ULTRA HIGH IMPEDANCE DIAGNOSTICS OF ELECTROSTATIC ACCELERATORS WITH IMPROVED RESOLUTION

N.R. Lobanov, P. Linardakis, D. Tsifakis and T. Tuningley
The Department of Nuclear Physics, Research School of Physics and Engineering, The Australian National University, Canberra, Australia

Abstract
This contribution describes a new technique to diagnose faults with high-voltage components in electrostatic accelerators. The primary applications of this technique are non-invasive testing of high-voltage grading systems; measuring insulation resistance or determining the volume and surface resistivity of insulation materials used in column posts and acceleration tubes. A simple and practical fault finding data interpretation procedure has been established based on simple concepts. As a result of efficient in-situ troubleshooting and fault elimination techniques, the relative resistance deviation $\Delta R/R$ is kept below $\pm 2.5\%$ at the conclusion of maintenance procedures. In 2015 the technique was enhanced by increasing the test voltage from 40 V to 100 V. Experimental verification of the improved resolution was conducted during recent scheduled accelerator maintenance in May-June 2015.

INTRODUCTION

In electrostatic accelerators, a voltage gradient between electrodes in acceleration tubes is established by resistors conducting current from the high voltage terminal to ground at the entry (low energy) and exit (high energy) of the insulating gas containment tank. The configuration of the 14UD accelerator produced by National Electrostatic Corporation is described in [1]. Typical resistors and ceramic failure modes have been classified by severity in [1–3].

A novel technique to diagnose issues with high-voltage components of electrostatic accelerators is described in [1, 4]. Recently, the resolution of the technique was improved by increasing the test voltage from 40 V to 100 V. The verification of the resolution improvement at higher test voltage is the main purpose of the investigation of this paper. The first section outlines the general concept of high impedance measurement and describes the experimental design, together with the protocols for collecting data and the data analysis procedures. The second section presents key experimental results collected from maintenance performed on the 14UD in May-June 2015 during tank opening (TO) #124. The third section presents the interpretation of the main test results.

METHODS

A good voltage measuring technique for electrostatic accelerators can be accomplished in the most efficient way by using an electrometer [5]. The basic configuration of the method is shown in Fig. 1.

For a chain of N identical resistors of value $R$ in series with applied voltage $U_{\text{meas}}$, if the value of single resistor is changed by $\Delta R$, the relative resistance change is $\Delta R / R = \Delta U / U = N / (U_{\text{meas}} - \Delta U)$. The resolution of this method is limited by the electrometer accuracy of the voltage measurement, $\Delta U / U = 0.1\%$. For an eight and eleven gap tube structure and $U_{\text{meas}} = 100$ V, the $\Delta R / R_{\text{SGT}} = 0.8\%$ and $\Delta R / R_{\text{GSP}} = 1.1\%$ correspondingly. For six and five gap post structure and the same test voltage, the calculated $\Delta R / R_{\text{GSP}} = 0.6\%$ and $\Delta R / R_{\text{SGP}} = 0.5\%$. Evaluation of the data presented in a table provides a feel of what is going on in the high impedance circuit under examination. Components with a measured error above $\pm 2.5\%$ are considered faulty. In the example results presented in Table 1, two faults are highlighted. It suggests that there...
is a lower than expected resistivity in the second tube gap and higher resistance across the second column gap. The comprehensive analysis of a particular pattern collected during the primary non-invasive test is presented in the form of a troubleshooting chart in [1].

The adaptors shown in Fig. 2 have been developed to position the sensor on the equipotential rings. The adaptor device shown in Fig. 2 (b) features a shorter slot geometry and more open space between the insulator and the probe tip electrode. This modification substantially reduces electrostatic interference.

Table 1: Voltage Distribution across an Eight Gap Acceleration Tube and the Corresponding Six Gaps on the Column Post with Suspected Faults Highlighted

<table>
<thead>
<tr>
<th>TP (V)</th>
<th>UgapT (V)</th>
<th>UgapP (V)</th>
<th>ΔL (%)</th>
<th>TP (V)</th>
<th>UgapT (V)</th>
<th>UgapP (V)</th>
<th>ΔL (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.6</td>
<td>12.5</td>
<td>0.0%</td>
<td>1</td>
<td>12.6</td>
<td>12.5</td>
<td>0.0%</td>
</tr>
<tr>
<td>2</td>
<td>24.6</td>
<td>12.0</td>
<td>-4.0%</td>
<td>LO</td>
<td>0.00</td>
<td>&lt;Ugap&gt;</td>
<td>LO</td>
</tr>
<tr>
<td>3</td>
<td>37.1</td>
<td>12.5</td>
<td>0.0%</td>
<td>1</td>
<td>16.8</td>
<td>16.8</td>
<td>0.78</td>
</tr>
<tr>
<td>4</td>
<td>49.8</td>
<td>12.7</td>
<td>1.6%</td>
<td>2</td>
<td>34.4</td>
<td>17.6</td>
<td>5.5%</td>
</tr>
<tr>
<td>5</td>
<td>62.3</td>
<td>12.5</td>
<td>0.0%</td>
<td>3</td>
<td>50.8</td>
<td>16.4</td>
<td>-1.6%</td>
</tr>
<tr>
<td>6</td>
<td>74.8</td>
<td>12.5</td>
<td>0.0%</td>
<td>4</td>
<td>67.10</td>
<td>16.30</td>
<td>-2.22%</td>
</tr>
<tr>
<td>7</td>
<td>87.4</td>
<td>12.6</td>
<td>0.80%</td>
<td>5</td>
<td>83.50</td>
<td>16.40</td>
<td>-1.62%</td>
</tr>
<tr>
<td>8</td>
<td>100.0</td>
<td>12.6</td>
<td>0.80%</td>
<td>6</td>
<td>100.00</td>
<td>16.50</td>
<td>-1.02%</td>
</tr>
</tbody>
</table>

