Effects of Materials on Temperature Distribution of a Compressor

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EFFECTS OF MATERIALS ON TEMPERATURE DISTRIBUTION OF A COMPRESSOR

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ABSTRACT

To evaluate the effects of the thermal properties of components on the overall temperature distribution of a compressor, a heat transfer model employing the lumped thermal conductance approach has been formulated. The model has been verified with extensive measurements and the overall discrepancy of less than 7% is obtained. The discrepancies in the prediction are mainly the results of assumptions made in assigning various heat transfer convection correlations, and simplification made in distributing the various components of the compressor into discrete parts. The model has been used to predict the effects on overall temperature distribution of a compressor when introducing new materials for some of the compressor components. Results are shown and discussed.

INTRODUCTION

Literature shows that limited research work has been carried out to provide heat transfer information on refrigeration compressors, let alone the temperature distribution of the whole compressors. Literature also showed that most of the heat transfer studies were mainly focused on convection heat transfer in the cylinder. However, in 1992 Padhy [1] employed the lumped capacitance model to predict temperature distributions of a rolling piston compressor. Using the same approach, Ooi and Ng [2] attempted to predict temperature distribution of a reciprocating compressors. The results showed that the lumped conductance approach is economical and efficient. The knowledge on the temperature of the compressor components plays an important role in designing a reliable and high efficiency compressor. With the advent in the materials technology, many new materials with good thermal and physical properties have been introduced. A good understanding of the temperature distribution of a compressor helps in selecting suitable materials with better thermal and physical properties for the compressor design.

This paper shows that the application of the heat transfer model [2] in an attempt to predict temperatures of the components in the compressor. This information is particularly important when assessing the performance and the reliability of the compressor by introducing newly available materials.

HEAT TRANSFER MODEL

In this study, the thermal conduction approach has been employed to study the temperature distribution of the complete reciprocating compressor. In the formulation [2], the complete hermetic refrigeration compressor unit has been divided into 46 discrete elements of simple shape, see Table 1. Each element is assumed to be at a uniform temperature. The lumped and isothermal elements are selected such that most of these elements conform with the natural geometric boundaries. The boundaries of the elements include solid parts, fluid flow paths and interfaces between solid parts and fluid. However, the actual parts in the compressor are usually made in intricate shapes which resulted in flow conditions which are too complicated to be modelled directly. Assumptions and simplifications have been introduced and these intricate parts have been made into simpler elements in order to allow the heat transfer
mechanisms to be modelled by available correlations. The simplified geometrical model of the compressor is shown in Figure 1.

The First Law of Thermodynamic and conservation of mass principle were applied, the working equations that modelled the heat transfer mechanisms were then formulated for each element.

Considering only the steady-state analysis, the total heat transfer to an element $i$ can be written as the sum of heat transfer other element either to or from the element, and the rate of heat generation $\dot{S}$ within the element, i.e.

$$\sum_{j \neq i} H_j (T_j - T_i) - \dot{S} = 0$$

where $H$ is heat transfer rate per unit temperature difference and is calculated from the actual geometry of the model, thermal properties of the elements and the convection heat transfer coefficients. More detail analysis could be found in reference [1&2].

In present study, the heat transfer in the cylinder is modelled separately by considering the convection heat transfer in the cylinder. The mechanical losses such as the heat generation and rubbing surfaces have been accounted for. The 46 elements yields a total of 46 simultaneous equations which could be readily solved using an aid of a digital computer. A computer program [2] has been developed in FORTRAN programming language to solve these equations by Gauss-Jordan method. The final result gives the temperatures of all the elements in the compressor.

RESULTS

In order to verify the prediction of the model, extensive temperature measurement of components in a refrigeration compressor has been carried out. The compressor was tested under ASHRAE operating conditions in an industrial standard compressor testing chamber. A total of 66 measurement points have been identified and collected. A typical comparison of the prediction and measurement is shown in Figure 2. Temperatures on moving components such as piston, connecting rod and others are not measured. A good agreement is obtained with an overall discrepancy of 6.2%. Major discrepancies are the consequence of using coarse elements and the simplifications made in employing convection heat transfer correlations. Measurement also reveals that there are significant variation in the shell temperature along the peripheral. It is however believed that the model can be used to assist parts and component design as well as to provide better insight of the heat transfer among the components.

The model has been used to study the effects of the thermal properties of some important components on the temperature distribution of the compressor. Figure 3 shows that as the thermal conductivity values of the cylinder block increases, the temperature of the components reduce, so as the inlet gas temperature. It is commonly known that as the inlet gas temperature reduces the volumetric efficiency of the compressor increases and hence the EER. Figure 4 shows that as the thermal conductivity of the cylinder head increases, the temperatures of the components drop slightly. The result also shows that higher temperature drops for components located near to the cylinder head than otherwise.

Figure 5 shows that the thermal conductivity of the inlet pipe has insignificant effects on the temperature of the components of the compressor. However, careful examination shows that as the thermal conductivity of the inlet pipe increases, the temperature of the gas on the suction side increases. It was caused by higher heat flow from the casing to the inlet pipe. Figure 6 shows that significant temperature drops may be expected as the thermal conductivity of
the compressor casing increases. The results also show that it is particular true for those components which were at higher temperatures than casing and have good thermal contact with the casing.

