Large-Current Variable Vacuum Capacitor (VVC)

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Abstract

The Variable Vacuum Capacitor (VVC) is used for the impedance matching in Radio-Frequency (RF) matching network, indispensable for thin-film vacuum coating processes where RF plasma is used. Electronic devices, mobile devices (smartphones or tablet PCs), semiconductor elements, and flat panel displays, for example, are essential to modern society. For manufacturing processes of such items, they need to go through thin-film vacuum coating processes. For these processes, RF matching network (mainly consisting of load and tune capacitors as well as an inductive coil) are being used. Along with increase in silicon wafer size and expansion of Flat Panel Displays (FPDs), the RF matching network is required to generate higher output power. The VVCs to be used in such network is required to carry more current and withstand more voltage. We are working on the development and commercialization of VVC products to meet the higher needs of our customers (semiconductor manufacturing equipment suppliers)

1 Preface

Fig. 1 shows a construction of the VP Series. The Variable Vacuum Capacitor (VVC) is composed of an insulation envelope to insulate the gap between electrodes, a pair of opposed electrodes to create static capacitance, hermetically sealed bellows used to set up electrode allocations in the vacuum chamber, and a shaft for static capacitance regulation by which the opposing area of electrodes can be changed. The VP Series of the large-current VVC employs our unique double bellows. Apart from the bellows intended for vacuum hermetic sealing, another large-sized bellows with low resistance is allocated to carry line current. Until now, we have been developing large-current type VVCs. Until 2016, we had developed six product series including a product series with a permissible current of 400Arms (at 13.56MHz air-cooled.) This paper introduces our programs to produce higher current VVCs.

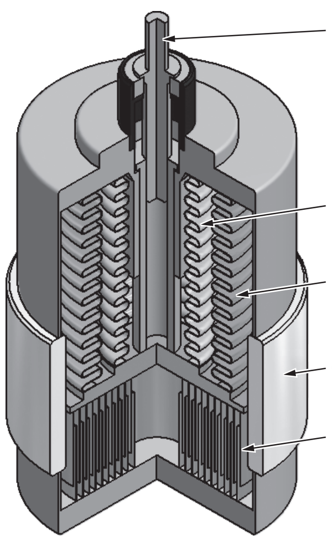

Fig. 1 Construction of the VP Series

Construction of double bellows is shown: one for hermetically sealed bellows to retain vacuum and the other one to carry current.

2 Background of Demand for Large-Current VVC

In the recent Flat Panel Displays (FPDs) market, the FPD panel suppliers in China, Korea, and Taiwan are making a huge investment for the next-generation glass substrates for displays.

In 2016, there were large investments into the FPD manufacturing plant for 10^{th} – generation glass substrates for displays (panel size: 2880 × 3130mm.)

In this connection, there were sizable demands for large over-40kW Radio-Frequency (RF) power supplies and matching units. There is a similar trend for VVCs. The market calls for larger currents and higher withstand voltage. In 2016, we released the large current VVCs – VP200 Series carrying large currents of 400Arms.

The FPD manufacturing equipment suppliers and high frequency power sources suppliers are developing for the 11th generation glass substrates for displays (panel size: 3000 × 3320mm.) We are working on the development of our VVCs and are proposing our products to meet the higher current VVC needs of our customers (above-mentioned suppliers.) Through such efforts, we would like to increase our market share of VVCs for such applications.

3 Our Programs for Higher Current Capacity VVCs

Fig. 2 shows Frequency – Max. Allowable Current Characteristics. The three domains of the maximum allowable current for the Meiden VVCs are as itemized below.

(1) The limit domain due to RF allowable voltage: $I = 2\pi fCVrms$ (C: Static capacitance)

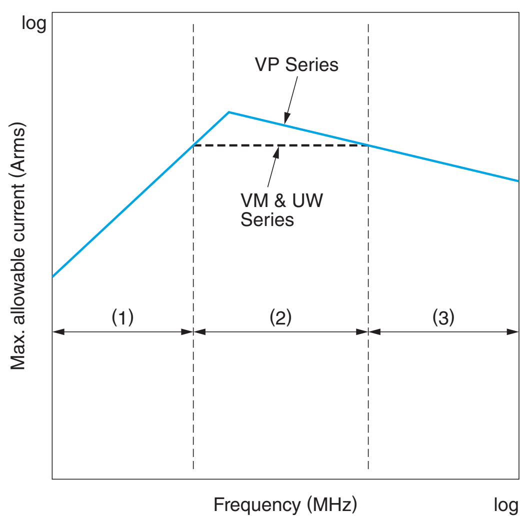

Fig. 2 Frequency – Max. Allowable Current Characteristics

The positive line to the central top of the maximum allowable current for the VP Series shows the domain where the current is limited by the maximum RF allowable voltage. The negative line from the central top belongs to the domain where the current is limited by the product's permissible temperature. For the UW Series, the range limited by permissible temperature is wide.

