# The Testing and Qualification of 105°C 2000 hours Sanp-in Aluminum Electrolytic Capacitor with Ultra-compact Size

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**Abstract:** The paper first presents the volumes of different lifespan series of 85°C and 105°C type 400V470μF and 450V470μF snap-in aluminum electrolytic capacitors owned by the Company while introducing the super-compact capacitors developed by the competitor for volume comparison. Then the author illustrates the calculation method of element filling rate and points out that element filling rate is the main indicator of whether the element can be filled into the aluminum shell. The methods of reducing element volume are discussed including the increase of anode foil capacitance and the thickness reduction of anode foil, cathode foil and electrolytic paper. At the end, it is indicated that it is not enough to reduce the element volume from the mechanical angle in order to hit the target of miniaturizing aluminum electrolytic capacitors. Further electrical property tests and a string of lifespan and environment certification tests are needed.

## 1. Introduction

Article [1] researches on the insulation performance of aluminum electrolytic capacitor under strengthening voltage; article [2] uses the technology of expanding effective surface area to miniaturize aluminum solid electrolytic capacitor; article [3] probes into the new structure adopted by large-scale aluminum electrolytic capacitors. In other words, new aluminum electrolytic capacitors with rectangle structure are made, whose performance is compared with that of aluminum electrolytic capacitors with common round copper shape. The advantages of capacitors with new structure in ESR, loss and ripple resistance are pointed out; article [4] sheds light on the influence of different structures and applications of aluminum electrolytic capacitors on their lifespan.

One of the future directions in the development of aluminum electrolytic capacitors is miniaturization. With the increasing requirement for miniaturized electronic devices and components, the smaller the product is, the more competitive it is, on the condition that aluminum electrolytic capacitors has the same volume and voltage.

## 2. Analysis on the Products of Competitor

### 2.1 Comparison of external dimensions

Formula 1 is used for the calculation of capacitor volume.

$$V = \frac{1}{2}\pi r^2 L \tag{1}$$

V=capacitor volume
r=capacitor radius
L=capacitor height

The 400V470μF subminiature aluminum electrolytic capacitors we get from competitor have two dimensions: 25X45mm and 30X35mm; there are two types of dimensions of 450V470μF subminiature aluminum electrolytic capacitor, that is, 30X45 and 35X35. And we have been aware of that these two kinds of products 400V470μF and 450V470μF belong to the compact series. The products of same voltage and capacity made by the Company can be divided into 85°C and 105°C depending on temperatures and into conventional type and compact type depending on dimensions.

 

We have compared the products got from the competitor with volume of different product series with the same capacity and voltage produced by the Company. The results are seen in figure 1 and 2:

