
Ken TAKENOUCHI¹, Junichi TAKADA¹, Hiroo IKEGAMI¹ and Masaki SHIRATORI²

¹Corporate Research & Development, Toyo Seikan Group; 22-4 Okazawa-cho, Hodogaya-ku, Yokohama, 240-0062, Japan
²Yokohama National University; 79-5 Tokiwadai, Hodogaya-ku, Yokohama, 240-8501, Japan

Two methods for evaluating tapping inspection aptitude of retort sterilized can body, Air Injection Method and FE Simulation Method, were developed. Optimum can bottom shape was investigated by the Statistical Design Support System combined with the FE Simulation Method. Depth of annular bead and bottom curvature were found to be dominant for each characteristic value. Evaluation results of the characteristic values for these optimum shapes by the FE Simulation Method and the Air Injection Method indicated qualitative consistency with those expected by optimization, and showed the improvement of tapping inspection aptitude of retort sterilized can body, as expected.

Keywords: Can, Tapping Inspection, Retort Sterilization, Optimization, Statistical Design Support System

1. Introduction.

Retort sterilization and tapping inspection are means for the assurance of canned products. During the retort sterilization process, canned products placed in pressure vessel are sterilized by high temperature steam. The temperature of heating steam, which is determined by the contents of canned products, is mostly kept in the range of 120-130°C. Can internal pressure rises with thermal expansion of contents. Although the relaxation techniques for can internal pressure behavior, such as air pressurized retort method, have been developed, it is required for can body to stand the rise of can internal pressure during retort sterilization process.

On the other hand, tapping inspection is a method to detect a change of can internal pressure, which is caused by leakage or spoilage, by detecting the change of the vibration frequency of can bottom. As shown in Fig. 1, the vibration is excited by electromagnetic pulse on the flat circular part of can bottom. The frequency of can bottom vibration is analyzed by Data Extended FFT[1]. Can internal pressure is determined by the tapping frequency with previously measured tapping calibration curve, a relationship between the can internal pressure and the tapping frequency. Tapping inspection is based on the fact that the fundamental vibration frequency for circular plate part of can bottom indicates the can internal pressure. Therefore, high frequency sensitivity to the can internal pressure, which corresponds to the formation of circular flat part, is required for the can body.

However, these two requirements, high pressure resistance and high sensitivity, are in the relation of trade-off each other. For the lightweight can body, which has recently been required from economical and ecological point of view, it is important issue to meet these two requirements at the same time.

Moreover, on designing of new can body, it is necessary to predict a change of tapping frequency caused by can body deformation during the retort sterilization process. Tapping inspection aptitude after retort sterilization process for a proposed design has long been evaluated by experimental measurement of trial manufactures. However, as this approach is time and money consuming, it is difficult to extract an optimum design by testing many trial manufactures.

Recently, optimization method combined with computer simulation has been utilized extensively. Some studies on design optimization for improving acoustic and vibrational characteristics were reported[2,3].

In this study, two methods for evaluating the tapping inspection aptitude after retort sterilization process were developed. Furthermore, optimum can bottom shape was investigated with Statistical Design Support System. In order to verify the proposed approach, characteristic values of the optimum shape were evaluated.


2.1 Air Injection Method. A test method for evaluating the tapping inspection aptitude of manufactured can body after retort sterilization process, named Air Injection Method (AIM), was developed. A test can body is connected with a pressure control equipment through a plug installed on a lid, which is the opposite side of vibration part by tapping inspection. On the first stage, can internal pressure is applied up to set pressure and kept for 3 minutes to induce can body deformation corresponding to the deformation occurred during retort sterilization process. On the second stage, tapping frequency of pressure-released can body is measured with controlling can internal pressure that corresponds to the initial can internal pressure. The above-mentioned procedure is conducted for several applied pressure levels. Relationships between the initial can internal pressure and the tapping frequency for each applied pressure indicate the tapping magnitude of each applied pressure level. For the lightweight can body, it is necessary to predict a change of tapping frequency caused by can body deformation during the retort sterilization process.
150kPa, 200kPa, 250kPa, 300kPa, 350kPa. The can bottom
AIM were conducted for the applied pressure level of 0kPa,
can body. Hence, the AIM can be adopted in evaluating the
been adopted in evaluating the buckling pressure resistance of
process. This method is based on the fact that the deformation of
analysis in consideration of large deflection. The
(FESM) was developed to evaluate the tapping inspection
2.2 FE Simulation Method. FE Simulation Method
(FESM) was developed to evaluate the tapping inspection
aptitude of the retrofit sterilized can body without any trial
manufactures. On the first stage, deformation due to applied
pressure for a FE model of proposed can body design is
calculated by elasto-plastic analysis. On the second stage, the
relationship between natural frequency of the deformed model
and initial can internal pressure is calculated by eigenvalue
analysis in consideration of large deflection. The
above-mentioned procedure is conducted in several applied
pressure levels. The relationship between the initial can
internal pressure and the natural frequency (which is called
“natural frequency curve” hereafter) for each applied pressure
indicate the tapping inspection aptitude of proposed can body

