2000

Vibration Characteristic Analysis of Welding Point Based on the Loss Factor of Rotary Compressor

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ABSTRACT

The overall aim of this paper is to determine optimum position of welding point and number of spot welding in the structure to obtain good characteristics of vibration and noise. For this purpose, two kinds of loss factor were adopted. One is loss factor of sub structure, another is structural loss factor based on the complex welded or assembled structure. Using these two parameters, it is possible to derive the coupling loss factor which represent characteristic condition of welding point behavior of vibration. Coupling loss factor of welded condition in complex structure has been derived by using Statistical Energy Analysis (SEA). The derived equation for a coupling loss factor has been simplified on the assumption of weak coupling between two welding sub structures.

Finally it shows some experimental results based on the proposed equation.

1. INTRODUCTION

Compressor structures can be considered as being composed of several sub structures such as plate, shells, cylinder, bottom cap, tri plate, etc. For these complex structures, it is very difficult to decide the good condition of welding position or number of spot welding including clearance problem. Also it is difficult to get an estimation equation of complex structure theoretical only.

Recently, attempts have been made to predict to structural loss factor of a simple structure. In this case, Structures composed of sub structures those each characteristics of sub structures vibration are known. All attempts theories are based on the Statistical Energy Analysis (SEA). A very important role of SEA is energy transferred between sub structures and reduced radiating noise. This Role of SEA being used to estimate vibration of the associated loss factor. Vibrational energy balance calculation were studied by D.A.Bies(1), H.G.Davis (2)and R.H.Ryon(3). Ungar and Carnell(4) suggested a practical method for evaluating the damping in built-up structure. But in these methods, estimating the loss factor of joint between sub systems is difficult. J.C.Sun and E.J.Richard(5) shows a formula for estimating total loss factors of a structures which derived from the linear steady state energy balancing equation. The formula was simplified by assuming by assuming that sub structures are coupled weakly. This assumption enabled the total loss factors of the structure to be calculated without the need for the solution of the linear equation. But this equation also using the
theoretical coupling loss factor and sub structural loss factor including modal density. In case of compressor have complex structures, so it is very difficult to calculate the coupling loss factor between sub structure due to the variety of welding or jointing condition. In this reason, it is necessary to evaluate coupling loss factor which means the parameter of welding or jointing condition. Using power balance equation, modal density and reciprocity, it is possible to derive the equation of coupling loss factor which represent the welding or jointing condition, between two sub structures. This method is not based on the prediction tool but the estimation tool of assembled sub structure from experiments. Also optimization obtained by several experiment between two sub structurals assembling by welding or jointing. For using sub structural tests, it is possible to predict the total structural vibration and noise characteristics of compressor.

2. THEORETICAL ANALYSIS

For a complex structure consisting of N sub structures vibrating in steady state, power balance equation can be written [1],

$$P_i = \omega \cdot E_i (\eta_i + \sum_{j=1}^{n} \eta_{ij}) - \omega \sum_{j=1, j\neq i}^{n} E_j \eta_j$$  \[1\]

Where $P_i$ in the time averaged power input to the i'th sub structure from applied force, $\eta_i$ is the internal loss factor of the i'th sub structure and $\eta_{ij}$ is the coupling loss factor from i to j sub structures. $E_i$ is the energy store in the i'th sub structure and $\omega$ (rad/sec) is the center frequency of the frequency band considered. Using reciprocity relation, it is possible to deduce the relation between $\eta_{ij}$ and $\eta_{ji}$.

$$n_i \cdot \eta_{ij} = n_j \cdot \eta_{ji}$$  \[2\]

where $n_i$ and $n_j$ are modal densities of i and j sub structures. Equation[1] can be simplified by assuming that only one of the sub structures is directly excited by an external force and assuming only one point power input. In this case, the set of equation[1] reduced to equation[3].

$$\begin{pmatrix}
(\eta_i + \sum_{j=1, j\neq i}^{n} \eta_{ij}) \cdot n_1 & -\eta_{12} \cdot n_1 & \cdots & -\eta_{1n} \cdot n_1 \\
-\eta_{21} \cdot n_2 & (\eta_2 + \sum_{j=1, j\neq 2}^{n} \eta_{2j}) \cdot n_2 & \cdots & -\eta_{2n} \cdot n_2 \\
\vdots & \vdots & \ddots & \vdots \\
-\eta_{n1} \cdot n_n & -\eta_{n1} \cdot n_n & \cdots & (\eta_n + \sum_{j=1, j\neq n}^{n} \eta_{nj}) \cdot n_n
\end{pmatrix}
\begin{pmatrix}
E_1 / n_1 \\
E_2 / n_2 \\
\vdots \\
E_n / n_n
\end{pmatrix}
= \begin{pmatrix}
P_1 \\
0 \\
\vdots \\
0
\end{pmatrix}$$  \[3\]

and it is possible to write two parts of equation. One is power relation term and another is the rest equation from equation[3].

$$P_1 = \omega \left( \phi_{11} E_1 - \phi_{12} E_2 - \phi_{13} E_3 - \cdots - \phi_{1n} E_n \right)$$
\[
\begin{pmatrix}
\phi_{22} & -\phi_{23} & \cdots & -\phi_{2n} \\
-\phi_{32} & \phi_{33} & \cdots & -\phi_{3n} \\
\vdots & \vdots & \ddots & \vdots \\
-\phi_{n2} & -\phi_{n3} & \cdots & \phi_{nn}
\end{pmatrix}
\begin{pmatrix}
E_2 / E_1 \\
E_3 / E_1 \\
\vdots \\
E_n / E_1
\end{pmatrix}
= 
\begin{pmatrix}
\phi_{21} \\
\phi_{31} \\
\vdots \\
\phi_{n1}
\end{pmatrix}
\]

where 
\[
\phi_{ij} = \eta_i + \sum_{j=1, j \neq i}^{n} \eta_{ij}, \quad \phi_{ij} = n_{ij} \eta_{ij}, \quad n_{ij} = \begin{cases}
\frac{n_j}{n_i}, & i \neq j \\
1, & i = j
\end{cases}
\]