CONCLUSION

The comparison between the predictions and the measurement show that the model is generally in good agreement with the measurement. An overall accuracy of below 7% was obtained. Refinement on the model is possible by increasing the element number. Such a model is useful in understanding the inter-component heat transfer characteristics of an overall compressor. It is also a useful tool in assisting design engineers in selecting suitable materials for compressor components under thermal consideration.

REFERENCES

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4. Ng, B.C. Final Year Report, B.Eng, School of MPE, Nanyang Technological University, April, 1997
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Acknowledgement

The authors would like to thank Matsushita Refrigeration Industries (S) Pte Ltd for sharing the measurement facilities and other convenience during the course of work.

Figure 1 Simplified compressor parts that form elements in the heat transfer model
Table 1 Elements number and description

<table>
<thead>
<tr>
<th>Element No.</th>
<th>Element Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Baseplate</td>
</tr>
<tr>
<td>2</td>
<td>Connecting rod base</td>
</tr>
<tr>
<td>3</td>
<td>Piston</td>
</tr>
<tr>
<td>4</td>
<td>Sleeve</td>
</tr>
<tr>
<td>5</td>
<td>Cylinder block</td>
</tr>
<tr>
<td>6</td>
<td>Gas in cylinder</td>
</tr>
<tr>
<td>7</td>
<td>Separation plate</td>
</tr>
<tr>
<td>8</td>
<td>Cylinder head</td>
</tr>
<tr>
<td>9</td>
<td>Gas in discharge plenum</td>
</tr>
<tr>
<td>10</td>
<td>Gas in suction plenum</td>
</tr>
<tr>
<td>11</td>
<td>Gas in suction muffler tube</td>
</tr>
<tr>
<td>12</td>
<td>Suction muffler tube</td>
</tr>
<tr>
<td>13</td>
<td>Suction muffler</td>
</tr>
<tr>
<td>14</td>
<td>Gas in suction muffler</td>
</tr>
<tr>
<td>15</td>
<td>Connecting rod frame</td>
</tr>
<tr>
<td>16</td>
<td>Connecting rod top</td>
</tr>
<tr>
<td>17</td>
<td>Inlet pipe</td>
</tr>
<tr>
<td>18</td>
<td>Gas in outlet path</td>
</tr>
<tr>
<td>19</td>
<td>Gas in accumulator</td>
</tr>
<tr>
<td>20</td>
<td>Accumulator</td>
</tr>
<tr>
<td>21</td>
<td>Outlet pipe A</td>
</tr>
<tr>
<td>22</td>
<td>Outlet pipe B</td>
</tr>
<tr>
<td>23</td>
<td>Gas in outlet pipe A</td>
</tr>
<tr>
<td>24</td>
<td>Gas in outlet pipe B</td>
</tr>
<tr>
<td>25</td>
<td>Lubrication oil</td>
</tr>
<tr>
<td>26</td>
<td>Gas below base plate</td>
</tr>
<tr>
<td>27</td>
<td>Gas above base plate</td>
</tr>
<tr>
<td>28</td>
<td>Upper bearing</td>
</tr>
<tr>
<td>29</td>
<td>Lower bearing</td>
</tr>
<tr>
<td>30</td>
<td>Offset shaft</td>
</tr>
<tr>
<td>31</td>
<td>Offset cam</td>
</tr>
<tr>
<td>32</td>
<td>Bearing housing</td>
</tr>
<tr>
<td>33</td>
<td>Stator iron</td>
</tr>
<tr>
<td>34</td>
<td>Stator copper winding</td>
</tr>
<tr>
<td>35</td>
<td>Rotor</td>
</tr>
<tr>
<td>36</td>
<td>Shaft above upper bearing</td>
</tr>
<tr>
<td>37</td>
<td>Gas at rotor gap</td>
</tr>
<tr>
<td>38</td>
<td>Gas at channel outlet</td>
</tr>
<tr>
<td>39</td>
<td>Gas above stator</td>
</tr>
<tr>
<td>40</td>
<td>Shaft below upper bearing</td>
</tr>
<tr>
<td>41</td>
<td>Case above stator</td>
</tr>
<tr>
<td>42</td>
<td>Case attach to stator</td>
</tr>
<tr>
<td>43</td>
<td>Case above base plate</td>
</tr>
<tr>
<td>44</td>
<td>Case below base plate</td>
</tr>
<tr>
<td>45</td>
<td>Case attach to oil sump</td>
</tr>
<tr>
<td>46</td>
<td>Gas in inlet pipe</td>
</tr>
</tbody>
</table>

Figure 2 Comparison between the measured and them predicted temperatures of the components
Figure 3 Temperature distributions with various thermal conductivity values of the cylinder block.

Figure 4 Temperature distributions with various thermal conductivity values of the cylinder head.
Figure 5 Temperature distributions with various thermal conductivity values of the inlet pipe.

Figure 6 Temperature distributions with various thermal conductivity values of the casing.