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Ultra high impedance diagnostics of electrostatic accelerators with improved resolution

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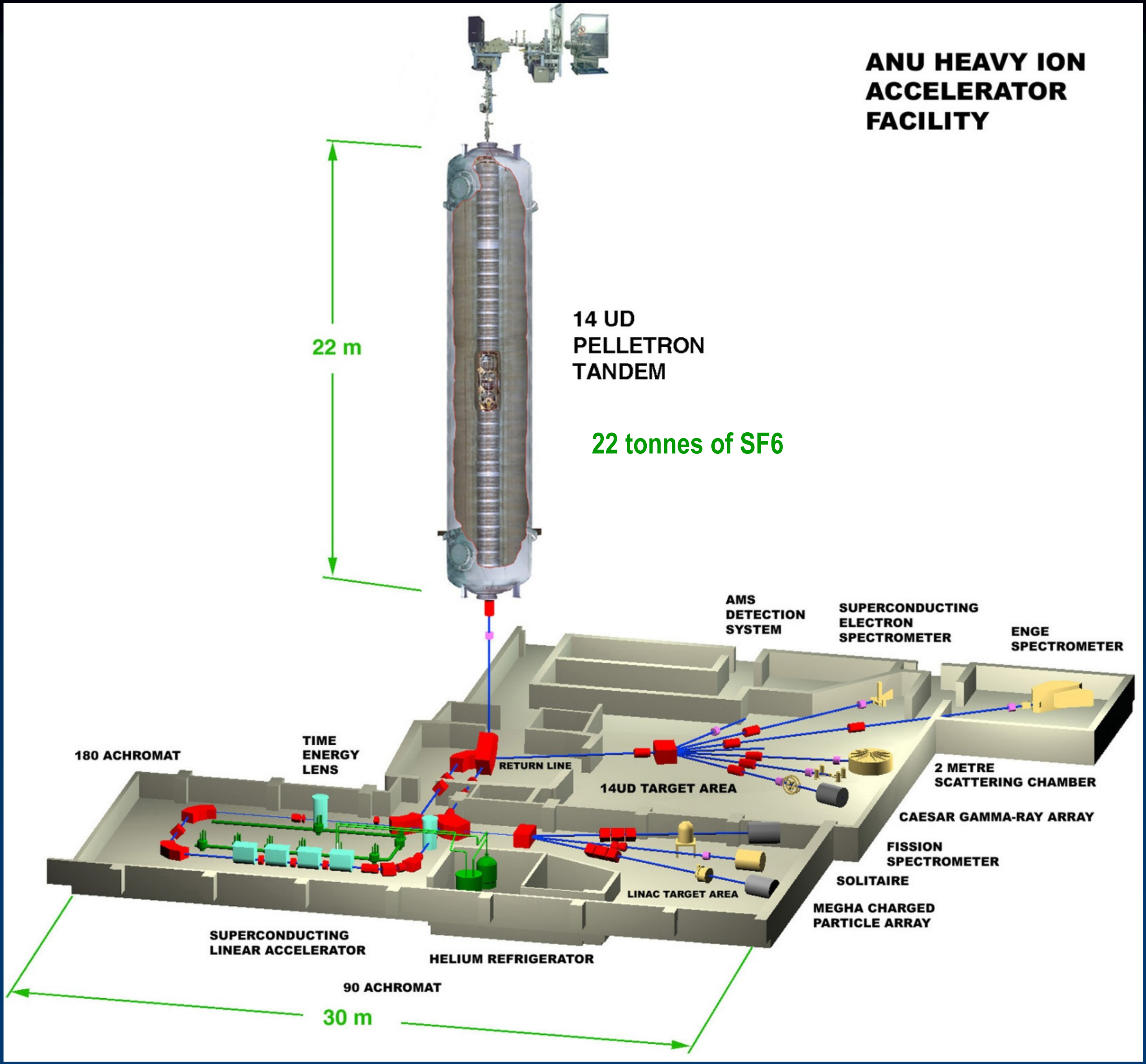
THE AUSTRALIAN NATIONAL UNIVERSITY

Heavy Ion Accelerator Facility ANU


ANU HEAVY ION ACCELERATOR FACILITY
14 UD PELLETRON TANDEM
22 m
22 tonnes of SF6
AMS DETECTION SYSTEM
SUPERCONDUCTING ELECTRON SPECTROMETER
ENGE SPECTROMETER
180 ACHROMAT
TIME ENERGY LENS
RETURN LINE
14UD TARGET AREA
2 METRE SCATTERING CHAMBER
CAESAR GAMMA-RAY ARRAY
FISSION SPECTROMETER
SOLITAIRE
MEGHA CHARGED PARTICLE ARRAY
LINAC TARGET AREA
SUPERCONDUCTING LINEAR ACCELERATOR
HELIUM REFRIGERATOR
90 ACHROMAT
30 m

Motivation

Typical R failure modes:

(A). Explosion when excessive stored energy is absorbed into the resistor.

(B). Mechanical failure due to prolonged strain, vibration or temperature.

(C). Exposure to corona can cause erosion and change R.

(D). Open circuit caused by failure of the external conductors or mechanical break.

(E). "Microbreak" caused by localised vaporization of film due to HV or magnetostrictive shock

(F). "Aging" with R values decreasing during first weeks under stressed conditions.

(G). Short circuit due to mechanical failure or from conductive debris.

Typical failure modes of insulation components:

(H). Mechanical failure varying from surface flaking, criss-crossed cracking to complete separation

(I). Permanent leakage current caused by dielectric failure due to environmental conditions.

(J). Insulator leakage current developed after being exposed to the atmospheric environment.

Open circuit condition can be caused by failure of external conductors:

(K). Breaks in the electrical path between equipotential rings and post electrodes.

(L). Lack of continuity between post electrodes and post to tube conductors.

(M) Lack of between post to tube conductors and tube electrodes.

(N). A break in the electrical path between a pair of resistors.