Table 1 Assignment of design factors to L27 orthogonal array and the resulting
characteristic values obtained by FE Simulation Method.

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inspection aptitude of test can body after pressurization
process.

This method is based on the fact that the deformation of
can body during retort sterilization process occurs only by the
effect of can internal pressure. Pressure application test has
been adopted in evaluating the buckling pressure resistance of
can body. Hence, the AIM can be adopted in evaluating the
pressure resistance in terms of tapping inspection aptitude.

Although the AIM can save the troublesome of retort sterilization process, it still requires to make trial manufactures of proposed can body design. It means that this method is still
time and money consuming, and that the characteristics of proposed design cannot be evaluated until forming process is established.

In this study, the evaluations of proposed design by the
AIM were conducted for the applied pressure level of 0kPa,
150kPa, 200kPa, 250kPa, 300kPa, 350kPa. The can bottom
was buckled over 400kPa. The tapping frequency was measured by Tapping Detector PED-M114 (Toyo Seikan Kaisha, Ltd.).

2.2 FE Simulation Method. FE Simulation Method
(FESM) was developed to evaluate the tapping inspection
aptitude of the retrofit sterilized can body without any trial
manufactures. On the first stage, deformation due to applied
pressure for a FE model of proposed can body design is
calculated by elasto-plastic analysis. On the second stage, the
relationship between natural frequency of the deformed model
and initial can internal pressure is calculated by eigenvalue
analysis in consideration of large deflection. The
above-mentioned procedure is conducted in several applied
pressure levels. The relationship between the initial can
internal pressure and the natural frequency (which is called
“natural frequency curve” hereafter) for each applied pressure
indicate the tapping inspection aptitude of proposed can body

![Cross sectional view of can bottom](image-url)
design after pressurization process.

A commercially available FE Analysis software Marc (MSC. Software Ltd.) was used for the analysis. The FE model consisted of about 300 axisymmetric shell elements.

The tapping inspection aptitude of conventional can body was evaluated by both methods. The shape of conventional can body is shown in Fig. 2a). It was made of 0.260mm thick electrolytic chromium coated steel plate with laminated polyester film. The laminated film layer was neglected in the FESM because of its small Young’s modulus. A good consistency between the results of both methods, as shown in Fig. 4a) and 4b), means that the FESM was able to evaluate the tapping inspection aptitude as well as the AIM.


Optimum can bottom shape for the tapping inspection aptitude after retort sterilization process was investigated by Statistical Design Support System (SDSS) combined with the FESM. SDSS is a kind of response surface method, in which a series of FE analyses are carried out under the planning of the design of experiments (5).

Test can bottom shape is shown in Fig. 2b). Following six dimensions were selected as design factors;

X1: Bead Depth,
X2: Bead Diameter,
X3: Circular Part Diameter,
X4: Bottom Curvature,
X5: Bead Ridge Radius,
X6: Edge Radius.

Thickness, material property and basic dimensions shown in Fig. 2a) were the same as those of conventional can body.

Following three characteristic values, corresponding to tapping inspection aptitude after retort sterilization process, were specified.

Y1: Sensitivity. Slope of natural frequency curve. In the tapping inspection system, accuracy of pressure measurement depends on accuracy of the tapping frequency measurement and the sensitivity. Higher sensitivity leads to higher accuracy of pressure measurement. In this study, difference between natural frequency for initial pressure -70kPa and that for 0kPa of applied pressure level 0kPa, corresponding to the curve characterized by the open circles in Fig. 4, was defined as the sensitivity.

