Realisation of technological inductors has some advantages which will be discovered in this paper. Two pole inductor was used for case we have four pole inductor in the other case – two antipodally situated windings or one winding. In the first case we use two pole inductor vice versa four pole inductor.

In the four pole inductor the windings of the same phase U1 and U2, V1 and V2, W1 and W2 are winded on the antipodal teeth. In the case of two pole inductor the half of winding of the same phase is placed in the hollow between two neighbouring teeth. Other half of the same phase winding is placed in the antipodal hollow. Therefore the winding span is equal to diameter. Practically the winding of any phase is divided into two windings: U1 and U2, V1 and V2, W1 and W2. In this case the ends of windings of any phase can be situated on the outer surface of pipe with technological liquid contrary one to other. Any pair of one phase windings creates two magnetic poles. Therefore we have the two pole inductor. For analysis we suppose that only one winding is used for exciting of any phase of magnetic field.

The uniformity of magnetic field was investigated by modelling of the both inductors types.

Modelling of inductors

The finite element modelling package JMAG was chosen. This package is specialized for electric motors. It can be used successfully for investigation of the technological rotating magnetic field inductors. We investigate the distribution of magnetic flux density in the areas of two and four poles technological inductors active zone (the area in which technological process proceeds) limited by some radius R (see Fig. 1). Modelling was performed using the finite element method. The modelling results are presented in the next section for different types of inductors and active zones.

Fig. 1. View of the four-pole inductor cross-section.
The intervals of relative deviations $\delta B$ for some ratios of radii $R/R_a$ are presented in the Table 1. The radius $R_a$ coincides with distance at active zone center to the edges of magnetic circuit teeth (see Fig. 1). The outer surface of technological reactor pipe touches these edges. The technological process performs in the inner volume limited by inner pipe surface, so the analysis was doing only to ratio value equal to $R/R_a=0.8$.

In Fig. 3 there are presented dependences of the magnetic flux density maximal relative deviation on relative radii in four pole and two pole inductors. We can see that two pole inductor allows obtain considerably more uniform magnetic field than four pole inductor. In the periphery of active zone the non-uniformity of magnetic field created by four pole inductor is more than 3 times large than non-uniformity of magnetic field created by two pole inductor.

**Comparison of magnetic properties of four- and two-pole inductors**

The same magnetic flux density in all volume of the active zone must be created in both cases. But modelling shows that inductance of any winding of two pole inductor with the same number of turns is 3.2 times more than inductance of four pole inductor. To explain such difference we can analyze the magnetic circuits of both inductors. In four pole inductor the magnetic field is created by the excitation windings which are winded on the upper and lower teeth of magnetic circuit. The upper winding creates the magnetomotive force $F$. We suppose that the positive scalar potential $V_m=F$ of this force is connected to the tooth edge. The scalar potential equal to zero is connected to the magnetic circuit basic cylinder. The negative potential of magnetomotive force created by lower winding, vice versa, is directed to the tooth edge, the positive potential is connected to magnetic circuit with magnetic potential equal to zero $V_{m}=0$. In this case the magnetic potential equal to zero will have central diameter $C$, which divides the upper and lower parts of magnetic circuit. We suppose that magnetic voltage is not fall in the magnetic circuit of inductor, i.e., the magnetic resistance of magnetic circuit is equal to zero.

The distribution of one phase magnetic field of four pole inductor is shown in Fig. 4. We can see that the most part of magnetic flux is distributed in the active zone. But some part of magnetic flux is distributed of the active zone limits. The magnetic flux density is the most near the surface of tooth on which is winded the winding of phase under consideration. Near the other teeth the magnetic flux density is lesser.

Distribution of magnetic field which is created by one phase in the active zone of two pole inductor is shown in the Fig. 5.

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Table 1. The intervals of magnetic flux density in the part of active zone limited by relative radius $R/R_a$.

<table>
<thead>
<tr>
<th>$R/R_a$</th>
<th>Four pole inductor $B_{max}$ $10^3$ T</th>
<th>$\delta B_{max}$</th>
<th>Two pole inductor $B_{max}$ $10^3$ T</th>
<th>$\delta B_{max}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>1.351</td>
<td>1.355</td>
<td>0.17</td>
<td>1.892</td>
</tr>
<tr>
<td>0.3</td>
<td>1.336</td>
<td>1.369</td>
<td>1.25</td>
<td>1.872</td>
</tr>
<tr>
<td>0.4</td>
<td>1.310</td>
<td>1.401</td>
<td>3.4</td>
<td>1.874</td>
</tr>
<tr>
<td>0.5</td>
<td>1.244</td>
<td>1.466</td>
<td>8.2</td>
<td>1.831</td>
</tr>
<tr>
<td>0.6</td>
<td>1.127</td>
<td>1.598</td>
<td>17.9</td>
<td>1.749</td>
</tr>
<tr>
<td>0.7</td>
<td>0.844</td>
<td>1.832</td>
<td>36.5</td>
<td>1.620</td>
</tr>
<tr>
<td>0.8</td>
<td>0.520</td>
<td>2.300</td>
<td>65.7</td>
<td>1.482</td>
</tr>
</tbody>
</table>

Fig. 2. View of the two-pole inductor cross-section.