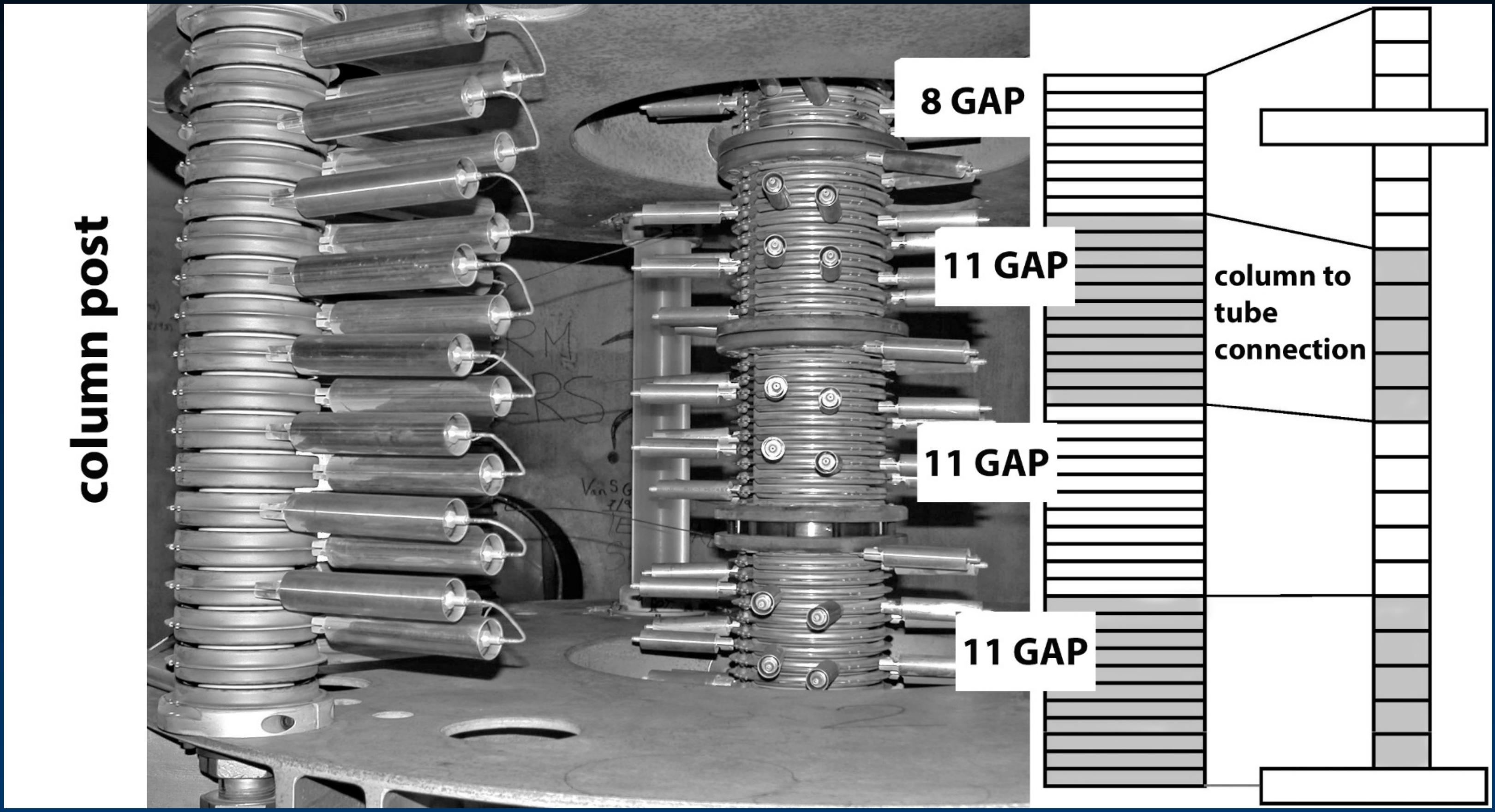
Fault conditions during installation of the resistors.

(O). Incorrect resistor values.

The summary of resistor and insulation components failure modes and diagnostic techniques

Test criteria	High voltage group test	High voltage single test	Low voltage conductivity test	Failure mode
Change of resistance	√	√	√	C, F, O
Open circuit	√	√	√	A, B, D
"Microbreak"			√	D
"Microbreak" spotting				D
Short circuit	√	√	√	G
Insulator failure				H
Insulator leakage	√	√		I, J
Continuity test			√	K, L, M, N
Non-invasive	√			
Immune to ambient			√	
Fast	√			
Transfer Function				

Half of the 14UD double unit



The ANU design employs a pair of 40 kV Welwyn resistors for each column gap. The R value is 982 MΩ in five gap sections and 575 MΩ in six gap sections. Tubes employ pairs of 20 kV 300 MΩ resistors throughout the entire accelerator.

Ultra high impedance voltmeter for electrostatic accelerator applications

Electrometer provides ultra-high input impedance Zi to minimise the current between the experiment and the device with the ultimate goal is to achieve an infinite input resistance and a zero input capacitance.

