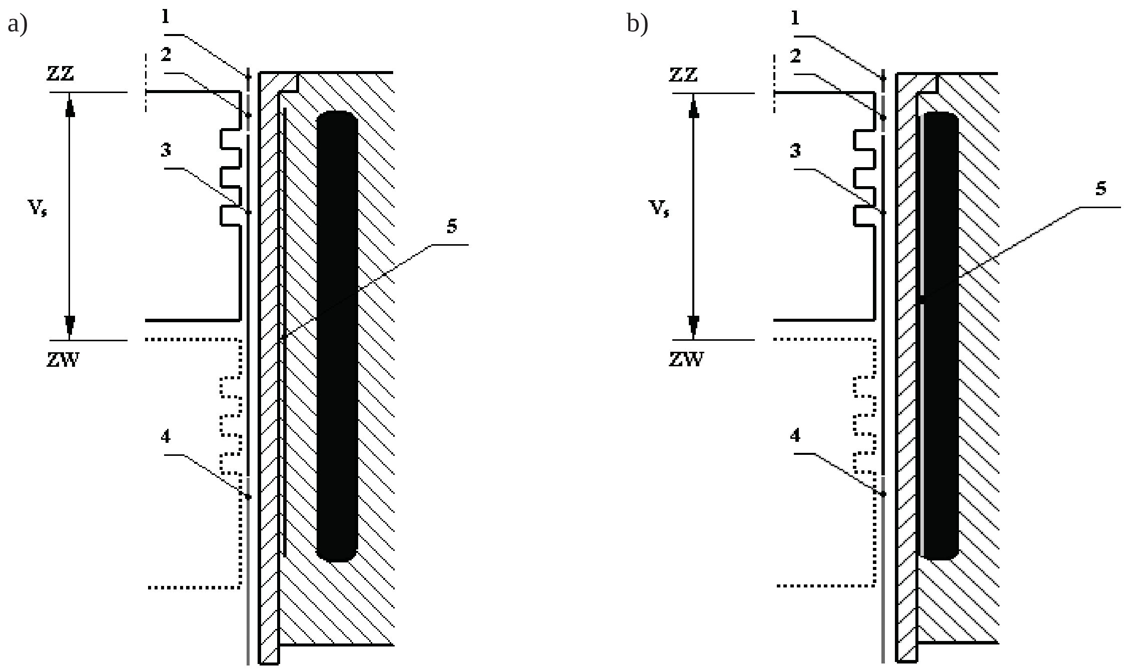
Fig. 2. Changes of the thermal conductivity coefficient λ in the cast iron as a function of temperature T

3.3. Initial conditions

Initial conditions determine temperature distribution in the whole space occupied by the body at the initial moment of time $\tau = 0$. In the analysed sleeve it was assumed that the distribution of temperatures at the beginning is steady and equal to the temperature of the surroundings (in many cases of unestablished heat flow, the reasoning is started from equal, steady temperature at every point of the body at the beginning of the considered phenomenon) [3].

4. Boundary conditions

The analysis of boundary conditions for a dry cylinder sleeve is similar to the analysis of boundary conditions of wet cylinder sleeve. In both sleeves 5 characteristic surfaces can be distinguished [2] (Fig. 3). The principal differences between the analysis of boundary conditions for dry and wet cylinder sleeves result from their different work conditions which are mainly influenced by their different contact with liquid coolant (surface number 5) while the conditions of heat exchange of surfaces l, 2, 3, 4 in both sleeves are the same. That is the reason why the article concentrates on the analysis of surface number 5 only.



Surface:
1 - from the side of combustion chamber,
2 - from the piston head in the inner dead centre (ZZ) to the first ring in ZZ of the piston,
3 - from the first ring in the inner dead centre (ZZ) to 3rd ring in the outer dead centre (ZW) of the piston,
4 - below the 3rd ring in ZW of the piston,
5 - from the side of the cooling liquid.

