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RESEARCH OF UNSEALING PROBLEM IN CYLINDRICAL SEALED VOLUMES OF VARIOUS PURPOSES BY THE EXAMPLE OF THIN-FILM CAPACITORS

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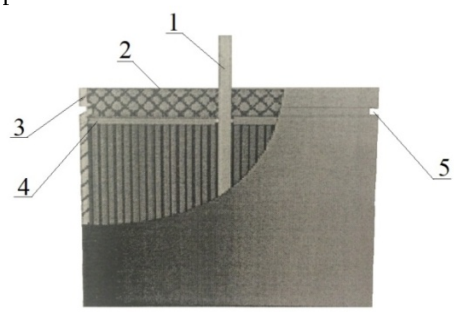
Hermetic sealing applied to electronic components, parts and units by using thermally reactive compounds based on synthetic resins is widely used in modern electronics. However, it is a matter of general experience that effect produced by hermetic sealing may not be completely achieved or even brings about lower reliability of a sealed unit because of cracking compound, breaking electric circuits and other failures caused by internal stresses. [1-3].

The paper theoretically researches this problem for cylindrical compounded hermetic units of the thin-film electrolytic capacitors.

Fig. 1 shows the scheme of the film capacitor. The capacitor's case 3 is represented as thin-wall cylindrical shell, with capacitor's section packaged inside, which is closed by non-hermetic textolite membrane 4 that has a hole for the contact pin 1.

After the capacitor has been assembled, its open side gets filled with the sealing compound. The compound polymerization occurs at 100 ºC temperature. The same scheme is applied to make sealed units of various forms, sizes and purposes. The sealed unit may also be in-built into these volumes by attaching (welding) a specific appliance to a capacitor's case.

The case of capacitor is made of aluminum alloy. The contact pin is made of copper wire. The membrane is stamped from textolite.



1 – pin; 2 – compound; 3 – body; 4 – membrane; 5 - stamping a housing

Fig. 1. Developing mathematical model of compound interaction with pin and shell, and methods for providing strength and hermetic seal

To research interaction of materials, which contact inside the water-prof sealed unit, the mathematical model has been developed, in which thin-wall aluminum can is assumed as cylindrical shell loaded over the part of its length (or over the complete length) by distributed contact pressure and the deformation of this shell is hereinafter studied [4]. The strength or rigidity of compound cylinder or disk can be considered which are subjected to the pressure of the same value but opposite sign. The interaction of the compound with shell and pin can be considered using the scheme of three-layer cylinders (shells), loaded by contact pressure in the metal/compound interface. The actual values of the contact pressure can be found from the condition of deformation compatibility in compound/shell and compound/pin contacting surfaces.

Obviously, the more the value of cylindrical rigidity is, the easier shell will follow the compound, and the less probability for compound exfoliation from shell surface will be.

Analysis of capacitor design allows assuming that having textolite membrane creates an additional circular support and in this way shortens the shell's length (by a factor of 8-10), which contacts with compound, increasing its rigidity. Therefore, we need to check if the substitution of the textolite membrane for a rubber one, which, because of its softness, cannot be actually considered a real support to tightly hold a shell, will not bring about significant shell deformation in the contact area with compound.

This paper considers a deformation of the can-shell and subsequent ways for improving flexibility of the surface contacting a compound.

The formulas derived for the case of the shell with membrane can be applied for calculation and analysis of the sealed units all along the height of the capacitor that extends from textolite membrane to its free end.

So we will consider the constant thickness round cylindrical shell being forced by the internal pressure with intensity q (fig. 2), which is symmetrical about axis and uniformly distributed all along the height of cylinder of the length l_2. The bend needs to be calculated for the middle surface of this short shell – the can of the length l_2 , that extends from the membrane to its free end.