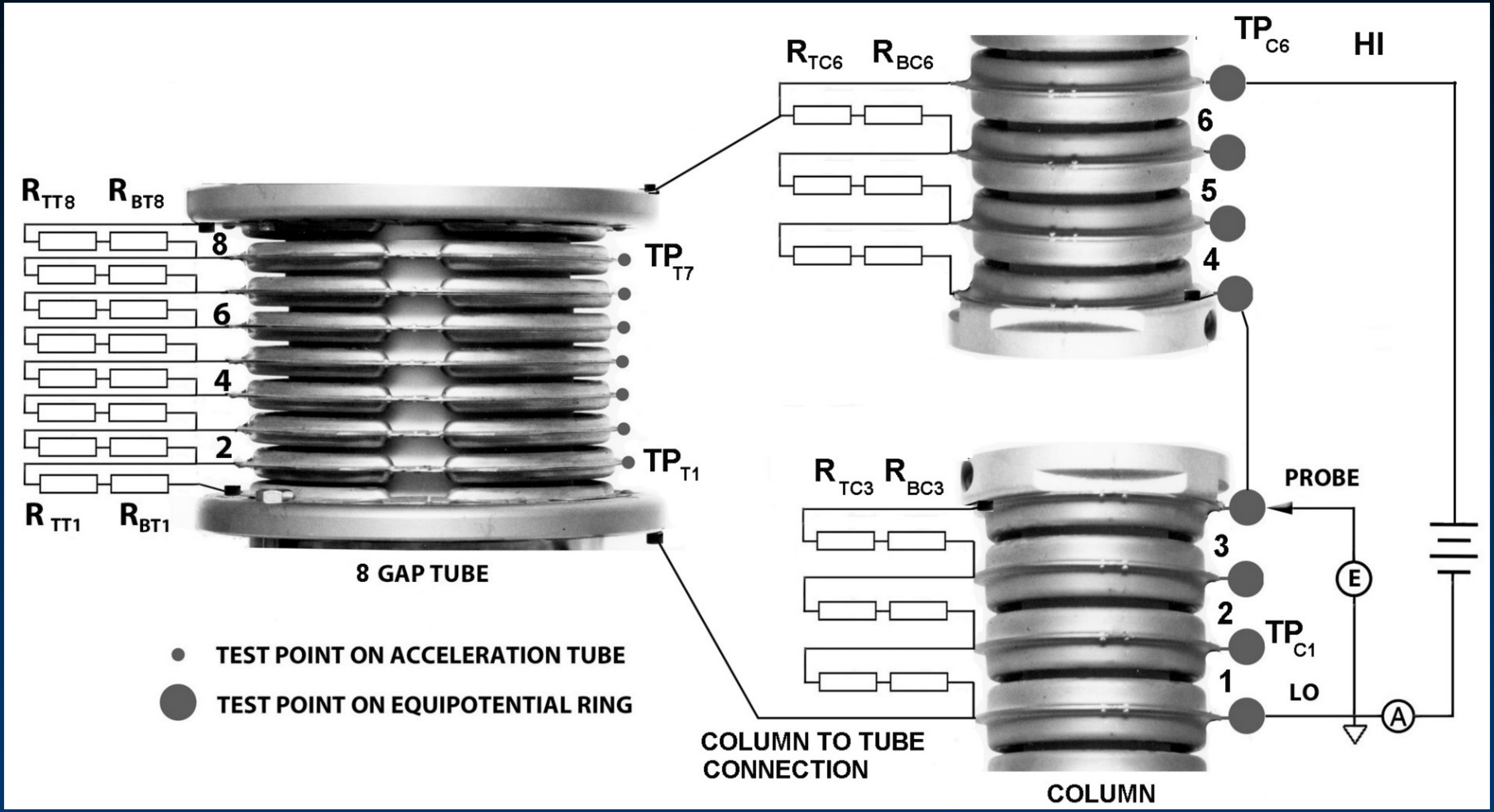
Features of 800 INFINITRON by TREK

- guarding (shield) technique, where the electric potential of the shielding system is feedback-driven to that of the voltage sensor
- the potential of the sensor and the OUI are equal (bootstrap technology)
- the location of the front end amplifier in the probe body

Electrometers specifications

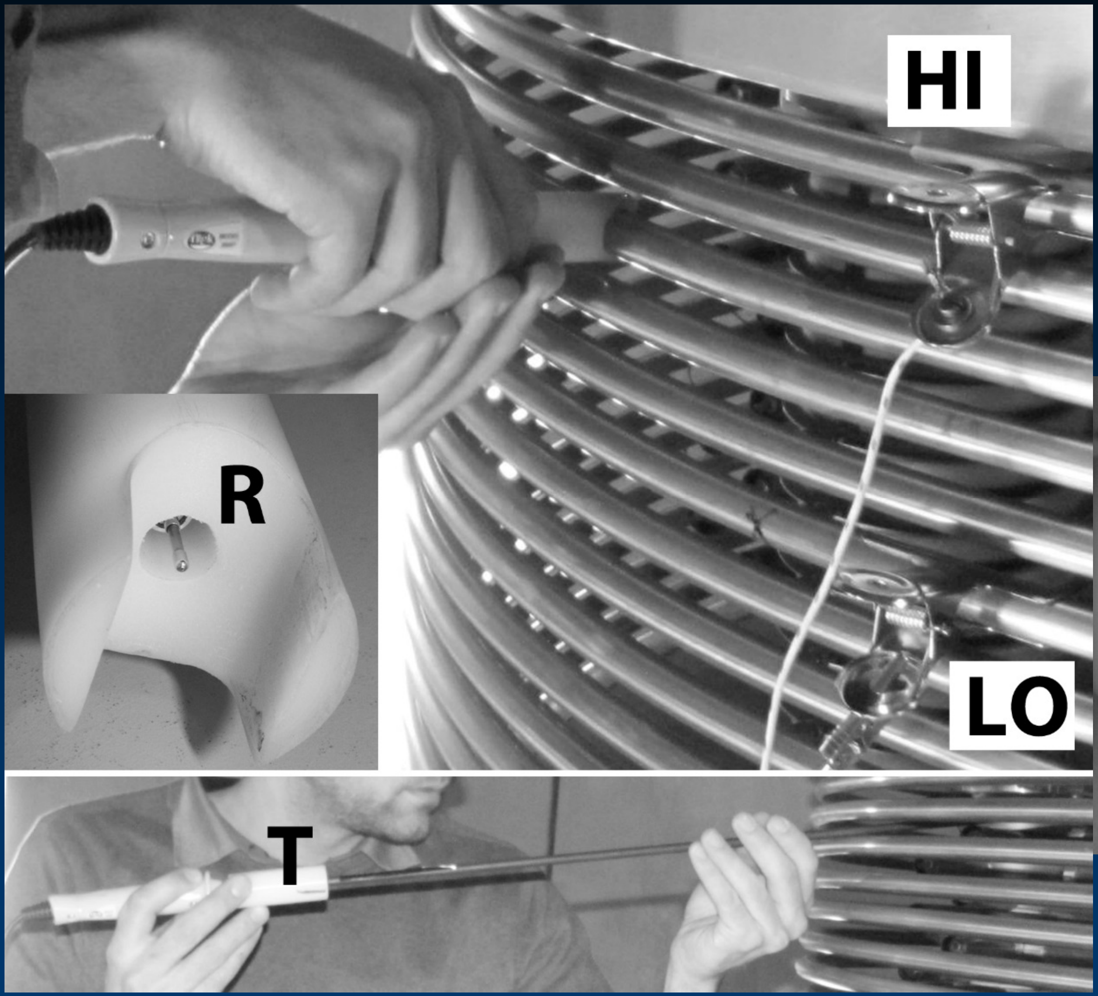
Model	Range, V	Bandwidth (10 V_{p-p})	Accuracy	Drift, mV/hour	Input capacitance	Input resistance
800	±100	10 kHz	±0.1%	<500	$<10^{-15}$ F	$>10^{16}$ Ω
617	200	-	0.4%	-	$<2 \times 10^{-12}$ F	$>2 \times 10^{14}$ Ω

The constant voltage method for non-invasive diagnostics of the high voltage grading system

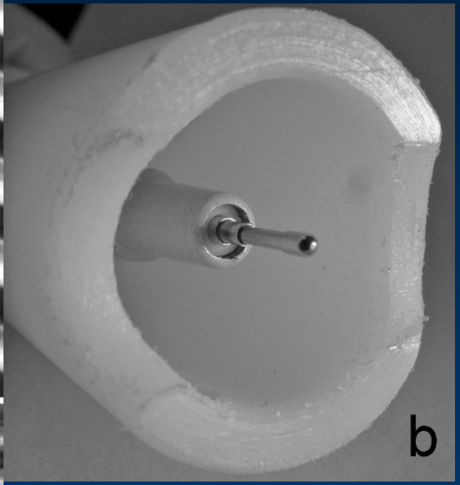


High resistance measurements on two terminal devices should be done in controlled conditions: electrostatic or ac fields; triaxial cabling; unnecessary power equipment off; max two operators conduct the measurements; triboelectric currents etc.

Adaptor devices for INFINITRON 800



2015 mods to adaptor "R"



Adaptor "R" is designed for reproducible positioning of the sensor on an equipotential ring. Adaptor "T" is used as insertion device for quick access to the electrodes on an acceleration tube.