Fig. 3. Drawing of the dry(a) and wet cylinder sleeve(b)

5. Modelling heat loads on the surface of the sleeve from the side of the liquid coolant

It was assumed that the temperature T_5 for dry and wet sleeves on surface number 5 increases alongside with the increase of the liquid coolant by 1 K in 1 s.

$$T_5 = 296\text{-}336 \text{ [K]}.$$

Because there are no literature data regarding surface film conductance on the side of liquid coolant in a transient state (engine warm-up phase) it was assumed that the value of coefficient α for a dry and wet sleeve will be achieved after about 5 minutes of engine work (from the moment of engine starting). It was assumed that the coefficient α in the time of 0-5 min has a linear course (Fig. 4). Substitute surface film conductance for a sleeve was calculated by the formula (1) [2].

$$\frac{1}{\alpha} = \frac{1}{\alpha_{opk}} + \frac{s_b}{\lambda_b} + \frac{1}{\alpha_{WK}} \quad \left[\frac{\mathrm{m^2K}}{\mathrm{W}}\right], \tag{1}$$

where:
α_{opk} - substitute surface film conductance in the point of contact of two adjacent surfaces,
α_{wk} - substitute surface film conductance on the side of liquid coolant and taking sedimentary scale into consideration,
λ_b - heat conduction of the engine block material,
s_b - engine block wall thickness between the sleeve and the liquid.

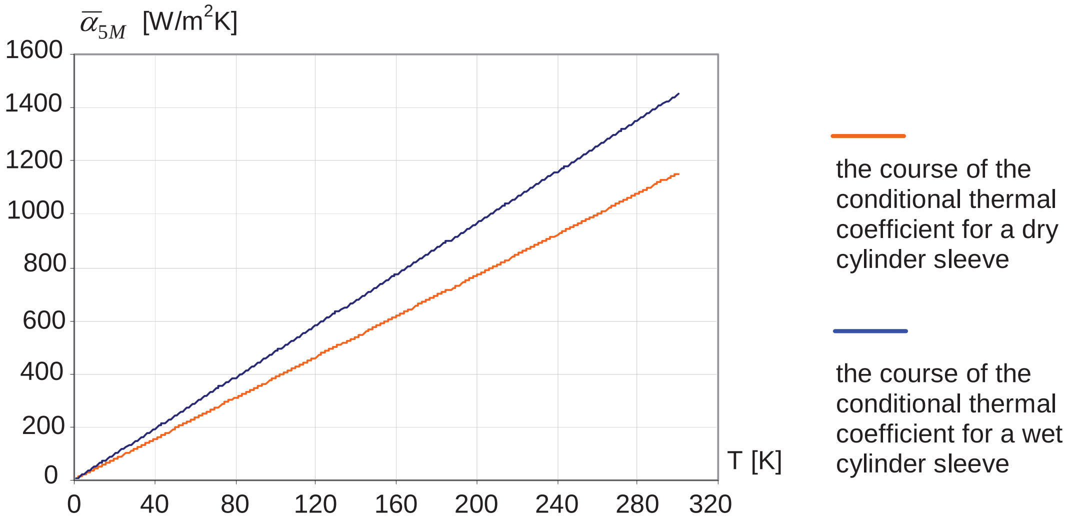


Fig. 4. Average coefficient of heat exchange $\overline{\alpha}_{5M}$ for the surface 5

6. Results of calculations

In this paper the heat loads for the dry and wet sleeve for a turbo engine of capacitance 2390 cm^3 and nominal power 85 kW and rotation speed equal 4250 rpm were modelled. In Fig. 5 and 6 comparison subsequent phases of the cylindrical dry and wet sleeve heating were shown for the same piston position, equal 5 crank angle after the external turning (filling cycle) after 0.5, 5, 10, 20, 30, 40 s of engine work. In Fig. 7 a chart of average temperatures for the whole cylindrical of the dry sleeve and its surfaces was shown. In Fig. 8 a chart of average temperatures for the whole cylindrical of the wet sleeve and its surfaces was shown. Surface 5 was not shown since for this surface there were taken average conditions of the heat exchange.

7. Conclusions

From the calculations it appears that the upper parts of the dry and wet sleeve warm fastest, i.e. in the region of precipitating collar, and the temperature in the lower part, i.e. below 3rd ring in ZW of the piston is lowest. Besides, it was determined that the maximum temperature (after 40 s of engine work) for the dry sleeve equals 510 K, while for the wet sleeve equals 444 K and appears in the upper part of the sleeve in the region of the precipitating ring.