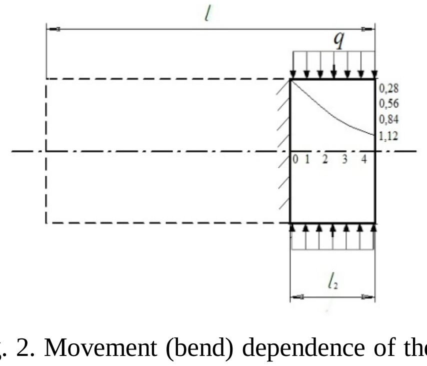


Fig. 2. Movement (bend) dependence of the short shell middle surface on its length

It is known [5] that problems relevant to symmetric deformations of constant thickness round cylindrical shell are confined integrating differential equation:

$$\frac{d^4 y}{dz^4} + \frac{E \cdot h}{R^2 \cdot D} \cdot y = \frac{f(z)}{D} \quad , \tag{1}$$

where $y(z)$ – radial movement of the shell middle surface points; h – shell thickness; R – radius of the shell middle surface; E – elasticity module of material; D – cylindrical rigidity; $D = \dfrac{E \cdot h^3}{12 \cdot (1-\mu^2)}$, μ – Poisson's ratio of material; $f(z)$ – distributed load, applied to shell middle surface; in our case we will assume that $f(z) = q = \text{const}$, meaning that possible irregularity of the contact pressure along the contact surface will not be considered. Then the problem is confined to finding function $y(z)$, i.e. solving equation:

$$\frac{d^4 y}{dz^4} + \frac{E \cdot h}{R^2 \cdot D} \cdot y = \frac{q}{d} \quad , \tag{2}$$

Using Krylov functions [6] which are described by expressions:

$$k_0(\varphi z) = \frac{1}{2} \cdot \left(e^{\beta z} + e^{-\beta z}\right) \cdot \cos \beta z \quad ,$$

$$k_1(\beta z) = \frac{1}{4} \cdot \left[\left(e^{\beta z} + e^{-\beta z}\right) \cdot \sin \beta z + \left(e^{\beta z} - e^{-\beta z}\right) \cdot \cos \beta z\right]$$

$$k_2(\beta z) = \frac{1}{4} \cdot \left(e^{\beta z} - e^{-\beta z}\right) \cdot \sin \beta z \quad ,$$

$$k_3(\beta z) = \frac{1}{8} \cdot \left[\left(e^{\beta z} + e^{-\beta z}\right) \cdot \sin \beta z - \left(e^{\beta z} - e^{-\beta z}\right) \cdot \cos \beta z\right] \quad ,$$

the final bend expression is represented as:

$$\begin{aligned} y(z) = 4 \cdot \alpha \cdot \frac{\overline{k_1^2} + \overline{k_0} \cdot \overline{k_2}}{k_0^2 + 4 \cdot \overline{k_1} \cdot \overline{k_3}} \cdot k_2(\beta z) - \\ -4 \cdot \alpha \cdot \frac{\overline{k_0} \cdot \overline{k_1} + 4 \cdot \overline{k_2} \cdot \overline{k_3}}{\overline{k_0^2} + 4 \cdot \overline{k_1} \cdot \overline{k_3}} \cdot k_3(\beta z) + \alpha \cdot \left[1 - k_0(\beta z)\right] \end{aligned} \tag{3}$$

where $\alpha = \dfrac{q}{4D\beta^4}$; $k_i(\beta l_2) = \overline{k_i}$, i = 0, 1, 2, 3.

The formulas derived for the case of the shell without membrane can be applied for calculation and analysis of sealed units of capacitor whose textolite membrane is substituted for rubber one (or absent at all), e.t. it does not limit movement of the capacitor's shell.

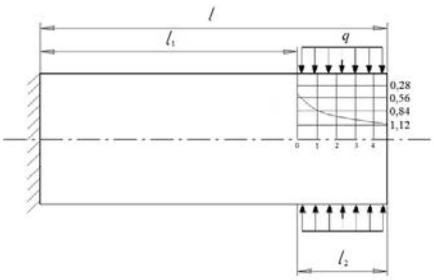


Fig. 3. Movement (bend) dependence of the long shell middle surface on its length

Now the constant thickness round cylindrical shell with the bottom at the left end, what means the shell of the length $l = l_1 + l_2$ (long shell) will be considered. The internal pressure of intensity q is distributed along the length l_2 of the cylinder at the right end of the shell. The bend calculation of the cylindrical shell for middle surface points is confined to integrating differential equation.