Fig. 3. Dependence of magnetic flux density deviation $\delta B$ on relative radius $R/R_a$ in the two pole (2p) and four pole (4p) inductors.
The excitation windings are mounted this way that the plane which separate two windings of the same phase coincides with central diameter C in the cross-section. We suppose that scalar magnetic potential \( V_{nm} \) of the upper part of magnetic circuit is equal to magnetomotive force of the one winding \( V_{nm}=F=NI \) (I – winding current). Analogically we suppose that scalar magnetic potential \( V_{nm} \) of the lower part of magnetic circuit is equal to magnetomotive force of the one winding with sign minus: \( V_{nm}=-F \). The distribution of magnetic flux density in the upper half plane of the cross-section is shown in Fig. 5.

By comparing this distribution with field distribution in the four pole inductor we can see that in the two pole inductor the teeth of magnetic circuit which are near the central diameter create the complementary magnetic flux. This flux is stronger than flux created by upper tooth. The magnetic flux is the most near all teeth edges. By such distribution total magnetic flux created by all windings is more uniform in the two pole inductor than in four pole inductor.

\[ \text{Fig.5. Distribution of magnetic field in the upper half plane of the two pole inductor.} \]

There is possibility to increase the magnetic flux density \( B_0 \) created in the four pole inductor with the same apparent power. It is needed to enlarge the edges of teeth on which the windings are mounted. But the teeth edges of neighbouring phases can’t to touch one other. Therefore, the maximal width of tooth edge \( l_{pmax} \) must meet the requirement \( l_{pmax}<\left(\frac{\pi}{4}\right)R_s R_e \). The modelling was performed for three cases: 1) the tooth edge is not broadened, \( l_p=15 \text{ mm} \) (non-broaden tooth), 2) width of tooth edge is \( l_p=30 \text{ mm} \) (middle width), 3) width of tooth edge is \( l_{pmax}=60 \text{ mm} \) (large width). The modelling results are presented in the Table 2.

We can see that in the inductor with maximal width teeth magnetic flux density increases 1,45 times in comparison with non-broadened teeth inductor. In this case the apparent power which is needed to create the same magnetic flux density \( B_0 \) in the two and four pole inductors is the same. But in the case of teeth with large edges the non-uniformity of the field distribution increases about 1,5 times in comparison with non-broadened teeth. Therefore, the use of two pole inductor is desirable in this case, too.

Conclusions
1. The rotating magnetic field needed for technological purposes must be distributed uniformly in the large air gap.
2. In the technological rotating magnetic field inductors the concentrated windings mounted in large cavities of magnetic circuit are used.
3. To obtain the same magnetic flux density value in the active zone center of the two-pole inductor we can with the 1,3 times lesser apparent power and 3 times lesser non-uniformity than of the four pole inductor.
4. In four pole inductor the apparent power can be decreased if the edges of teeth are broadened, but in this case the non-uniformity of magnetic field distribution increases.

**Table 2.** Dependence of magnetic flux density deviation on the relative radius \( R/R_s \) for teeth with different edge width

<table>
<thead>
<tr>
<th>( R/R_s )</th>
<th>Non-broaden</th>
<th>Middle width</th>
<th>Large width</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>1.353</td>
<td>0.17</td>
<td>1.755</td>
</tr>
<tr>
<td>0.3</td>
<td>1.354</td>
<td>1.25</td>
<td>1.755</td>
</tr>
<tr>
<td>0.4</td>
<td>1.355</td>
<td>3.4</td>
<td>1.757</td>
</tr>
<tr>
<td>0.5</td>
<td>1.355</td>
<td>8.2</td>
<td>1.758</td>
</tr>
<tr>
<td>0.6</td>
<td>1.362</td>
<td>17.9</td>
<td>1.760</td>
</tr>
<tr>
<td>0.7</td>
<td>1.385</td>
<td>36.5</td>
<td>1.763</td>
</tr>
<tr>
<td>0.8</td>
<td>1.410</td>
<td>65.7</td>
<td>1.820</td>
</tr>
</tbody>
</table>

**Power characteristics of four- and two-pole inductors**

The more part of flux is distributed of the limits of active zone in the two-pole inductor. If we connect the windings of two- and four-pole inductors to the same voltage source in the active zone center of two-pole inductor the magnetic flux density \( B_0 \) was obtained 1.57 times lower than of the four-pole inductor. To obtain the same value of \( B_0 \) in the two pole inductor the voltage must be increased. The modelling was performed for voltage ratio of two \( U_2 \) and four \( U_4 \) pole inductors equal to \( U_2/U_4=1.57 \). The same value of \( B_0 \) was obtained for the current ratio of two \( I_2 \) and four \( I_4 \) pole inductors equal to \( I_2/I_4=0.49 \). Therefore, the apparent power \( S_2 \) which is operated in the two pole inductor is lesser than the apparent power \( S_4 \) of the four pole inductor: \( S_2=0.77S_4 \).