From the calculations it is seen that both sleeves heats faster in first 20 seconds of the engine work (in average 3.5 K/s for the dry cylinder sleeve and 3 K/s for the wet cylinder sleeve), then the temperature stabilizes and in 40 s it changes in a small range (0.5 K/s for the dry cylinder sleeve and 0.7 K/s for the wet cylinder sleeve).Higher temperature and higher speed heating of the dry sleeve as compared to the wet one results from the assumption of two different heat transfer coefficients on the side of cooling liquid. The heat outflow from the surface of the dry sleeve is difficult because of the double walls (the sleeve and corpus wall), which is not seen in the wet sleeve that is in a direct contact with the cooling liquid. In order to verify the results obtained in the near future experimental measurements will be performed on real models.

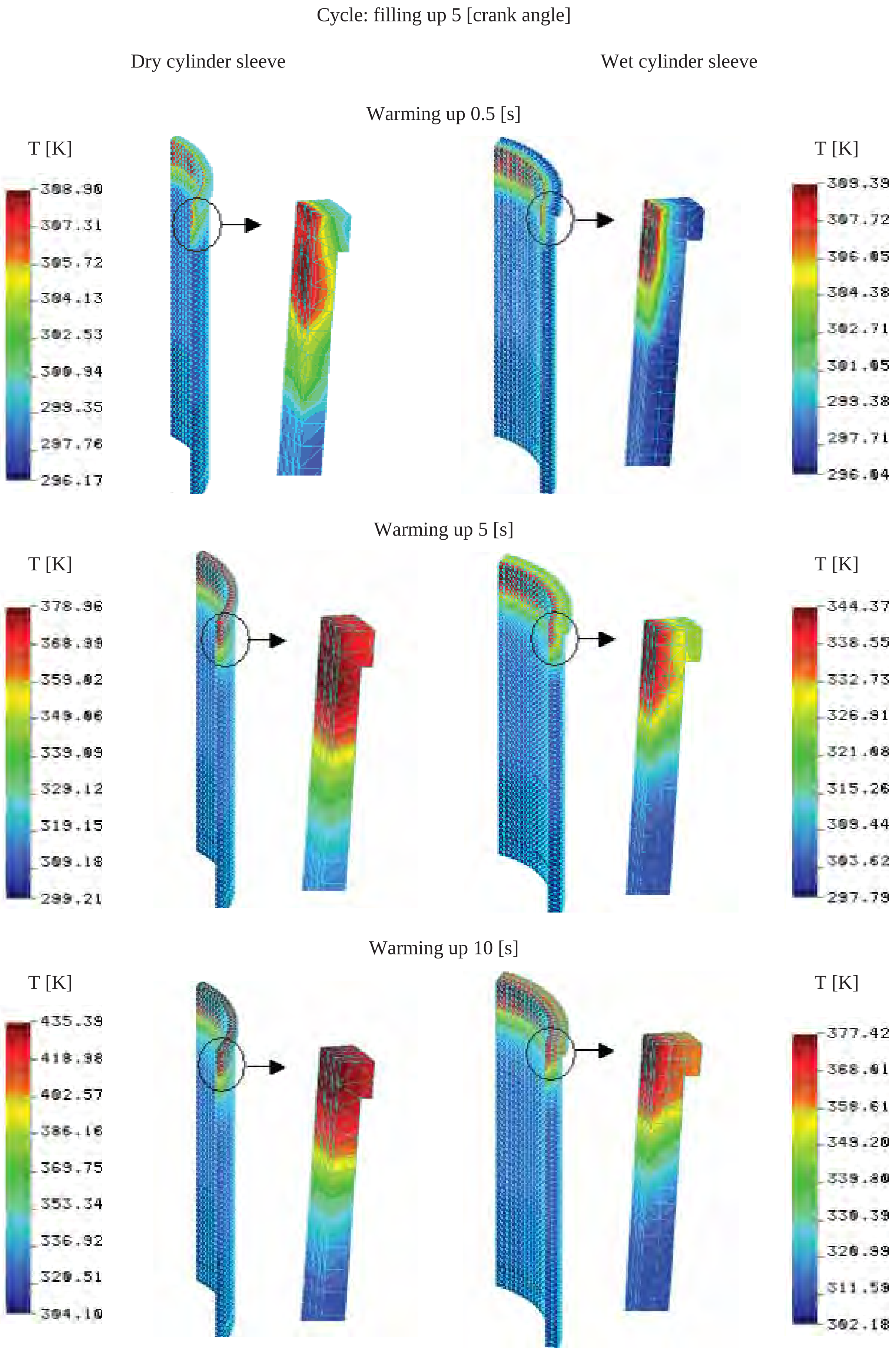


Fig. 5. The following phases warming up of the cylinder sleeve

