Protection of accelerator hardware: RF systems

Joint Accelerator School
November 11, 2014

SANG-HO KIM
SNS/ORNL
This course will go through some selective topics only will not touch details (90 min. course)
RF system layout
arching/discharge mechanism
possible damages from high intensity beam
discuss about protection

Due to large spread of area expertise between students, the lecture materials are prepared accordingly

One homework for student credit
HOMEWORK:

A RF structure is running at f=200MHz and has a gap (g=2 cm).
A plane parallel geometry is a good approximation for this RF structure.
The electric field between gap is

$$E \approx E_0 \sin(\omega t)$$

\(\omega\): RF angular frequency
\(E_0\): electric field amplitude
\(t\): time

Assume that electron starts with zero energy at i=0 from one end.
The gap voltage is

$$V_g = E_0 g = \frac{m_e \omega^2 g^2}{\pi e} \frac{1}{(2n - 1)}$$

\(g\): gap length (m)
\(m_e\): electron mass (=9.11x10^{-31} kg)
\(e\): electron charge (=1.6x10^{-19} C)
\(n\): order of multipacting level (n=1,2,3,...)

1. Ignore magnetic field effect.
   Calculate the gap voltages \(V_g\) and electron impact energies for \(n=1, 2, 3, 4, 5\).

2. What is the threshold electric field \(E_0\) for no multipacting condition in any order of \(n\), before knowing secondary emission yield (purely kinematic resonance condition)? Above this threshold no multipacting can occur.

3. The secondary emission yield of the material for this RF structure is shown above.
   Which order of multipacting levels would be dangerous?
RF system layout
Typical RF system for particle accelerators

RF source; klystrons are the most popular devices for f>300MHz and high power.

  Tetrode, solid state amplifier for relatively lower power and/or lower frequency

RF transmission; Waveguides or coaxial lines

Circulator; usually used as an isolator with matched load to protect RF source

Power coupler; feed RF power to a cavity

Cavity or accelerating structure; electro-magnetic energy storage device

RF control; control cavity field and phase

And protection system
High power RF circuit

- HVPS
- Load
- Main RF Amplifier
- Transmission line

Low-level RF circuit
- I&Q (or A&P)
- Resonance detection & control

AND...

- Timing system & Synchronization
- Protection system (machine & personal)
- Diagnostics & user interfaces
High Voltage Power Supply

High power RF source

Transmitter

Waveguide Network

Waveguide/couplers

Field Probe

Fundamental Power Coupler

EPICS user interface

Control/monitoring

RF control/protection system
RF Structures for Particle Acceleration

Normal Conducting Structures

Superconducting Structures

$\beta = 0$ $\beta = 1$

0.05 0.1 0.25 0.5 0.8

SRF applications are expanding for lower beta region using different cavity shape (Quarter wave, half wave, spoke-type, etc)
What could go wrong regarding machine protection?

Goal: Keep the system in a reliably operable condition preferably forever or till equipment lifetime! (normal large scale machines run about 40-50 years, klystron’s life time 10-15 years, etc.)

In general, high voltage, high power RF system and RF structures give the most downtime in operating machines.

Equipment/parts damages – would require long and expensive rework/rebuild/replacement (and require large numbers of spares)

There are lots of elements that can cause damages and lead to catastrophic failures
For example;

- Water leak into the RF system
- Air leak into the vacuum boundaries
- Sharp edges in the high electric field region
- Dirty RF surfaces
- Possible multipacting bands
- Beam hits RF surfaces
  - beam halo/loss $\rightarrow$ activation
  - errant beam
  - mis-steered beam by mistake
- Large reflected power to the RF source
- Over-powered (over voltage, over current), etc....

Machine protection deals with mostly abnormal conditions and should be well prepared for upset conditions. No perfect system! Continuous efforts are needed.
Critical issues in the RF systems mostly end up

with RF interaction \(\rightarrow\) arcing/sparkling/discharge
sometimes processed out
sometimes makes surface damage

When mis-steered beam directly hits the structure
also surface damage could occur

When a surface damage happens on bad spots (high electric field region, ceramic surface, welding/brazing joints, multipacting region),
\(\rightarrow\) Could results in irreversible process
Discharge mechanism
Gas discharge condition at >~10 mTorr

Paschen curve: DC discharge

Discharge experiment with SRF cavity
Glows and Arcs

Glow discharge:
Cold surfaces or electrodes (thermionic emission and field emission: negligible). Electron emission source: secondary from the surface by ion, radical, photon. Large fraction of electrons: from electron avalanche multiplication in the gas layers adjacent to the cathode (or surfaces). In DC glow discharge, large potential drop (a few hundred V) near cathode → sputtering of cathode material. (often glow discharge application: sputter deposition or etching)