(2) The limit domain due to maximum allowable temperature

(3) The limit domain due to skin effect: $I = I_{RF}\,(F_{RF}/f)^{1/4}$

Regarding the development of our large-current VVC, our major challenge lies in the current-carrying bellows. Within the limit domains of (2) and (3) above, the maximum allowable current can be increased further by suppressing the bellows loss and heat generation. The amount of heat generation while a heavy current is carried in the VVC is obtainable from the expression below.

$$P_{loss} = (ESR_f + R_c)\,(I_{RF})^2$$

Given I_{RF} Arms is a current carried in the VVC and R_c is a current carrying conductor connection resistance, heat generation in the VVC while current is carried is expressed mainly by the resistance loss P_{loss} W in the Equivalent Series Resistor (ESR). Since the surface temperature on the VVC main body while a maximum current is carried is specified at 125℃ (Δ100℃ when room temperature is 25℃), the bellows is required to assure low heat generation and low loss when the attainment of large current is plotted.

In the case of VVC, resistance due to the effect of "skin effect" on the surface of the bellows is the major factor of ESR, and this ESR is dependent on frequency. Our VVCs are mainly used in the RF matching network and the typical frequency is 13.56MHz. **Fig. 3** shows an example of ESR – frequency characteristics. Compared with the UW

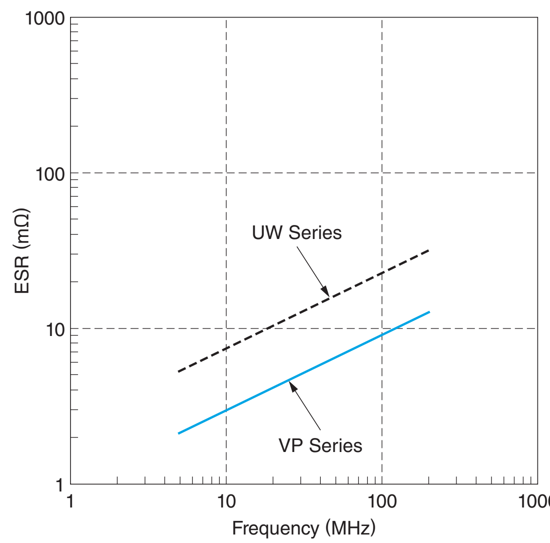

Fig. 3 Example of ESR – Frequency Characteristics

Compared with the ESR characteristics of the UW Series, those of the VP Series are almost half, i.e. 3～4mΩ (at 13.56MHz).

Series, measured values of ESR are extremely low for the VP Series where a double bellows construction is adopted. Such a feature results from the enlarged surface area thanks to the larger diameter of current-carrying bellows and the reduction of conductor resistance by the copper materials that are excellent in electrical characteristics. Nevertheless, the level of requirements for the most advanced equipment in the market is much higher. We have been working on the R&D on new technologies such as low-loss bellows. Performance characteristics requested to the bellows are not only low loss but other factors as well. These are, material shape and strength that can withstand repeated expansion and contraction, and the acquisition of a low spring constant that does not affect the rotating torque performance of shaft for the static capacitance adjustment. Development of bellows is an important factor for the competitive advantage of our products against other competitors.

4 Postscript

The VVC Series using our unique double bellows offers the external diameter range: from 65mm to 200mm. The maximum allowable current ranges from 130 to 400Arms. The rotating torque of the shaft for static capacitance regulation is 0.18N·m that is common to 65mm to 110mm in diameter. For diameters 150mm and 200mm, 0.6N·m is applicable. These figures are the smallest values in this industry. Water-cooled flanges and ball screws are available as options.

Going forward, we expect there will be a demand for large-current VVC models with a maximum allowable current of 500Arms or above in the future. We will continue to develop new VVCs with larger allowable currents. In doing so, we would like to meet the higher expectation of our customers (the FPD manufacturing equipment suppliers and high frequency power sources suppliers.)