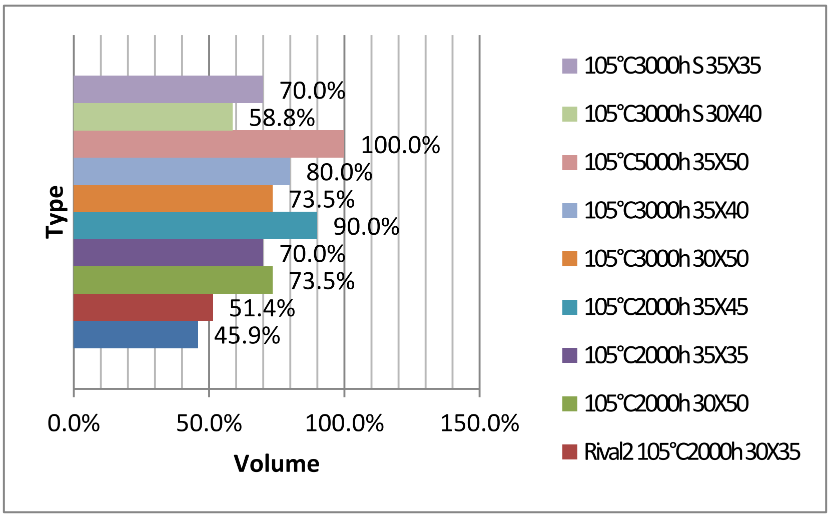


Figure 1 400V470μF Volume compare

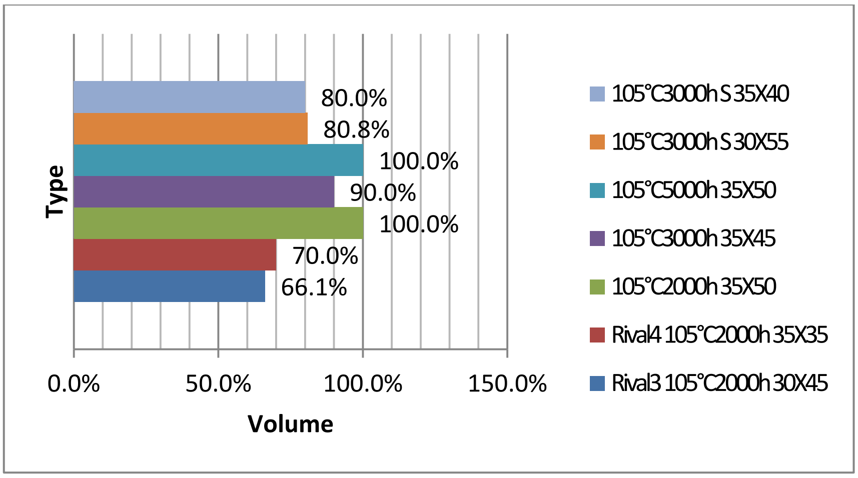


Figure 2 450V470μF Volume compare

Figure 1 and Figure 2 show that the compact aluminum electrolytic capacitor products developed by the competitor have a great advantage in volume. 25X45mm 400V470μF subminiature products of the competitor have the smallest volume, only accounting for 45.9% of the volume of our conventional products and 13% smaller than the volume of our 30X40mm 105°C 3000h miniaturized products. 30X45mm 450V470μF subminiature products have the smallest volume, only 66.1% of the volume of our conventional products and 14% smaller than the volume of our 35X40mm105°C 3000h subminiature products.

### 2.2 Capacity, loss, ESR and current leakage performance of the competitor's products

We test the electrical performance including capacity, dissipation factor, ESR, impedance and leakage current with the competitor's products of 450V470μF 30X35 shell size. and 450V470μF 35X35 shell size. It is shown in Table 1:

As seen in Table 1, the rated capacity requirement of capacitor developed by the competitor is 470μF±20%. And the actual capacity of capacitor designed by the competitor is about 405μF. Thus, it is found that the designed capacity of the competitor is 86% of the rated capacity. That is to say, the listing coefficient adopted in the design of this product is 0.86.

Table 1 Competitor's products electric performance analysis

| | Required value | 400V470μF | 450V470μF |
|---|---|---|---|
| Shell size | | 30X35 | 35X35 |
| Capacity/μF(120Hz25°C) | 470±20% | 404.2 | 407.5 |
| Dissipation Factor (120Hz25°C) | ≤0.15(400V) ≤0.20(450V) | 0.0612 | 0.0641 |
| ESR/mΩ(120Hz25°C) | - | 201.4 | 208.7 |
| ESR/ mΩ(1kHz25°C) | - | 156.8 | 155.3 |
| impedance/mΩ(1kHz25°C) | - | 431.5 | 432.2 |
| impedance/ mΩ(10kHz25°C) | - | 156.1 | 152.1 |
| Current leakage/μA(1min25°C) | ≤1300(400V) ≤1380(450V) 5min | 110 | 120 |

Here the concept of listing coefficient is introduced. The calculation of listing coefficient is seen in formula 2:

$$Listing\ Co = \frac{Designed\ Capacity}{\text{Rated Capacity}} \tag{2}$$

This is because the produced capacity of capacitor from manufacturing is not consistent with the rated capacity. There is always a certain deviation. In order to control the error of capacitor in a certain range, we classify the error of capacitor into different levels. For instance, J level is ±5%; K level is ±10%; M level is ±20%, etc. The error of most capacitors in current use is controlled within ±20%. The manufacturer often has a more accurate control of the error of capacitor in manufacturing process, usually between 1% and 3%.