ANU

Measured voltage distribution

TP_T	U_{meas}, V	U_{gap}, V	Δ_T, %
8	100.0	12.6	0.80
7	87.4	12.6	0.80
6	74.8	12.5	0.00
5	62.3	12.5	0.00
4	49.8	12.7	1.60
3	37.1	12.5	0.00
2	24.6	12.0	-4.00
1	12.6	12.5	0.00
LO	0.1	$\langle U_{gap} \rangle$	
		12.5	

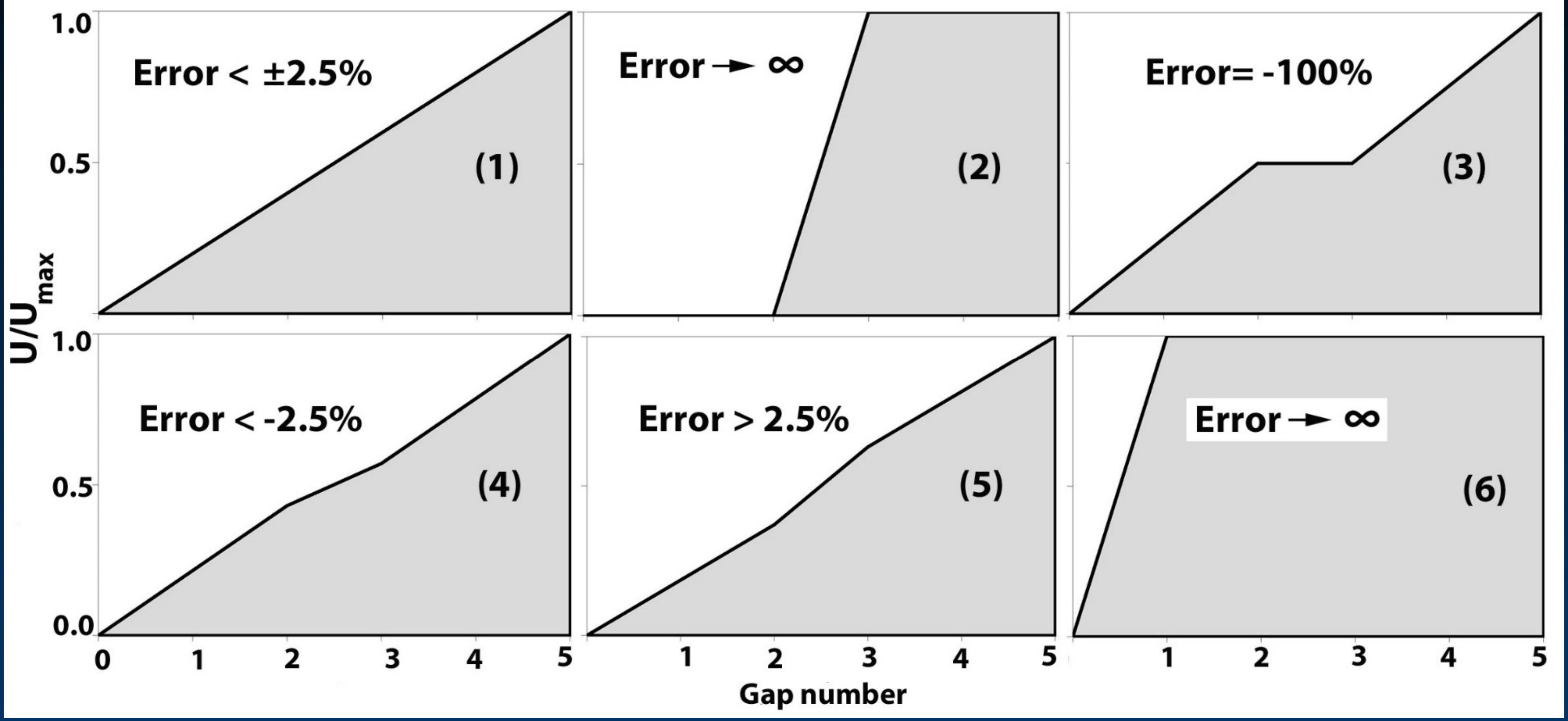
TP_C	U_{meas}, V	U_{gap}, V	Δ_C, %
6	100.00	16.50	-1.02
5	83.50	16.40	-1.62
4	67.10	16.30	-2.22
3	50.80	16.40	-1.62
2	34.40	17.60	5.58
1	16.80	16.80	0.78
LO	0.00	$\langle U_{gap} \rangle$	
		16.67	

TP_T - test point on tube

TP_C - test point on column

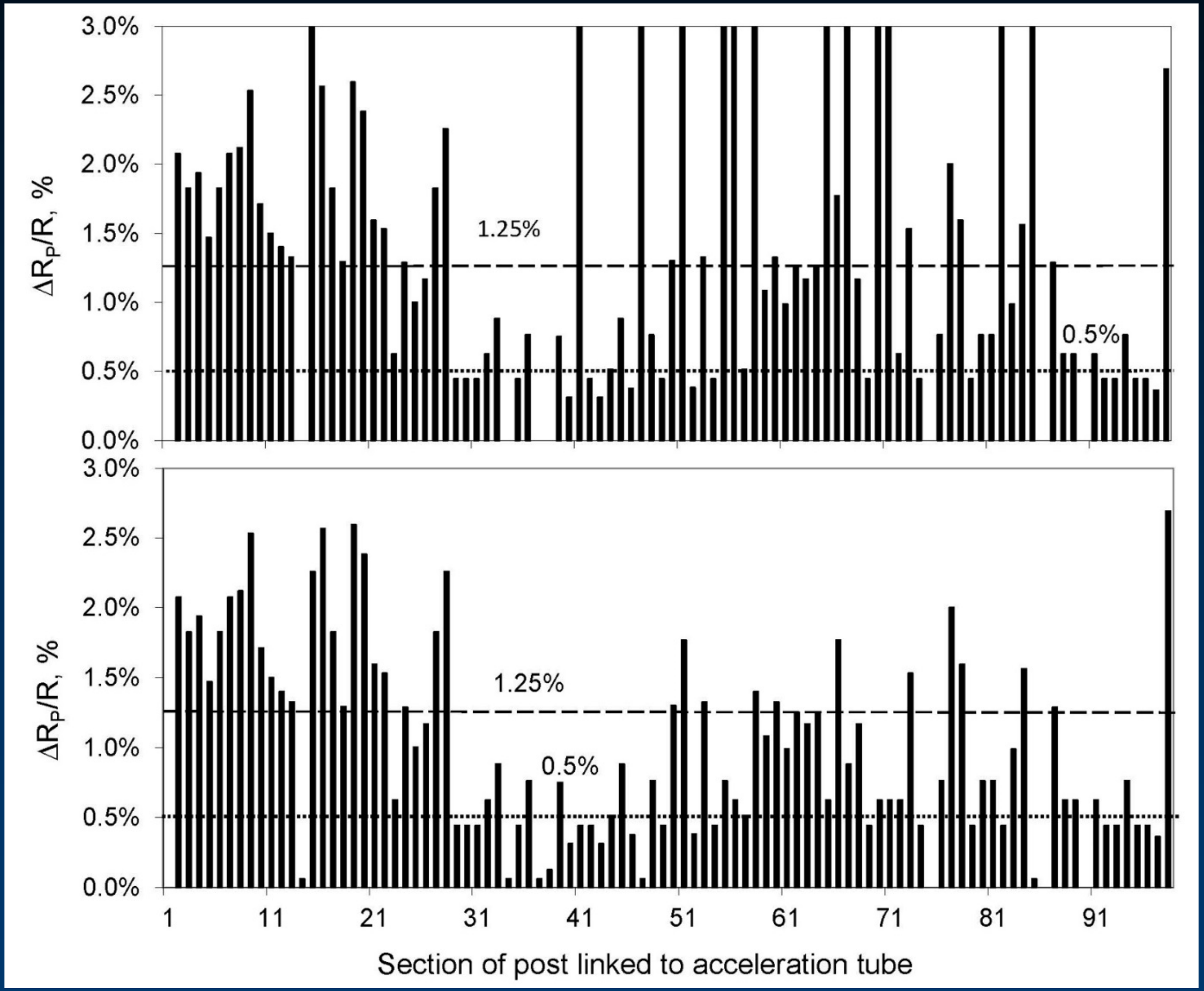
A voltage of 100 V is applied to six gaps on the column by connecting cable leads to equipotential rings marked as LO and HI. The same voltage is applied to the corresponding top and bottom gaps of the eight gap tube via column to tube wire conductors