Y2: Pressure Resistance. Maximum applied pressure at which natural frequency curve is unchanged from that of applied pressure level 0kPa. Plastic deformation induced by applied pressure over elastic limit gives significant change to the natural frequency curve. Pressure resistance, which indicates elastic limit, depends on material property, thickness, and initial bottom shape.

Y3: Inversion Resistance. Maximum applied pressure at which inversion point does not exist in the operation field (vacuum area in this study). The natural frequency curve has symmetry structure with respect to the inversion point, which corresponds to bottom curvature induced by the initial pressure. Monotonicity or nonexistence of inversion point in the operation field is required to determine can internal pressure from tapping frequency. The inversion resistance should be equal to or greater than the pressure resistance.

Optimum shapes were determined according to the rule that Y1 should be maximum under the constraint that Y2 and Y3 were greater than each critical value. By allocating each design factor to L27 orthogonal table, 27 shapes were analyzed by the FESM. The assignment of the design factors to the L27 orthogonal array was shown in Table 1, with the characteristic values obtained from the analyses. The response surface for each characteristic value was determined as follows;

\[
Y_1 = -21317.23 - 1235.00X_1 + 416.67X_1^2 - 1393.75X_4 - 125.00X_1X_4,
\]
\[
Y_2 = 181.25 + 20.83X_1 + 156.25X_1^2 - 112.67X_4 - 1573.96X_1X_4 + 1002.08X_1^2X_4^2,
\]
\[
Y_3 = 10825.48 - 933.33X_1 + 567.71X_1^2 - 735.19X_2 + 18.52X_2^2 - 315.33X_3 + 8.00X_3^2 - 1258.89X_3^2 + 38.22X_5 - 70.83X_5^2 + 40.28X_6 - 122.78X_6^2 + 3223.33X_1X_4 - 1953.33X_1X_4^2 - 79.012X_2^2 + 30.72X_3 - 125.00X_1X_4 - 79.012X_2^2 + 30.72X_3 - 125.00X_1X_4 + 1002.08X_1^2X_4^2,
\]

4. Results and discussions.

4.1 Optimum shape. Effective ratios of the design factors for the characteristic values, obtained from the analysis of variance, are summarized in Table 2. It was found from the analysis of variance that X1, depth of annular bead, and X4, bottom curvature, were dominant for each characteristic value, as shown in Table 2. The bottom shape was formed by press forming with forming tools shown in Fig. 2c). The dimensions X2, X3, X5, and X6 were determined by the shape of the forming tools, whereas X1 and X4 were determined by relative position of the tools at bottom-dead point of press machine. The result of the analysis of variance has shown that the characteristic values can be controlled without preparing forming tools of various dimensions. Throughout this study, using the same tool set, only the design factors X1 and X4 can be changed by controlling relative positions of the forming tools.

Fig. 3 shows a contour map of the characteristic value Y1, Y2, and Y3 for X1 and X4. In Fig. 3, Y1 increases towards lower left from upper right, Y2 towards upper left from lower right, and Y3 towards upper right from middle left, respectively. Hence, the constraints about Y2 and Y3 forms wedge-shaped area that spread from a crest at lower left,
where $Y_1$ tends to be maximum.

Three optimum shapes, indicated by the symbols in Fig. 3, were determined by setting different critical values of $Y_2$ and $Y_3$. Each critical value of $Y_3$ was set to be equal to that of $Y_2$. Optimum shape A is for $Y_2$ and $Y_3=200\text{ kPa}$, optimum shape B for $Y_2$ and $Y_3=250\text{ kPa}$, and optimum shape C for $Y_2$ and $Y_3=300\text{ kPa}$, respectively. Optimum dimensions and expected characteristic values are summarized in Table 3. From optimum shape A to C, expected value of $Y_1$ decreased as critical value of $Y_2$ and $Y_3$ increases.

4.2 Verification test. In order to verify the above results, the characteristic values of these optimum shapes were evaluated by the FESM, and further, by the AIM. Trial manufactures of optimum shapes were made from the same original plate for conventional can body. The results of the FESM and the AIM are shown in Fig. 4 and Table 3.

The result of the FESM showed decrease of $Y_1$, with increase of $Y_2$ and $Y_3$, starting from optimum shape A to C. This result was qualitatively consistent with that expected by SDSS. For Optimum shape A, the sensitivity $Y_1$ of the FESM, 766 Hz, was higher than that expected by the SDSS, 602 Hz, the pressure resistance $Y_2$, 200 kPa, was unchanged, and the inversion resistance $Y_3$, 250 kPa, was higher than the SDSS critical value, 200 kPa. For optimum shape B and C, the characteristic values obtained from the FESM also indicated higher sensitivity and higher inversion resistance than those expected from the SDSS. This means that the present response surface is not accurate enough to express the real response. Response surfaces that have higher order structure of design factor or further optimization in narrower area of design factors will lead more precise result.