From lower part of equation[4], diagonal term of matrix mean the total loss factor. This means that the coupling between sub structures is neglected and only energy transfer occurred directly from excited sub structure is considered. Lower part of Equation[4] reduced to

\[
\begin{pmatrix}
\phi_{22} & 0 & \cdots & 0 \\
0 & \phi_{33} & \cdots & 0 \\
\vdots & \vdots & \ddots & \vdots \\
0 & 0 & \cdots & \phi_{nn}
\end{pmatrix}
\begin{pmatrix}
E_2 / E_1 \\
E_3 / E_1 \\
\vdots \\
E_n / E_1
\end{pmatrix}
= 
\begin{pmatrix}
\phi_{21} \\
\phi_{31} \\
\vdots \\
\phi_{n1}
\end{pmatrix}
\]

From above equation and power balance equation of sub structure i, it is possible to obtained relationship between internal loss factor and total loss factor of i sub structure.

\[
\eta_{\text{total}} = \eta_i + \sum_{j=1, j \neq i}^{n} \frac{n_j \cdot \eta_{ji} \cdot \eta_i}{(\eta_{ji} + \eta_j)}
\]

This paper assumed weak coupling over all the welding and joint structure. So it is possible to apply Tayler expansion to equation[6] and neglect the high order item and then obtained a new equation which consist of total loss factor and internal loss factor.

\[
\eta_{\text{Total}} - \eta_{\text{internal}} = \sum \frac{n_j}{n_i} \cdot \eta_{ji} 
\]

Combination of equation[2] and [7], coupling loss factor which means welding or joint characteristics of vibration obtained from total loss factor, internal loss factor and modal density of each sub structure. Total loss factor is the same meaning of structural loss factor. In this point of view, Total loss factor means the assembled structure loss factor.

Equation[7] means that the total loss factor due to the welding or jointing in the sub structure is the same that the sum of internal loss factor of substructure and transfer energy loss due to the welding or jointing. Therefore it is possible to find the vibration characteristic of welding or jointing using transfer energy loss(coupling loss factor) in equation[7].
3. EXPERIMENTS

There are many methods to evaluate the loss factor of the structure. This paper adopted reverberation time delaying method. Reverberation time was calculated using Schrader theory and calculated the loss factor.

From the equation[7], considering 2 substructures structure. We need loss factor (internal loss factor) of individual sub structure and modal density of individual sub structure. So internal loss factor of individual sub structure were measured by using reverberation method before assembled. In this case, plane averaged reverberation time were obtained from multi point measurement of one sub structure. All the loss factor calculation carried out with reference [6]. Modal densities of sub structure were calculated from reference[4] or calculated using commercial CAE software, such as ANSYS, IDEAS. Reference[4] deal with modal density equation in various shape but real structure was more complicated and very difficult to find the value of modal density. In this case, 3 dimensional CAE software is very helpful to calculate the modal density of substructure. Or, it is possible to measuring the modal density of substructure with natural frequency distribution using impulse response function of vibration.

Also, total loss factor which were assembled by using welding or jointing, were measured by using reverberation method after assembled. To get a good results, it is desirable to obtained plane averaged loss factor.

In the case of rotary compressor, clearance combination between bottom cap and shell was very sensitive in noise and vibration of compressor. To deal with this problem, sample was manufactured at several conditions such as table.1.

<table>
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<tr>
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<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
<th>#5</th>
</tr>
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<tbody>
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<td>CYL</td>
<td>121.5025</td>
<td>121.5025</td>
<td>121.5000</td>
<td>121.4900</td>
<td>121.5000</td>
</tr>
<tr>
<td>B/CAP</td>
<td>121.2500</td>
<td>121.2500</td>
<td>121.2450</td>
<td>121.2375</td>
<td>121.2450</td>
</tr>
</tbody>
</table>

Table.1. Specification of test Samples

This experiment is to know the best clearance condition between shell, cylinder and bottom cap. The results of Table.1 specification show at Fig.1. X axis means the frequency and Y axis means the non coupling loss factor multiplied modal density ratio. In this reason, coupling loss factor is bigger than the real estimation value. Black circle is conventional type condition. During this test, we select red square condition and manufactured compressor with No 2 specification. The noise test results shows at Fig.2. Comparing old types and new one, new type is lower than old one at high frequency range and a little bit higher at the lower frequency range. This trend is very similar to obtaining the coupling loss factor experiments. Fig.4 and Fig.5 shows the test jig which decide optimum spot welding position between shell and cylinder. In this case have 2 dimensional variables. Fig.6 and Fig.7 show the experimental results. A,B,C means the vertical position of cylinder and Fig.6 and Fig.7 is the difference position of circumference in cylinder.

4. CONCLUSION

Using Above equation, estimation of welding or jointing characteristic of vibration was possible. It is prove that estimation value and Set noise have a closer relationship.
with respect to the set noise and vibration.

Reference

Fig. 1 Coupling loss factor test result of Table 1

Fig. 2. Compressor noise improvement
Fig. 3 Picture of Sample for coupling loss factor

Fig. 4. Test Jig of cylinder and shell

Fig. 5 Top view of test jig

Fig. 6. Coupling loss factor of case A

Fig. 7. Coupling loss factor of case B