The generalized solution of the differential equation can be represented as the sum: $y = y_0 + y_1$, where:

$$y_0 = C_1 \cdot k_0(\beta z) + C_2 \cdot k_1(\beta z) + C_3 \cdot k_2(\beta z) + C_4 \cdot k_3(\beta z)$$

is generalized solution of homogenous differential equation, y_1– particular solution of that equation.

Method of operational calculus [7] is used to find particular solution of the equation $y_1(z)$. The generalized solution of the original equation will be:

$$\begin{aligned} y(z) = C_1 K_0(\beta z) + C_2 K_1(\beta z) + C_3 K_2(\beta z) + C_4 K_3(\beta z) + \\ + \frac{q}{4D\beta^4} \cdot \left[1 - K_0\left(\beta(z - l_1)\right)\right] \cdot \eta(z - l_1) - \\ - \frac{q}{4D\beta^4} \cdot \left[1 - K_0\left(\beta(z - l)\right)\right] \cdot \eta(z - l). \end{aligned} \tag{4}$$

The values of arbitrary constants C_1, C_2, C_3, C_4 will be determined from boundary conditions.

Solving the expressions, and denoting $\alpha = \dfrac{q}{4D\beta^4}$, $K_i(\beta l) = \overline{K}_i$, i = 0, 1, 2, 3, solution will appear as:

$$\begin{aligned} y(z) = 4\alpha \cdot \frac{\overline{k_1} \cdot k_1 \cdot (\beta(l - l_1)) - \overline{k_0} \cdot k_2 \cdot (\beta(l - l_1))}{k_0^2 + 4\overline{k_1}\overline{k_3}} \cdot k_2(\beta z) - \\ -4\alpha \cdot \frac{\overline{k_0} \cdot k_1 \cdot (\beta(l - l_1)) + 4 \cdot \overline{k_3} \cdot \overline{k_2} \cdot (\beta(l - l_1))}{k_0^2 + 4\overline{k_1}\overline{k_3}} \cdot k_3(\beta z) + \\ +\alpha \cdot [1 - k_0(\beta(z - l_1))] \cdot \eta \cdot (z - l_1) - \alpha \cdot [1 - k_0(\beta(z - l))] \cdot \eta \cdot (z - l). \end{aligned} \tag{5}$$

Formulas (3) and (5) have been used to perform bend calculation of the middle surface of the short cylindrical shell (with installed textolite membrane) and the long one (without the membrane), correspondently, in points shown in fig. 2-3 with the following numbers of the shells' geometric sizes $l = 50$ mm, $l_2 = 50$ mm, $h = 0{,}2$ mm, $R = 16{,}9$mm. The material of the shell is aluminum alloy AD1.

The calculation results are represented in graphs in figures 2-3, where the bend y(z) is expressed in relative units:

$$\alpha = \frac{q}{4D\beta^4}.$$

The assessment of calculation results (graphs) demonstrates that the bends of the researched shells significantly differ only in small interval, 0.2 mm, near the membrane, what means that in the can with membrane the compound exfoliation may start near the membrane and furthermore spread, in favorable conditions, all the way along the compound. Therefore, one of the recommendations made on this assessment is to provide sufficient clearance between capacitor's shell and textolite membrane.

To prevent the compound leaking into this clearance, that can be closed, for an instance, by rubber-type compound.

For this purpose textolite membrane can be substituted for rubber one, which will allow free shell's deformations when it is forced by the load of compound. Finally, the flexibility of the shell can be increased in the area l_2, where it contacts with compound and that will be demonstrated in the second part of the paper.