Troubleshooting chart for express identification of faults



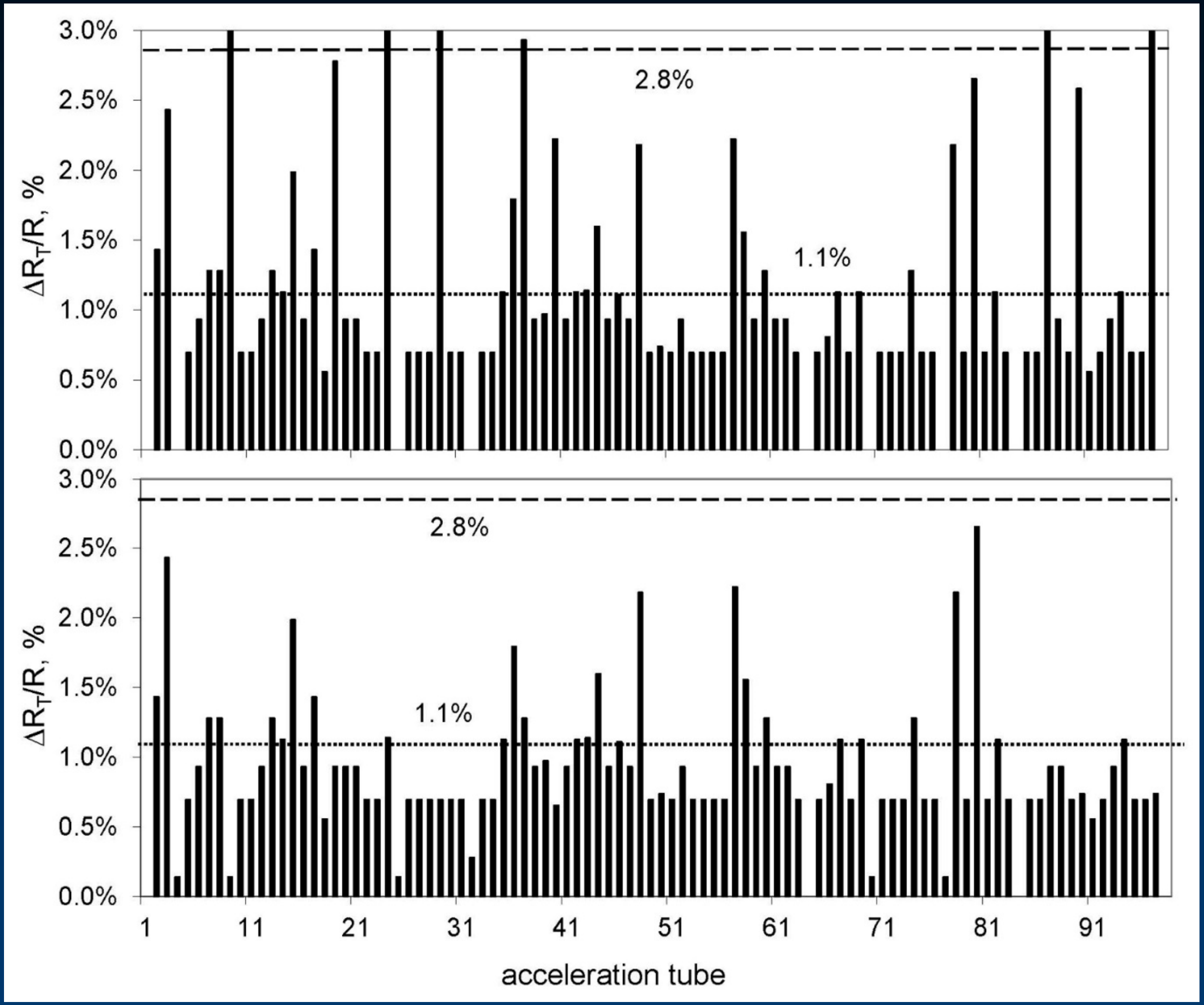
The vertical axis for all graphs is the normalised voltage distribution across five gaps corresponding to different fault conditions such as: (1) fault free system; (2) open circuit in gap 3; (3) short circuit in gap 3; (4) lower resistance in gap 3; (5) higher resistance in gap 3 and (6) open circuit in gap 1.

Experimental results column posts TO #119 up to TO #123 in July 2014.



