Mechanical Design of Metal Dome for Industrial Application

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Abstract. In this paper, the mechanical design of metal domes is studied using finite element analysis. The snap-through behavior of a practical button design that uses a metal dome is found. In addition, the individual click ratio and maximum force for a variety of metal domes are determined. This paper provides guidance on button design for industrial engineers.

1. Introduction

The metal dome shown in Fig. 1 is a type of thin shell structure, which is known as a spherical cap in solid mechanics. This element is usually applied in the button design of electronic products such as cameras, mobile phones, or audio players. Due to the snap-through/buckling deformation typical of a metal dome, one can feel the jumping or clicking motion when pressing the button.

Using either an analytical or a numerical method, the snap-through deformation of a spherical cap or arch shell has been extensively studied [1-7], while their applications were discussed by Tomitsuka et al. [5]. However, the practical application and discussion of a metal dome for button design was presented in very few references.

In this paper, non-linear finite element analysis will be applied for a metal dome used in a button design. The snap-through deformation and click ratio will be obtained for some practical design cases. Design guidelines will be proposed on the basis of the results of this research.

Figure 1. Metal dome.

2. Problem definition and finite element model

The geometry of the metal dome to be analyzed is shown in Fig. 2. It is composed of a curved cap and flat ring. The dome is a thin-shell structure and made of high-strength stainless steel (JIS SUS 301 EH). Its main dimensions are \( R, Q, H, \) and \( t \). The indenter with radius \( r \) experiences a downward force and displacement that cause it to press into the metal dome. In Table 1, the material constants of JIS SUS 301 EH are listed, while the elasto-plastic stress–strain curve is shown in Fig. 3. Due to its relative
rigidity, the indenter is assumed to be a rigid body. The metal dome is constrained on $L_2$ and subjected to the load from the indenter.

![Figure 2. Geometry of metal dome.](image)

![Figure 3. Elasto-plastic stress-strain curve of stainless steel (JIS SUS 301 EH).](image)

![Figure 4. Finite element model.](image)

### Table 1. Material properties of stainless steel (JIS SUS 301 EH).

| Material            | Young’s modulus $E$ (GPa) | Poisson’s ratio $\nu$ | Yielding strength $S_y$ (MPa) |
|---------------------|---------------------------|-----------------------|-------------------------------|
| JIS SUS 301 EH       | 186                       | 0.30                  | 1250                          |
| Stainless steel     | 186                       | 0.30                  | 1250                          |

ANSYS software is employed for the non-linear finite element analysis. The contact condition between the dome and indenter is considered as well as the large displacement and elasto-plastic stress–strain curve. For the finite element simulation in ANSYS, the element types used are as follows: SHELL93, TARGE170, and CONTA174.
A typical finite element model is shown in Fig. 4. The indenter has a prescribed displacement along the y-direction, which can be downward or upward to control its motion.

3. Design rules
The snap-through behavior (path a-b-c) of the metal dome is shown in Fig. 5. In this figure, \( F \) and \( v \) represent the applied force and indentation displacement, respectively. Along the snap-through path a-b-c, one can feel a click or jump motion when the dome or button is pressed.

The click ratio \( R_c \) is defined as follows:

\[
R_c = \frac{(F_1-F_2)}{F_1} \times 100\% \tag{1}
\]

\( R_c \) is an important parameter for the metal dome or button. A larger \( R_c \) value represents a more obvious jump motion when the button or dome is pressed. Referring to past studies [5], the click ratios are designed within a range of 30\% to 60\% to achieve a satisfying feeling for the user when the button is pressed. Past studies [5,8] also proposed that the range of maximum force \( F_1 \) should be designed to be from 1 N to 5 N for mobile communication products.

![Figure 5. Snap-through behavior.](image)

4. Numerical results
First, the effects of the thickness on the click ratio \( (R_c) \) and maximum force \( (F_1) \) are discussed. The dimensions \( R = 1 \) mm, \( Q = 0.2 \) mm, \( H = 0.1 \) mm, \( i_1 = 0.2 \) mm, and \( r = 0.3 \) mm are kept constant. In Fig. 6, the \( F-v \) relation, \( R_c \) variation, and \( F_1 \) variation for different thicknesses are obtained from the finite element analysis.

The color bands in figures (b) and (c) denote the design ranges according to past research [5,8]. Only the cases of \( t = 0.0325 \) mm and \( t = 0.035 \) mm meet the design requirements. For the cases of \( t \leq \)
0.0225 mm, the snap-through behavior is lost and the click ratio cannot be defined. In summary, the click ratio decreases when the thickness increases.

![Graph](image1)

**Figure 7.** (a) $F$-$v$ relation, (b) $R_c$ variation, (c) $F_1$ variation. (effects of $H$)

![Graph](image2)

**Figure 8.** Special case.

![Graph](image3)

**Figure 9.** (a) $F$-$v$ relation, (b) $R_c$ variation, (c) $F_1$ variation. (effects of $W$)

The effects of $H$ are also discussed. The dimensions $R = 1$ mm, $Q = 0.2$ mm, $t = 0.03$ mm, $i_1 = 0.2$ mm, and $r = 0.3$ mm are kept constant; the results are shown in Fig. 7. Only the cases of $H = 0.02$ mm and $H = 0.03$ mm meet the design requirements. In figures (b) and (c), we see that the case of $H = 0.02$ mm gives the peak value.

A special case for a metal dome with four holes is shown in Fig. 8. The dimensions $R = 1.95$ mm, $Q = 0.3$ mm, $H = 0.2$ mm, $t = 0.05$ mm, $i_1 = 0.2$ mm, and $r = 0.3$ mm are kept constant. The dimension $W$ is a variable.
The results of these cases are shown in Fig. 9; they nearly meet the design requirements. Similar $F$–$v$ curves are plotted as for the previous case. We can see that the click ratios vary slightly with different $W$ values. However, $F_i$ consistently increases as the width increases.
In addition, Fig. 10 shows the stress and deformation of the metal dome with $W = 0.7$ mm.

5. Conclusion
The finite element results provide information and a methodology for metal dome and/or button design. The ideal snap-through behavior, click ratio, and maximum force of various metal domes were obtained. The mechanical behavior of the dome was shown to be affected by the geometric condition. By controlling the shape, the metal dome can meet the design requirements. In particular, the disappearance of the snap-through behavior for some domes must be avoided. In summary, the JIS SUS 301 EH stainless steel is a good choice for metal dome design.

6. References
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