The chart in Fig. 4 shows the service entry and exit test distributions of gap voltages in the column post structure linked to the acceleration tube by means of column-to-tube connection wires. The horizontal axis is the number of the post gap from the low- to high-energy end of the machine. Dashed lines display ±2.5% acceptance margin at different column gap voltages UgapP corresponding to the following measurement conditions: 16.7±0.4 V for six gaps on posts linked to eight gap tubes; 20.0±0.5 V for five gaps on the posts linked to eleven gap tubes; 22.2±0.56 V for column sections where the voltage distribution is set with nine active resistors and remaining resistors are shorted. In case of sections with five gaps, only one resistor is shorted.

Figure 3: The distribution of gap voltage in the accelerating tubes. The horizontal axis is the gap number in the acceleration tubes starting from low energy to high energy. The red series is the compilation of entry test distribution. The green series is the exit distribution. Dashed lines display the ±2.5% acceptance margin at different tube gap voltages UgapT corresponding to the following measurement conditions: 9.1±0.23 V for tubes with eleven gaps; 10.0±0.25 V for eleven gap tubes with one shorted gap; 11.1±0.28 V for eleven gap tubes with two shorted gaps and; 12.5±0.3 V for eight gap tubes.

A test voltage of 100 V is applied to an assembly incorporating an eleven gap acceleration tube in parallel with five column post gaps or an eight gap acceleration tube in parallel with six gaps on the column post. Each end of an acceleration tube is connected to the column section. In the case of ceramic gap failure in an acceleration tube, a quick fix solution is to short out the gap. Since the number of the gaps on the column post is nearly half of the corresponding number of gaps on the acceler-
tion tube, only one of two resistors bridging across the column post gap is shorted in order to maintain a uniform voltage distribution. The calculated voltage distributions across an arbitrary number of column post gaps is shown in Table 2.

Table 2: Calculated Voltage Distribution across an Arbitrary Number of Column Gaps at a Test Voltage of 100 V

<table>
<thead>
<tr>
<th>Number of resistors per section</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>(U_{\text{calc}}) per gap with two resistors</td>
<td>33.5</td>
<td>28.6</td>
<td>25.0</td>
<td>22.2</td>
<td>20.0</td>
<td>18.2</td>
<td>16.7</td>
</tr>
<tr>
<td>(U_{\text{calc}}) per gap with one resistor</td>
<td>16.7</td>
<td>14.3</td>
<td>12.3</td>
<td>11.1</td>
<td>10.0</td>
<td>9.1</td>
<td>8.3</td>
</tr>
</tbody>
</table>

Table 2 represents the current configuration of the resistive divider of the 14UD accelerator. The data highlighted in Table 2 corresponds to boxes of the same colour shown in Fig. 4. For instance, the column post gaps from the section in which the voltage distribution is set with nine active resistors and remaining resistors shorted can be seen highlighted in yellow in Fig. 4 and Table 2. For this, the voltage per gap containing one resistor is 11.1 V and 22.2 V across gaps with two resistors.

The classification of faults observed during TO#124 is shown in the Pareto chart in Fig. 5.

**DISCUSSION**

According to the Pareto chart shown in Fig. 5, the most common failure mode is lack of continuity or poor electrical connection between the column to tube connection at approximately 30%. Of these, failures of the rivet style mountings are the most common.

The next most common fault is an open circuit or poor continuity between pairs of resistors with a fault proportion of 20% for tube resistors and 8% for column post resistors. Pairs of resistors are connected together with a wire inserted into a machined nut at the end of each resistor. The design has proved to be very successful based on operational performance over last two decades. Spark damaged wire leads are still found but are easily replaced.

The next most commonly observed fault category, at 15%, is mechanical failure of the acceleration tube resistor. An example is when the resistor or its spark gap electrode becomes loose in its shield.

The next important fault is a variation of the column post resistor value at 15% or tube resistor value at 8%. The erosion of the resistor conductive layer can occur due to exposure to corona discharge.

The total proportion of faults is 46% for tube components and 23% for column posts. This higher proportion of faults on acceleration tubes is consistent with results reported in [1]. Despite acceleration tubes usually being better protected when compared to column posts, the posts and their resistors are more accessible and historically have been replaced more often as a part of a post refurbishing program.

Finally, the green series in Fig. 3 and Fig. 4 denotes the exit test distribution of gap voltage \(U_{\text{gap}}\). Overall, it can be seen that as a result of in-situ diagnostics and fault elimination, the maximum deviation of \(\Delta U_{\text{gap}}\) is kept well within the acceptable level \(\pm 2.5\%\).

**REFERENCES**