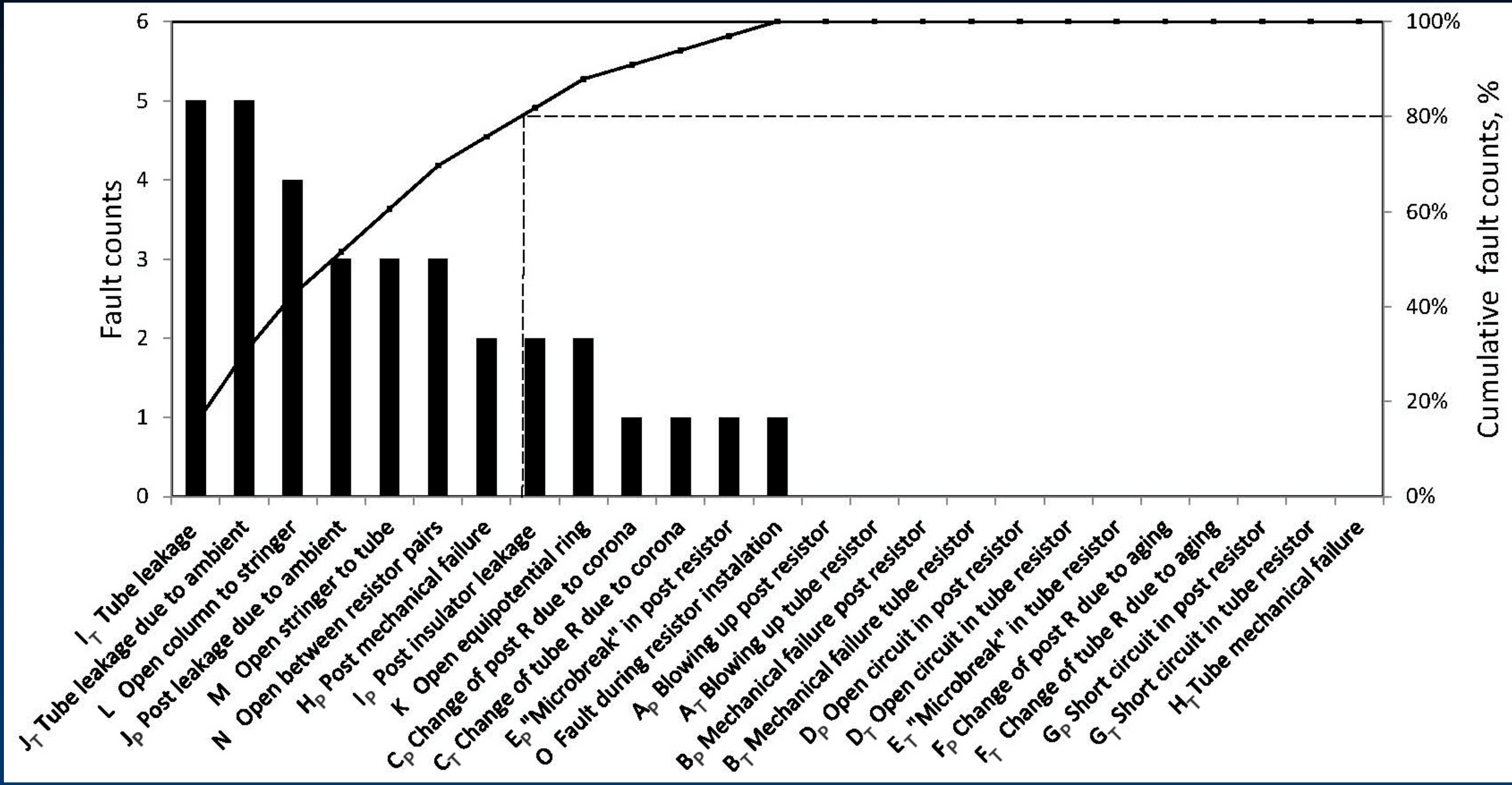
|(ΔRP/R)max| in the posts. Top chart is the compilation of entry test distributions The bottom chart is the exit distribution collected in the end of TO #123. Dashed line is 1.25% resolution at 40 V. Dotted line corresponds to 0.5% resolution if testing at 100 V.

Experimental results tubes TO #119 up to TO #123 in July 2014.



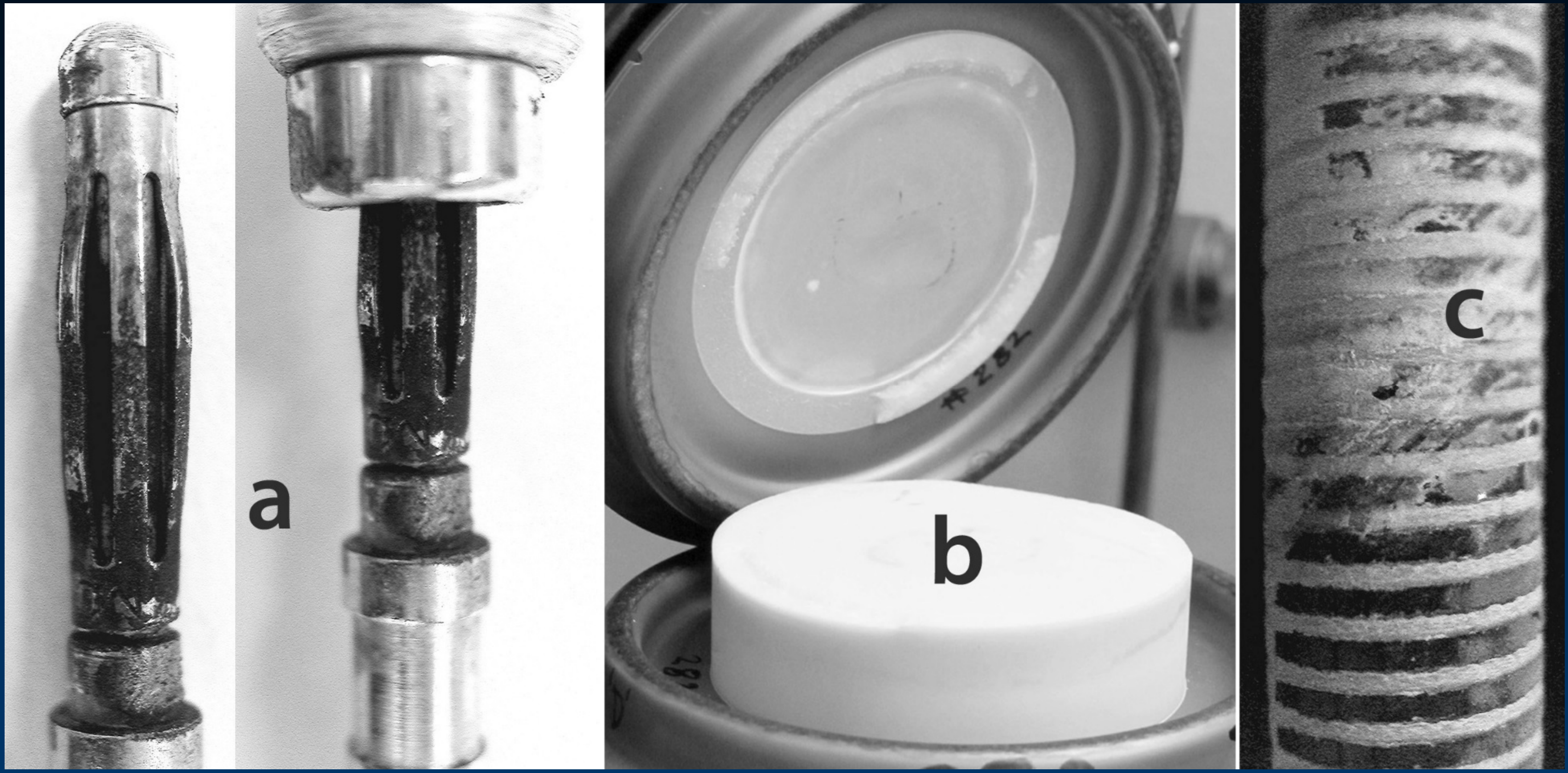
|(ΔRP/R)max| in the tubes. Top chart is the compilation of entry test distributions The bottom chart is the exit distribution collected in the end of TO #123. Dashed line is 2.8% resolution at 40 V. Dotted line corresponds to 1.1% resolution if testing at 100 V.