Thus, for the manufacturer of capacitors, after the consideration of the error of products in the manufacturing process, the selection of a reasonable listing coefficient will allow for a control of the lower limit of tolerance based on the satisfaction of the requirement for manufacturing error range. In such a case, it is helpful for the saving of raw materials and thus for the reduction of product cost.

### 2.3 Calculation of element filling rate

The structure of snap in capacitor mainly includes anode foil, cathode foil, electrolytic paper, electrolyte, tab foil, cover disc and aluminum shell. Anode foil, cathode foil, and electrolytic paper of different widths and lengths are coiled to form the element of capacitor. The element fully immersed with electrolytic solution is put into the aluminum shell. The original capacitor is completed with the installation of cover disc and sealing. After the aging process and electrical property performance selection, a qualified capacitor can be acquired.

The size of capacitor element has a direct influence on that of the capacitor volume. The volume of element needs to be reduced if we want to minimize that of the capacitor. The major factors which influence the size of element are thickness of anode foil, the capacitance of anode foil, thickness of cathode foil and width of element etc.

The anode length refers to the length of anode foil used in the coiling of element. The smaller the anode length is, the smaller the length of anode foil is. The calculation of anode length is seen in formula 3:

$$\mathrm{L}=\frac{(\mathrm{C}*(\mathrm{Ca}+\mathrm{Cc}))}{(\mathrm{W}*\mathrm{Ca}*\mathrm{Cc})} \tag{3}$$

C: capacitor capacitance

Ca: anode foil capacitance

Cc: cathode foil capacitance

W: element width

As the capacitance of cathode foil is often far larger than that of anode foil, the larger the capacitance of anode foil in formula 3 is, the smaller the calculated anode length is.

The calculation of element diameter is seen in formula 4:

$$D = 1.13\sqrt{L(Da + Dc + 2(Dp1 + Dp2))} \quad (4)$$

Da: thickness of anode foil
Dc: thickness of cathode foil
Dp1: thickness of paper 1
Dp2: thickness of paper 2
D: the diameter of element

It is seen from formula 4 that the reduction of element anode length and the selection of thin anode foil and cathode foil and electrolytic paper can reduce the diameter of the element.

The calculation of element filling rate is seen in formula 5:

$$FR = \frac{Delement^2}{Dshell^2} \quad (5)$$

The filling rate of element offers reference data for the installation of element into the aluminum shell. If the filling rate is larger than 100%, then the element is too large to be put into the aluminum shell. If the filling rate is too small, it is not good for the heat dissipation. Moreover, in such a case, there is still large room in the capacitor after the installation of element, the element may move up and down, making it hard to pass the vibration test.

### 2.4 Analysis on the Product Design of the Competitor and Company

Table 2 shows the basic data of anode foil, cathode foil and electrolytic paper adopted by the design of 400V470μF capacitor products of the competitor and Company.

