Comparison of Component Mode Synthesis Method
with MSC-NASTRAN*

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The authors proposed a component mode synthesis method (CMS in
brief) and a multiple component mode synthesis method (MCMS in brief) in
the former papers on their study for analyzing the vibration of complex
mechanical structures.

In the present report, CPU time and accuracy of calculation by CMS
and MCMS are compared with those with MSC-NASTRAN concerning the natural
frequencies and the dynamic responses of two model structures. It has
been made clear that the vibration of these structures can be analyzed
by both CMS and MCMS with much less CPU time than by MSC-NASTRAN and
with the same accuracy.

Key Words: Vibration, Natural Mode, Natural Frequency, Dynamic Response,
Component Mode Synthesis Method, Finite Element Method,
MSC-NASTRAN

1. Introduction

The procedure of vibration analysis by the component mode synthesis method
(CMS) proposed by the authors is as follows. A structure is divided into some
components. The natural modes of all components are calculated. Using those
natural modes of each component as the generalized coordinates, the vibration of
the total structure is analyzed. The degree of freedom of the equation of
motion of the total structure by CMS is much lower than in the usual analysis with
the physical coordinates, so both CMS and the multiple component mode synthesis
method (MCMS) seem to be much better than the finite element method (FEM) with
regard to the necessary memory size of the computer.

In the present report, CPU time and accuracy of analysis by CMS and MCMS are
compared with those by the FEM system MSC-NASTRAN in calculation of the natural
frequencies and the dynamic responses of two model structures.

The basic procedures of CMS and MCMS are not explained in the present paper,
because they have already been explained in the former papers [13-17] by the authors.

2. Computer and Finite Element

MSC-NASTRAN is run with the model IBM
3081D, and both CMS and MCMS are with the
model HITAC M-200H. Since the calculating
speeds of both of these two computers are

10 MIPS, CPU time of calculation by CMS,
MCMS and by MSC-NASTRAN can be compared
directly with one another.

In calculation with MSC-NASTRAN, the
models are divided into quadrilateral
elements and/or triangular elements. In
calculation of CMS and MCMS, the models
are divided into triangular elements. It
seems that the difference in used finite
elements does not influence CPU time so
much.

3. First Model of Structure

First a model structure shown in
Fig.1 is analyzed. The thickness of all
parts of this structure is 4 mm. The
values of density, Young's modulus and
Poisson's ratio used in the calculation
are 7.86×10³ Kg/m³, 2.058×10^11 N/m², and
0.3 respectively.

![Fig.1 The first model](image)

F: Excited point
R: Measured point

3.1 MSC-NASTRAN

In analysis with MSC-NASTRAN, the
model is divided into quadrilateral finite
elements.

The natural frequencies and the
natural modes are obtained by a modified
Gevens method. And the dynamic responses
in the frequency domain are calculated by
using the technique of the modal analysis.
Two kinds of calculation are performed with MSC-NASTRAN. First, the eigenvalue calculation is done after reducing the degree of freedom of the total structure to only 10 by Guyan’s reduction method. Next, the eigenvalue calculation is done without reduction of the 1314 degree of freedom. The former way of calculation is often adopted when the structure of large degree of freedom is analyzed with MSC-NASTRAN.

3.2 CMS
Two kinds of divisions into components are tried in calculation by CMS. First, the model is divided into 9 components as shown in Fig.2. Changing the number of adopted natural modes of the components, the interface region and the total structure in three ways, the model is analyzed by CMS. These three ways are denoted as 1, 1' and 1'' in Table 1.

Second, the model is divided into 15 components as shown in Fig.3. Changing the number of adopted modes like the case of the first way, the model is analyzed. These three ways are denoted as 2, 2' and 2'' in Table 1.

Fig.4 The first way of division into the first divided components by CMS

![Fig.4](image)

3.3 MCMS
Two kinds of division into the first components are used in MCMS. First, the model is divided into 7 first components as shown in Fig.4, and these first components are divided into 18 second components as shown in Fig.5. Second, the model is divided into 5 first components as shown in Fig.6, and these components are divided into 18 second ones as shown in Fig.7. The values of parameters of each case of MCMS are shown in Table 2.

Fig.5 The way of division into the second divided components by MCMS

![Fig.5](image)

Table 1 CPU time by CMS

<table>
<thead>
<tr>
<th>Division</th>
<th>1</th>
<th>1'</th>
<th>1''</th>
<th>2</th>
<th>2'</th>
<th>2''</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of components</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Number of adopted modes of each component</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Number of adopted modes of interface region</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Number of demanded modes</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>CPU time for getting natural frequencies and natural mode (sec.)</td>
<td>18.0</td>
<td>16.1</td>
<td>17.8</td>
<td>18.7</td>
<td>20.3</td>
<td>16.5</td>
</tr>
<tr>
<td>CPU time for making forced vibration response (sec.)</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig.6 The second way of division into the first divided components by MCMS

![Fig.6](image)

Table 2 CPU time by MCMS

<table>
<thead>
<tr>
<th>Division</th>
<th>3</th>
<th>3'</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of second grade components</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Number of first grade components</td>
<td>7</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Number of adopted modes of each component</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Number of adopted modes of interface region</td>
<td>20</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Number of demanded modes</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>CPU time for getting natural frequencies and natural mode (sec.)</td>
<td>18.7</td>
<td>16.1</td>
<td>32.2</td>
</tr>
<tr>
<td>CPU time for making forced vibration response (sec.)</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig.7 The second way of division into components by CMS