The result of the AIM also showed decrease of $Y_1$, with increase of $Y_2$ and $Y_3$ from optimum shape A to C, which was again qualitatively consistent with the results expected by SDSS. For optimum shape A, the sensitivity $Y_1$ of the AIM, 520 Hz, was lower than that expected by the SDSS, 602 Hz, the pressure resistance $Y_2$, 200 kPa, was unchanged, and the inversion resistance $Y_3$, 350 kPa, was higher than the SDSS critical value, 200 kPa. For optimum shape B and C, the

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<td>X1</td>
<td>X2 (fixed)</td>
<td>X3 (fixed)</td>
<td>X4</td>
</tr>
<tr>
<td>Opt. A</td>
<td>0.38</td>
<td>400</td>
<td>0.17</td>
</tr>
<tr>
<td>Opt. B</td>
<td>0.74</td>
<td>340</td>
<td>0.28</td>
</tr>
<tr>
<td>Opt. C</td>
<td>0.98</td>
<td>340</td>
<td>0.35</td>
</tr>
<tr>
<td>Conv.</td>
<td>0.00</td>
<td>400</td>
<td>0.30</td>
</tr>
</tbody>
</table>
Fig. 4 Evaluation result of tapping inspection aptitude. Symbols of each figure indicate the applied pressure of 0kPa, 150kPa, 200kPa, 250kPa, 300kPa, 350kPa, respectively.
characteristic values obtained from the AIM also indicated lower sensitivity, higher pressure resistance and higher inversion resistance than those expected from the SDSS. The result of the AIM was affected by the accuracy of design parameters of the trial manufacture, which will be improved by refinement of the design of forming tool. Change of thickness and material property caused by the deformation process, as well as the deviation of dimension, should be considered for further precise optimization.

In practical operation of the tapping inspection system, can internal pressure has been determined by accuracy of 1kPa from the measurement of tapping frequency which has resolution of 10Hz. Hence, the slope of tapping calibration curve should be 10Hz/kPa, which corresponds to the sensitivity Y1 = 700Hz. The sensitivity of the conventional shape, which indicated in Table 3, was greater than the appropriate value. On the other hand, reinforcement of pressure resistance and inversion resistance have been required to bear the can internal pressure rise in the retort sterilization process, which has some fluctuations over the cans in the retort vessel due to deviation of temperature or contents volume of each can, etc. The result of FESM showed that the optimum shape A indicated the reinforcement of Y2 and Y3 with allowable sacrifice of Y1 from the conventional shape. Although the result of the AIM indicated the sensitivity Y1 smaller than the appropriate value, further optimum shape will be obtained by adjusting the critical values of Y2 and Y3 because the results of the AIM were qualitatively consistent with those expected by SDSS. The relationship between the tapping inspection aptitude and the design factors obtained in this study is difficult to acquire by conventional design procedure because it requires many experiments of trial manufactures.

5. Conclusion.

Two methods for evaluating tapping inspection aptitude of retort sterilized can body, the Air Injection Method (AIM) and the FE Simulation Method (FESM), were developed. The AIM simulates the deformation during retort sterilization process by injecting air into the trial manufacture of can body, while the FESM simulates it by elasto-plastic analysis. Optimum can bottom shape for the tapping inspection aptitude after retort process was investigated by the Statistical Design Support System (SDSS) combined with the FESM. Three characteristic values, sensitivity, pressure resistance, and inversion resistance were specified. Response surfaces of six design factors for these characteristic values were derived from SDSS. The depth of annular bead and the bottom curvature were found to be dominant for each characteristic value. Three optimum shapes were derived by setting three different levels of critical values of pressure resistance and inversion resistance.

The characteristic values of these optimum shapes were evaluated by the FESM, and further, by the AIM. The results for the optimum shapes indicated qualitative consistency with those expected from optimization, and indicated the possibility for the improvement of tapping inspection aptitude after retort sterilized process, as expected.

The proposed procedure will contribute to improve the efficiency of can body design process by saving trial manufacturing, which is time and money consuming.

References.