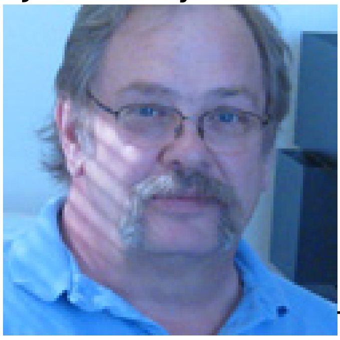
High-Voltage Capacitors: Design and Testing

Joe Moxley, Senior Engineer, Custom Electronics, Inc.



There are many industries that depend on the proven design concepts that require high voltages to operate. Radar, X-ray machines, traveling wave tubes, down-hole logging, particle accelerators, aerospace ignition systems, partial discharge detection, power utilities and welding equipment are some examples. Many of the aforementioned applications are also examples of industries in which equipment failure can have disastrous or even fatal consequences and therefore demand special attention to design, testing and application.

Mica plates or reconstituted mica paper are excellent choices as the dielectric for these high-voltage capacitors. The permittivity or dielectric constant of about six allows for good energy density designs. It has excellent temperature characteristics, showing a -3 percent max drift at -65°C from nominal reading at 25°C to a +5 percent maximum drift at +125°C . Unlike oil-filled capacitors, mica plates or reconstituted mica paper are not position sensitive and will not create hazards in case of failure or accidental puncture. Unlike ceramics, they tolerate thermal shock, physical shock/vibration and high current discharges very well. Mica is also naturally resistant to radiation with an approximate loss of voltage/charge of absorbed dose at 0.12 percent per krad.

When thinking about the testing and the design of high-voltage capacitors, design engineers must think of the two operations as separate but intertwined concepts. Destructive testing is first required to determine the safe design limitation. Good design practice utilizes the results of the destructive testing and its correct application requires little testing (i.e., quality is thereby designed into the product as it can not tested into the capacitor). Final testing establishes that the design requirements have been met, that the processes are under control and that the infant mortalities have been weeded out of the production run.

Destructive testing or testing to failure is required to find the operating parameters of the components and processes used in the construction of the electrical device. For high-voltage capacitors, this would include short-term breakdown testing to determine the volts per mil dielectric stress and the volts per mil electrical stress for the margin area. Keep in mind that the voltage stress levels are different for AC and DC operations and are also subject to the temperatures at which they are tested. Corona inception and extinction levels should be determined as volts per mil stress at this stage, as well. Other areas that need to be defined are dissipation factor, IR, ESR, and temperature coefficient and drift between the rated temperature extremes. The results from this testing will allow the use of statistical analysis programs to provide safe operating levels for the design of the capacitor. Note any change of the components or processes used to manufacture the capacitors would require another set of testing to failure data.

Once the safe operating design parameters are determined, they can be applied to designing the capacitor as specified by the end user. While maintaining the specified size, the following questions need to be answered affirmatively: Will the capacitor design accept the desired electrical charge safely? Will it hold the desired charge for the required amount of time with an adequate margin of time? Will the amperage applied cause internal heating, and if so, how much and how will it be handled? Will the capacitor be in operation with partial discharges / corona? These are the major concerns that need to be addressed early. Some compromises by the end user may be needed, either allowing more room or reducing voltages / stresses so that they fall within allowable standards as defined by the destructive testing. Other problems associated with these specialized applications are that the design requirements can be at extremes, life can be as short as a one-pulse discharge for missile systems to >100 X 10^8 pulses for aircraft ignition systems. Voltage can range from 1 kVdc to more than 100 kVdc with an unending variety of wave forms that need to be studied for their effects in the circuit. Temperatures can range from the severe cold of outer space to the intense temperatures encountered in deep-well logging. Other design criteria that need to be considered are atmospheric pressures (high and low), thermal shocks / cycles, physical shock/vibrations and radiation. Are there other customer requirements that need to be met such as peak current, roor mean square (RMS) current, inductance, impedance, ESR, humidity, special terminals, operating at reduced or increased pressures, sheds or corona shields?

Designs of 1300 volts per mil are the industry standard for the dielectric stress between foils associated with reconstituted mica paper capacitors with 26 volts per mil for the margin area. Different winding techniques such as straight winding with embedded foil, series winding with embedded foil and extended foil can be used to maximize desire characteristics. The number and location of tabs (terminals) are calculated to obtain the best current, voltage and induction performance. Many times, capacitor requirements are such that multiple capacitors must be connected in parallel, series or a combination of parallel / series connections to achieve the desired capacitance / voltage rating. The customer usually specifies the capacitor packaging based on his application. If the final application entails potting the capacitor into an assembly then a bare section design offers the best economy and smallest size. If the capacitor is to be left exposed to atmospheric conditions, then a range of options are available. Tape wrapped and end-filled, fiberglass/plastic/metal potting form or epoxy molded units offer varying levels of environmental protection, structural strength and mounting options.

As a minimum, all capacitors should be tested 100 percent for capacitance, dissipation factor and dielectric stress at the bare, single-element stage to ensure that all the infant mortalities have been weeded out. The typical dielectric stress voltage is 200 percent of the rated voltage up to voltage ratings of 8 kVdc at which point the stress is reduced linearly to 110 percent at >45 kVdc. Burn-in voltage is selected midway between the rated voltage and the dielectric stress voltage. Capacitance is again checked after soldering, assembly and burn-in operations. Capacitance, dissipation factor (DF) and dielectric stress are once more 100 percent tested at the completion of packaging options. Other customer-specified testing might include, but is not limited to burn-in voltage/temperature and length of time, corona inception and extinction voltages, capacitance, DF, ESR, IR at various temperatures, thermo cycling/shock, shock and vibration, moisture resistance, fungus resistance and resistance to various chemicals.

Joe Moxley is a senior engineer at Custom Electronics, Inc. [1], a manufacturer of high-quality, high-reliability electronic products for military, commercial/industrial, renewable energy, aerospace and oil exploration markets. Joe has 31 years of experience in the design and manufacturing of reconstituted mica paper capacitors with short forays into stacked/plate mica capacitors and polypropylene capacitors.

Links:
[1] http://www.customelec.com/index.htm