References

1. Ройзман В.П., Возняк А.Г., Горошко А.В. Проблема міцності і герметичності компаундованих виробів РЕА, збірник тез і доповідей, Угорщина, 2016, 37–39 с.
2. Марков В.Ф., Мухамедзянов Х.Н., Маскаева Л.Н. Материалы современной электроники. – издательство Уральского университета, 2014. – 270 с.
3. Иванова Н.Ю., Комарова И.Э., Бондаренко И.Б. Электрорадиоэлементы. Часть 2. Электрические конденсаторы. – Санкт-Петербург, 2015. – 34 с.
4. Ройзман В.П. Термопрочность компаундированых пассивных электронных элементов / В.П. Ройзман, И.И. Ковтун, С.А. Петращук // Современные информационные и электронные технологии : тр. Третьей междунар. научно-практ. конф. (СИЭТ-2002). – Одеса: Одесский политехн. университет, ОАО «Нептун», 2002. – 145 с.
5. Биргер И.А. Расчет на прочность деталей машин : справочник / И.А. Биргер, Б.Ф. Шор, Г.Б. Йосилевич. – М.: Машиностроение, 1993. – 502 с.
6. Амосов А.А. Техническая теория тонких упругих оболочек. – М.: Издательство ассоциации строительных узлов, 2009 – 303 с.
7. Владимиров В.С., Жаринов В.В. Уравнения математической физики. – Москва: Физматлит, 2004. – С. 318-333.

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ПОДВИЖНОСТЬ НОСИТЕЛЕЙ ЗАРЯДА В ПОЛУПРОВОДНИКОВЫХ ТОНКИХ ПЛЕНКАХ PbSnTe

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Полупроводниковые соединения $A^{IV}B^{VI}$ PbTe и SnTe являются материалами с хорошими термоэлектрическими свойствами а также интересны как потенциальные материалы для длинноволновых инфракрасных детекторов [1-3]. Ширина запрещенной зоны этих материалов изменяется от E_g = 0,18 eV для SnTe до E_g = 0,32 eV для PbTe [4]. Эти соединения кристаллизуются в кубической решетке типа NaCl и являются во многих отношениях аналогами. По сходству структур соединений SnTe и PbTe и близости величин постоянных кристаллических решеток можно предположить наличие между этими соединениями непрерывного ряда твердых растворов. PbTe кристаллизуется в составе, близком к стехиометрическому, и необходимая концентрация носителей тока получается добавлением соответствующих примесей (например, галогенов для получения *n*-PbTe и щелочных металлов для получения *p*-PbTe). Вакансии в подрешетке свинца являются акцепторами, а в подрешетке теллура – донорами. В специально нелегированных образцах электрические свойства в первую очередь определяются концентрацией избыточных атомов теллура и свинца. SnTe всегда кристаллизуется с большой концентрацией вакансий в металлической подрешетке. Вакансии металла в кристаллической решетке образуют в запрещенной зоне этого полупроводникового соединения акцепторные энергетические уровни и данное полупроводниковое соединения имеет *p*-тип проводимости. Изменение состава системы PbTe-SnTe приводит к изменению всех свойств. Поэтому исследование свойств такого полупроводникового соединения, полученного в виде тонких пленок представляет большой интерес как для термоэлектрического так и для фотоэлектрического применения.

Для получения пленок PbSnTe выбран метод термического вакуумного нанесения типа «горячей стенки». При этом методе перенос паров испаряемого материала мишени проходит в цилиндрическом канале, температура стенок которого не ниже температуры испарителя. В качестве подложек были использованы стекла марки Corning 7059. В качестве исходного материала для напыления использовались порошки поликристаллических слитков, предварительно синтезированных методом сплавления в вакуумированных кварцевых ампулах. В данной работе приведены результаты исследований температурных зависимостей подвижности носителей заряда в тонких пленках PbSnTe разных составов.

Температурные зависимости подвижности носителей заряда регистрировались в температурном интервале 100-400К, при этом