Table 2 400V470μF capacitor products component compare

| No. | Shell Size | | Anode foil | | | Cathode foil | | | Electrolytic paper | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | H | V | C μF/cm$^2$ | T μm | V | C μF/cm$^2$ | T μm | A density g/cm$^3$ | A μm | B density g/cm$^3$ | B μm |
| 400V470μF | | | | | | | | | | | | |
| Rival1 105°C2000h | 25 | 45 | 590 | 0.7 | 120 | 0 | 40 | 20 | \ | 35 | \ | 20 |
| Rival2 105°C2000h | 30 | 35 | 590 | 0.7 | 120 | 0 | 40 | 20 | \ | 35 | \ | 20 |
| 105°C2000h | 30 | 50 | 590 | 0.58 | 110 | 2 | 70 | 20 | 0.65 | 40 | 0.8 | 30 |
| 105°C2000h | 35 | 35 | 580 | 0.64 | 115 | 2 | 70 | 20 | 0.65 | 40 | 0.8 | 30 |
| 105°C2000h | 35 | 45 | 590 | 0.58 | 110 | 2 | 70 | 20 | 0.65 | 40 | 0.8 | 30 |
| 105°C3000h | 30 | 50 | 590 | 0.58 | 110 | 2 | 70 | 20 | 0.65 | 40 | 0.8 | 30 |
| 105°C3000h | 35 | 40 | 590 | 0.58 | 110 | 3 | 90 | 30 | 0.65 | 40 | 0.8 | 30 |
| 105°C5000h | 35 | 50 | 600 | 0.55 | 110 | 3 | 90 | 30 | 0.65 | 40 | 0.8 | 40 |
| 105°C3000h small size | 30 | 40 | 580 | 0.625 | 115 | 3 | 40 | 20 | 0.85 | 30 | 0.93 | 20 |
| 105°C3000h small size | 35 | 35 | 580 | 0.625 | 115 | 3 | 40 | 20 | 0.85 | 30 | 0.93 | 20 |

Table 3 shows the basic data of anode foil, cathode foil and electrolytic paper adopted by the design of 450V470μF capacitor products of the competitor and company.

Table 3 450V470μF capacitor products component compare

| No. | Shell Size | | Anode foil | | | Cathode foil | | | Electrolytic paper | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | H | V | C μF/cm$^2$ | T μm | V | C μF/cm$^2$ | T μm | A density g/cm$^3$ | A T μm | B density g/cm$^3$ | B T μm |
| 450V470μF | | | | | | | | | | | | |
| Rival3 105°C2000h | 30 | 45 | 670 | 0.55 | 115 | 0 | 60 | 20 | \ | 40 | \ | 20 |
| Rival4 105°C2000h | 35 | 35 | 670 | 0.55 | 115 | 0 | 60 | 20 | \ | 40 | \ | 20 |
| 105°C2000h | 35 | 50 | 640 | 0.52 | 115 | 2 | 70 | 20 | 0.65 | 40 | 0.8 | 30 |
| 105°C3000h | 35 | 45 | 640 | 0.48 | 110 | 3 | 90 | 30 | 0.65 | 40 | 0.8 | 40 |
| 105°C5000h | 35 | 50 | 660 | 0.46 | 110 | 0 | 80 | 30 | 0.65 | 40 | 0.8 | 40 |
| 105°C3000h small size | 30 | 55 | 650 | 0.52 | 115 | 3 | 40 | 20 | 0.74 | 35 | 0.93 | 25 |
| 105°C3000h small size | 35 | 40 | 650 | 0.52 | 115 | 3 | 40 | 20 | 0.74 | 35 | 0.93 | 25 |

It is seen from the tables that the anode foil selected by the competitor has a very high capacitance under the same voltage in a bid to design a small element volume. The thickness of cathode foil is very thin, controlled within 20μm. And the thickness of the combination of two electrolytic papers is also controlled to be very low, 55μm for 400V470μF and 60μm for 450V470μF.

We use the competitor's 400V470μF 25X45mm shell size product to calculate the filling rate in aluminum shell. Capacitance of anode foil, capacitance of cathode foil, width of anode and capacity of capacitor are put into formula 3 to get the anode length 195.2cm. When considering listing coefficient as 86%, so the actual anode length would be 167.9cm. And then the anode length, anode foil thickness, cathode foil thickness and electrolytic paper thickness are put into formula 4 to get the element diameter 2.31cm. The inner diameter of aluminum shell is chosen as 2.4cm and formula 5 is used to calculate the element filling rate as 93%.

Table 4 shows the comparison of anode length, element diameter and filling rate calculated with the above-mentioned formula according to the provided basic data of anode foil, cathode foil and electrolytic paper for 400V470μF products of the competitor and company.