Classification of the observed faults



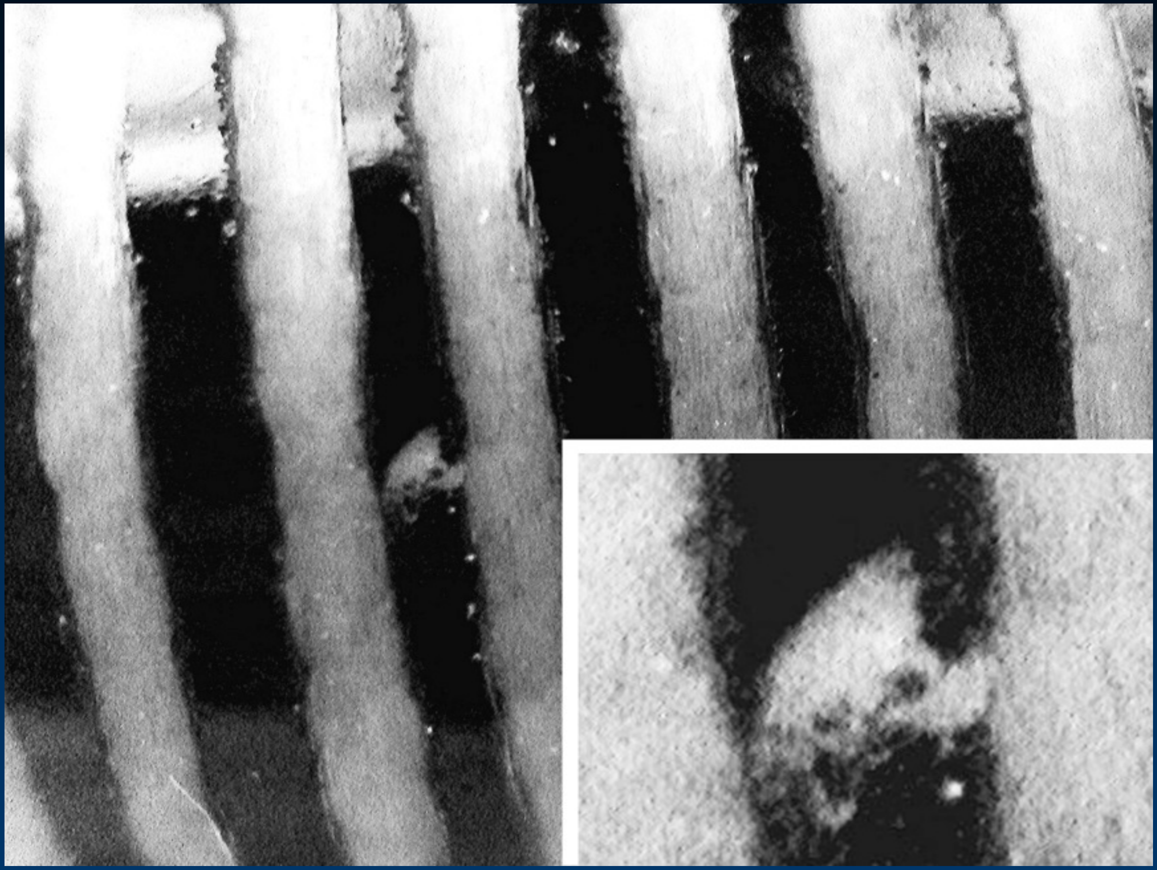
the most common failure modes are tube insulator leakage and tube insulator current developed after being exposed to ambient environment (any gap that exhibits current leakage has at least a hairline crack in the insulator); next fault category is poor electrical connection between post/tube electrode and stringer; next is the open circuit or poor continuity between pairs of resistors etc

Few examples of faults



(a) spark-eroded resistor plug connecting flexible lead to resistor circuit and the same plug inserted partially into resistor receptacle;
(b) (b) the complete separation of the bond between the post ceramic and titanium electrode;
(c) (c) the erosion of conductive layer of post resistor due to exposure to corona discharge.

Example of "microbreak"



"microbreak" on a Welwyn 982 MΩ post resistor. Rounded edges of the film suggest possible localised vaporization of the film due to high instantaneous voltage.