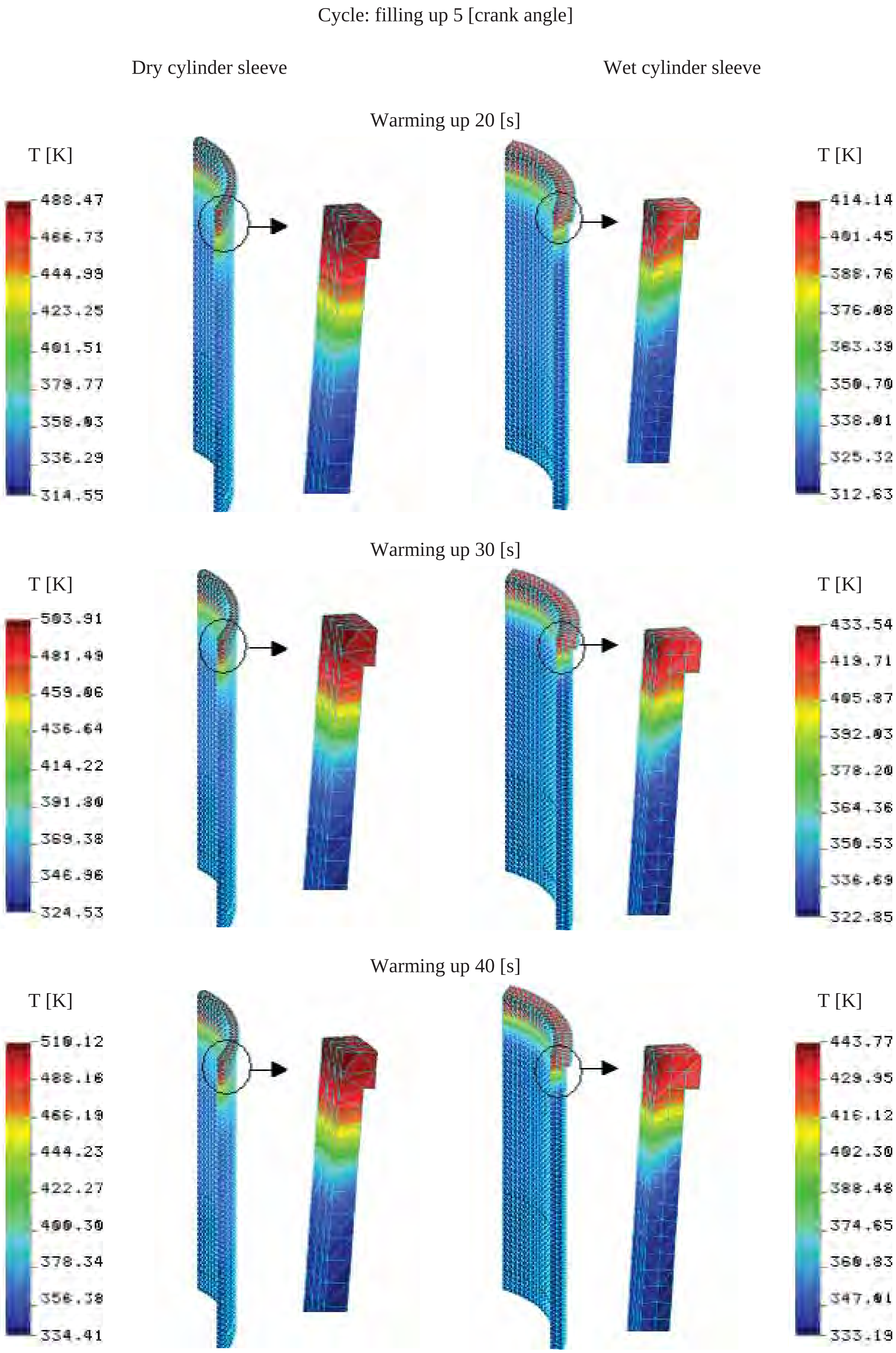


Fig. 6. The following phases warming up of the cylinder sleeve

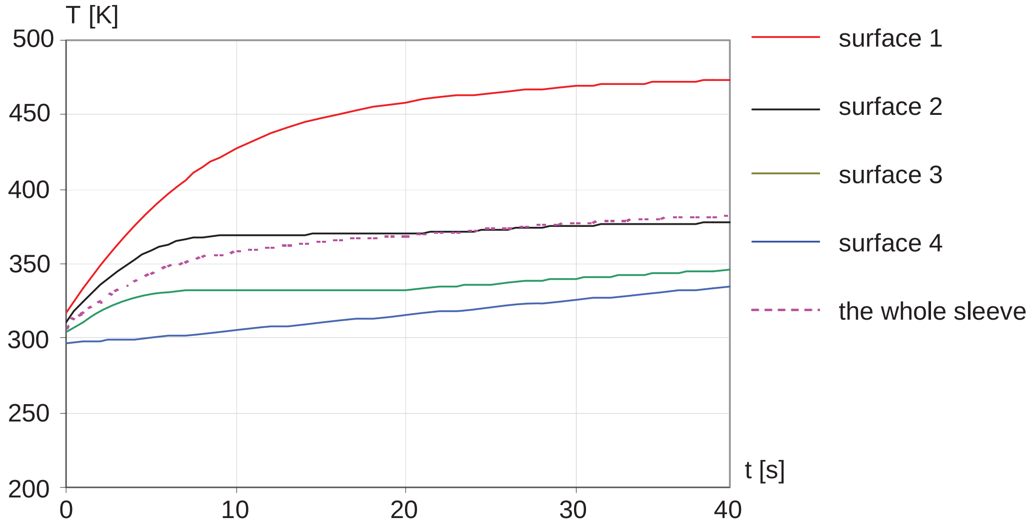


Fig. 7. The chart of the average temperatures of the whole cylindrical sleeve and its areas (dry cylinder sleeve)

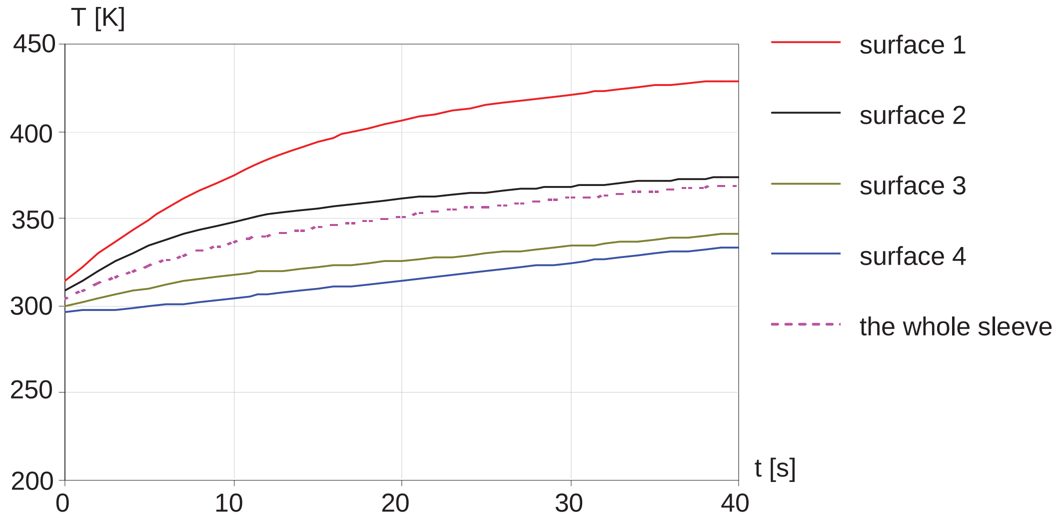


Fig. 8. The chart of the average temperatures of the whole cylindrical sleeve and its areas (wet cylinder sleeve)

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