![Fig.7](image)
3.4 Comparison of CPU time

CPU time of calculation with MSC-NASTRAN is shown in Table 3. It takes 121.1 seconds to calculate 10 natural modes, 10 natural frequencies and the dynamic responses from 50 Hz to 800 Hz in each 0.5 Hz in case of using the dynamic reduction. It takes 255 seconds with MSC-NASTRAN when the dynamic reduction is not adopted. On the other hand, it takes only 20 seconds by both CMS and MCMS. In the case of MCMS, it takes 34 seconds because the symmetry of the structure is not considered in calculation of MCMS. It takes only 17 seconds when this symmetry is considered. Thus, it takes much less CPU time to analyze the vibration by CMS and MCMS whose programs made by the authors are much cruder than that of MSC-NASTRAN. Since the level of the authors' programming technique is not high, their programs can be improved much. If they are revised by the specialists of programming, CPU time of calculation by CMS and MCMS will be much shorter than the authors' calculation. MCMS in the case of 3 and 3' needs 65% of the memory size of CMS.

Table 3 CPU time by MSC-NASTRAN

<table>
<thead>
<tr>
<th>N A S T R A N</th>
<th>CPU time in case of 10 degree of freedom</th>
<th>121.1 sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU time in case of 100 degree of freedom</td>
<td>256.9 sec.</td>
<td></td>
</tr>
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</table>

3.5 Natural frequency and response

Natural frequencies obtained by CMS and MCMS and with MSC-NASTRAN are shown in Table 4. The results by CMS and MCMS agree well with those with MSC-NASTRAN. Only when the number of adopted modes is 10, the 9th and the 10th natural frequencies by CMS and MCMS become a little larger. It is clear that the natural frequencies are calculated by CMS and MCMS as accurately as with MSC-NASTRAN. The dynamic responses at the points R and F are shown in Fig.7 and Fig.8 respectively. All the results agree well with one another.

Table 4 Natural frequency of the first model

<table>
<thead>
<tr>
<th>N A S T R A N</th>
<th>C M S</th>
<th>MCMS(double)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIVISION</td>
<td>1</td>
<td>1*</td>
</tr>
<tr>
<td>2</td>
<td>186</td>
<td>163</td>
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<tr>
<td>3</td>
<td>310</td>
<td>310</td>
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<td>4</td>
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<td>5</td>
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<td>6</td>
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<td>8</td>
<td>715</td>
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<tr>
<td>9</td>
<td>722</td>
<td>720</td>
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<tr>
<td>10</td>
<td>777</td>
<td>780</td>
</tr>
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</table>

4. The Second Model

As a second specimen, the vibration of a cylinder block model with 6 cylinders as shown in Fig.9 is analyzed. The thicknesses of all parts are 5 mm. The model is divided into finite elements with 684 nodal points. The values of density, Young's modulus and Poisson's ratio are 7.96×10⁻⁶ Kg/mm², 9.8×10⁴ N/mm² and 0.3 respectively. The boundary condition is free-free.
4.1 Calculation with MSC-NASTRAN

In analysis with MSC-NASTRAN, the model is divided into 626 quadrilateral elements and 112 triangular elements. As the algorithms of the eigenvalue calculation, a modified givens method and the inverse power method are used.

In calculation using the modified givens method, the degree of freedom of the structure is reduced to 16 and 75. In calculation using the inverse power method, only three natural frequencies and three natural modes are obtained. It is expected to take more than 100 minutes to calculate 10 natural frequencies.

4.2 Calculation by MCMS

When the vibration of the second model is analyzed by MCMS, it is divided into 4 first components as shown in Fig.10. Next, these components are divided into the second ones as shown in Fig.11 and Fig.12. The numbers of adopted natural modes of all components and the interface regions are all 40. This model is not analyzed by CMS because it needs a larger memory size of computer than the permitted memory size in the authors' computer center.

4.3 Comparison of CPU time

CPU times of calculations with MSC-NASTRAN are shown in Table 6, and those by MCMS are in Table 5.

The second model is analyzed much faster by MCMS than with MSC-NASTRAN.

4.4 Comparison of natural frequency

The natural frequencies obtained by MCMS and with MSC-NASTRAN are shown in Table 7. The difference between the results with MSC-NASTRAN and those by MCMS is a little larger than that in Table 4. The reasons for this difference seem to be in the difference of the kind of finite elements.

5. Conclusions

The vibration of two kinds of models is analyzed by CMS and MCMS and with MSC-NASTRAN. CPU time of these calculations and the accuracy of the results are compared with one another.

It is clear that the vibration of structures can be analyzed by CMS and MCMS much faster than with MSC-NASTRAN, and all the results are accurate.
Table 7 Natural frequency of the second model

<table>
<thead>
<tr>
<th>Order</th>
<th>NASTRAN</th>
<th>W</th>
<th>C</th>
<th>M</th>
<th>S</th>
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<tr>
<td>1</td>
<td>221</td>
<td>238</td>
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<tr>
<td>2</td>
<td>256</td>
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<td>3</td>
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<td>4</td>
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<td>6</td>
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<td>10</td>
<td>369</td>
<td>394</td>
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References