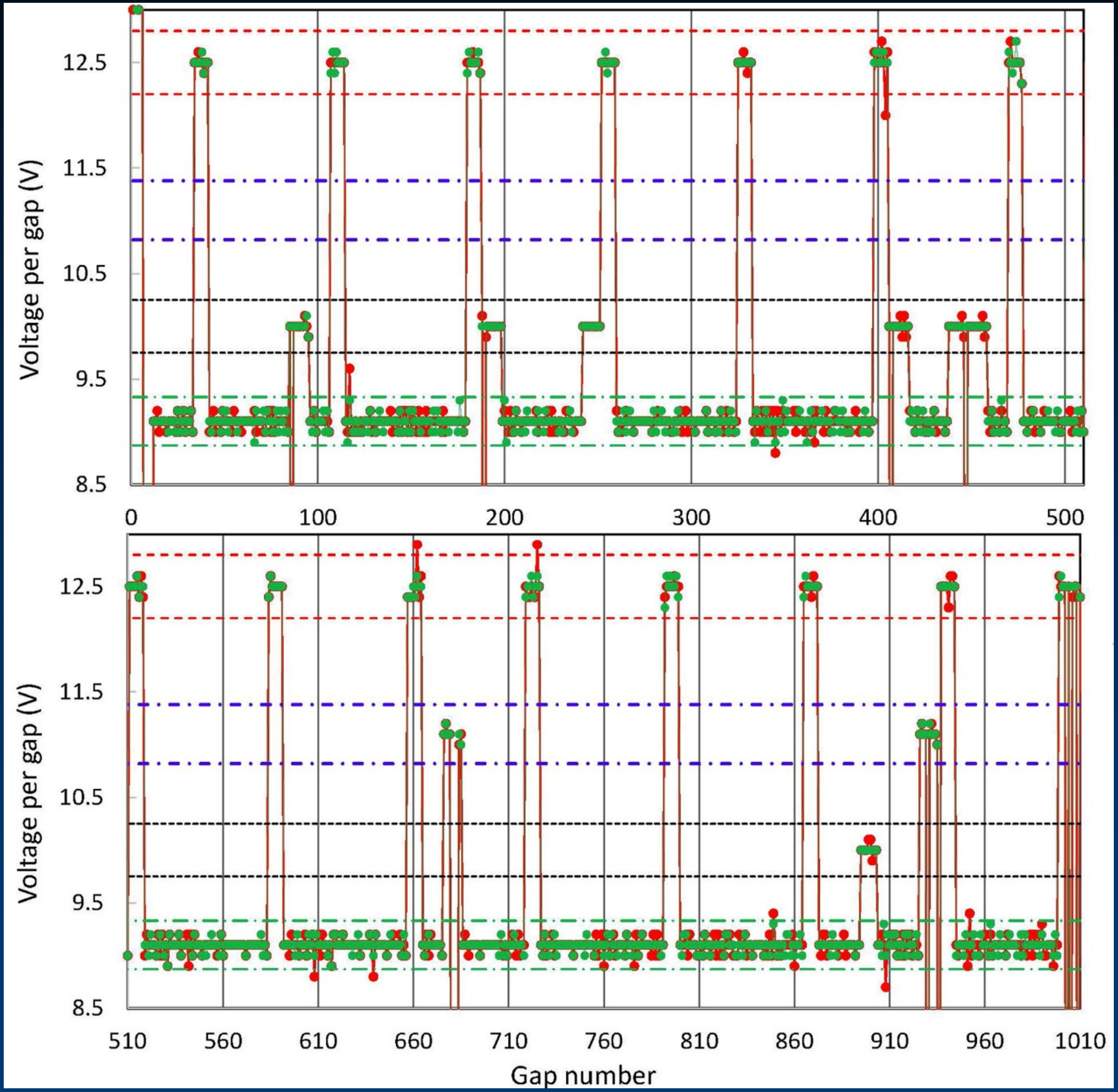
Experimental results at 100 V during TO#124 June 2015

Distribution of gap voltage in tubes.

The red series is the entry test.

The green series is the exit distribution.

Dashed lines displays ±2.5% acceptance margin at different gap voltages.



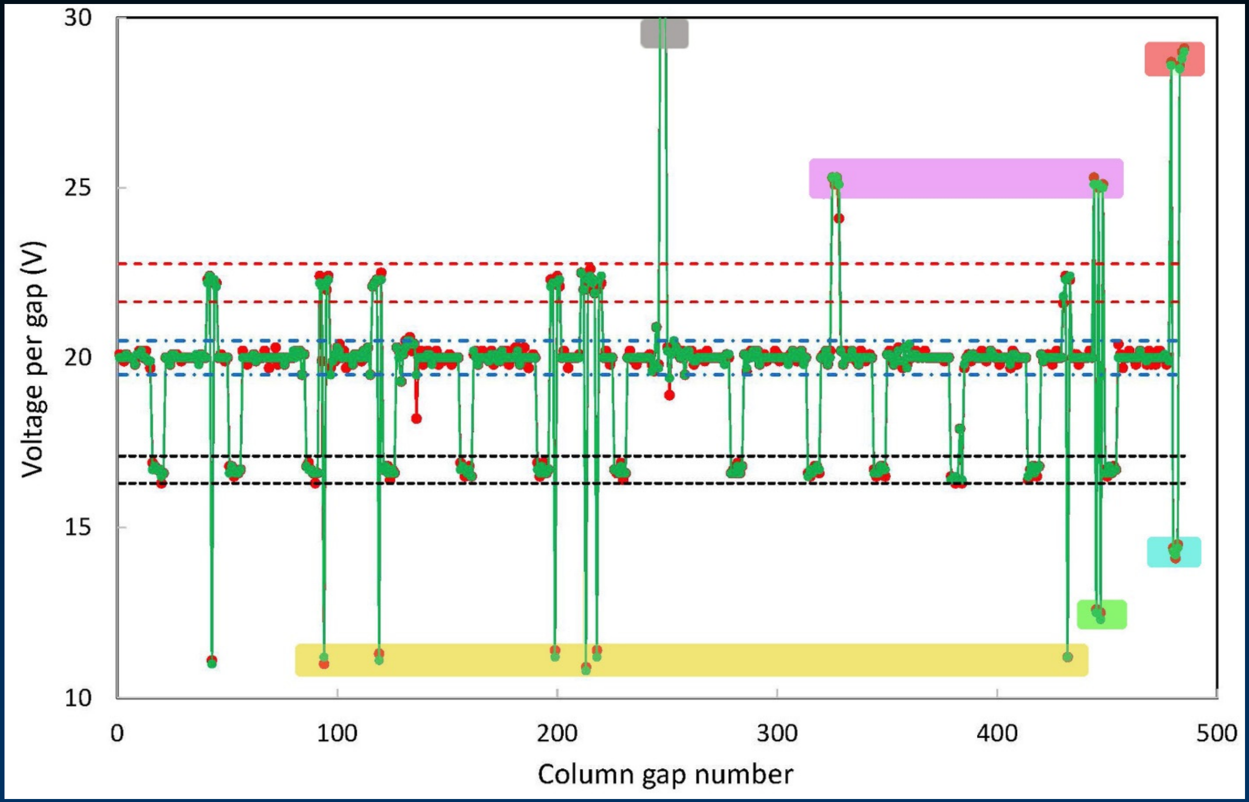
Experimental results at 100 V during TO#124 June 2015

Distribution of gap voltage in column posts.

The red series is the entry test.

The green series is the exit distribution.

Dashed lines displays ±2.5% acceptance margin at different gap voltages.



Calculated voltage distribution across arbitrary number of column gaps at test voltage of 100 V.

Number of resistors per section	6	7	8	9	10	11	12
U_{meas} per gap with two resistors	33.3	28.6	25.0	22.2	20.0	18.2	16.7
U_{meas} per gap with one resistor	16.7	14.3	12.5	11.1	10.0	9.1	8.3

Conclusion and future work

Infinitron technique has become routine diagnostic tool during machine maintenance resulting in better high voltage performance

The resolution at 100 V test voltage is better than 1%

More effort required to improve data interpretation and reduce collection time

Scavenger Hunt 2013

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