Table 4 400V470μF products calculated filling rate compare

| No. | Shell Size | | Listing coefficient | Anode length | Element diameter | Filling rate |
|---|---|---|---|---|---|---|
| | D | H | | mm | mm | % |
| 400V470μF | | | | | | |
| Rival1 105°C2000h | 25 | 45 | 0.86 | 1669.99 | 23.09 | 92.55% |
| Rival2 105°C2000h | 30 | 35 | 0.86 | 2312.30 | 27.17 | 87.77% |
| 105°C2000h | 30 | 50 | 0.94 | 1863.29 | 25.35 | 76.38% |
| 105°C2000h | 35 | 35 | 0.94 | 2665.07 | 30.59 | 80.95% |
| 105°C2000h | 35 | 45 | 0.94 | 2122.08 | 27.05 | 63.29% |
| 105°C3000h | 30 | 50 | 0.94 | 1863.29 | 25.35 | 76.38% |
| 105°C3000h | 35 | 40 | 0.94 | 2459.86 | 29.66 | 76.08% |
| 105°C5000h | 35 | 50 | 0.94 | 1960.69 | 27.41 | 64.97% |
| 105°C3000h small size | 30 | 40 | 0.94 | 2303.57 | 26.29 | 82.19% |
| 105°C3000h small size | 35 | 35 | 0.94 | 2746.56 | 28.71 | 71.29% |

Table 5 shows the comparison of anode length, element diameter and filling rate calculated with the above-mentioned formula according to the provided basic data of anode foil, cathode foil and electrolytic paper for 450V470μF products of the competitor and Company.

Table 5 450V470μF products calculated filling rate compare

| No. | Shell Size | | Listing coefficient | Anode length | Element diameter | Filling rate |
|---|---|---|---|---|---|---|
| | D | H | | mm | mm | % |
| 450V470μF | | | | | | |
| Rival3 105°C2000h | 30 | 45 | 0.86 | 2108.04 | 26.20 | 81.62% |
| Rival4 105°C2000h | 35 | 35 | 0.86 | 2918.82 | 30.83 | 82.21% |
| 105°C2000h | 35 | 50 | 0.94 | 2076.52 | 27.00 | 63.08% |
| 105°C3000h | 35 | 45 | 0.94 | 2556.68 | 31.30 | 84.72% |
| 105°C5000h | 35 | 50 | 0.94 | 2343.46 | 29.96 | 77.66% |
| 105°C3000h small size | 30 | 55 | 0.94 | 1861.05 | 24.62 | 72.05% |
| 105°C3000h small size | 35 | 40 | 0.94 | 2761.56 | 29.99 | 77.78% |

As seen in Table 4 and 5, the listing coefficient of the competitor is 0.86 in order to minimize the volume. While the listing coefficient of conventional and miniaturized products of the Company are both 0.94. On the basis of meeting ±20% capacity tolerance for the produced capacitors, the capacity value of the competitor's products is smaller than those of our conventional and miniaturized product series.

## 3. Conclusion

First, we have a design analysis of the raw materials of the 400V470μF and 450V470μF aluminum electrolytic capacitors of different sizes produced by the competitor and Company. Then, the anode length, element diameter and filling rate of the products are calculated and compared. Thus, we have a preliminary understanding of the design characteristics of subminiature products of the competitor. In order to achieve miniaturization of products, we come to the following conclusion.

Selecting anode and cathode foils of high capacitance to increase the combined capacitance.

Selecting thin anode and cathode foil.

Selecting a combination of thin electrolytic paper in the allowed limit.

Increasing the width of anode foil and reducing the width difference between anode foil and electrolytic paper (still keeping the height of products unchanged).

Selecting mandrel of small diameter for coiling.

Increasing the width of anode foil and the height of products.

Besides, such a subminiature aluminum electrolytic capacitor produced by the competitor meets the requirements both for size and for the performance of 105°C 2000h. Therefore, in order to develop such a miniaturized product, both the design of size and performance need to be taken into account to meet a series of performance requirements including 105°C 2000h ripple lifespan, DC lifespan and high-temperature storage. This also gives birth to more complicated requirements for the development of miniaturized products in the next step.

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