Arc:
Large electron emission from surfaces (by thermionic and/or field emission) in a small area of the surface can occur. The concentrated current flow can produce a very high temperature very locally. even though majority of surface is cold → local dense plasma We are talking about very small dimension→ small potential can lead a very high peak electric field. high electron current can be produced without electron multiplication in a gas.
In high vacuum
; electron mean free path >> structure dimension
; no formation of electron avalanches in space as in gas discharge

Breakdown mechanism is not well understood yet
• Particle exchange mechanism
• Clump theory
• Field emission mechanism

Raymond L. Boxman, Handbook of vacuum arc science and technology (1995)
M S. Naidu, V. Kamaraju, High voltage engineering (1995)
Particle exchange theory

Charged particle come out of one electrode under high electric field; statistically always possible
Accelerated and hit another electrode; liberate particles
Oppositely charged particle back to the first electrode
When this process becomes cumulative → chain reaction
Usually when applied voltage is > a few hundred kV

Clump theory

When loosely bound particles (clusters) exist on surface
This particles (clusters) get charged under high electric field
Accelerated and hit the other surface → vaporization → breakdown
Field emission theory

- **Anode heating mechanism**
  - Electron emission at micron scale protrusion $\rightarrow$ bombard anode $\rightarrow$ cause local temperature increment, release gas $\rightarrow$ electrons ionize gas, produce ions $\rightarrow$ ions arrive at the cathode $\rightarrow$ increase electron emission (by space charge formation and secondary electrons $\rightarrow$ chain reaction until breakdown
  - Longer gap length

- **Cathode heating mechanism**
  - Assumption; existence of pre-breakdown at the field emitter near the breakdown voltage
  - Electric field increases $\rightarrow$ Field emission increases $\rightarrow$ current density at the field emitter goes high $\rightarrow$ reach melting point $\rightarrow$ plasma forms (thermo field electrons) explodes $\rightarrow$ vacuum breakdown
  - Short gap length ($\sim$ a few mm)
Cathode spot (crater formation)

- Rapid and intense heating of the surface (by ion impact and Joule heating)
- Formation of molten layer and evaporation
- Acceleration of the melt mainly by the extremely high ion pressure acting on the surface → pushing the liquid metal outwards → parts of the melt that achieved the highest velocities are thrown out
Schematics of cathode spot

1. Solid metal
2. Molten metal layer
3. Space charge layer
4. Ionization and thermalization layer of the spot plasma
5. Dense central spot plasma
6. Plasma expansion region
7. Ejected molten droplets
Breakdown/arc development

- Before breakdown; quasi static
- At ignition; very short pulse (high frequency)

Function of Capacitances, Field emitter characteristics, Potential development, Field profile, Geometry, Details of contacts, Current, Material, etc.

When the power supply or stored energy is large enough, full arcing condition can occur
Plasma formation and Crater

- some analogies; can have rough guessing about power density and duration of breakdown
- Thermal load; intense, short laser on aluminum surface

Breakdown in solid/surface (dielectric)

- Ionic breakdown
- Electromechanical
- Treeing (streamer)
- Thermal
- Electrochemical
- From internal partial discharge

In practice
- Electrochemical deterioration
- Treeing and streamer
- Internal discharge (void or cavity)
- Surface; Flashover/treeing

Catastrophic failure in insulator
- Driven by electrical power
- Ultimately thermal
- Carbonization or vaporization
- Mechanical failure
Dielectric breakdown enhancing factors

- external source for charge buildup
- Non-uniformity
  - Provide initiation
  - Field concentration
  - Non-uniform charge buildup
  - void, impurity, inhomogeneity of material, insulator related at contact, junction at the boundary, absorbed gases, wrinkles, contact/boundary material, temperature dependencies, etc.
Treeing

- An electrical pre-breakdown phenomenon
- A damage process from partial discharges
- High field concentration
  - at around the edge of trees
  - Charge inhomogeneity near electrodes
- Progress through the stressed dielectric insulation
- Finally breakdown/failure
- Could result in vacuum arc

Surface Flashover in general

- Field establishment from trapped charge
- Surface charging due to diffusion of trapped charge or from the multiplication of secondary electrons
- Subsequent avalanche of the surface discharge
- Streamer growth of charges
- Breakdown (atoms or clusters)

- Three stage
  - Initiation
  - Development
  - Final
Initial stage

- Electron emission at ‘Triple junction point’

Development and breakdown

- Electron multiplication by
  - Surface secondary electron emission avalanche
  - Or electron cascade in a thin surface layer
- Travelling electrons
  - Form a pre-breakdown current
  - Desorption of gas or evaporation and ionization
  - Further increase in current
- Breakdown
- If sufficiently large current density then, vacuum arc will happen
- If field concentration is large at anode, flashover can start at anode triple point
Surface treeing

Curved discharging trace

Jet-like discharging trace

Trapped charge

Diffused electrons


RF breakdown in high vacuum

1. Electrons (multipacting, field emission) heats surface
   Electron bombardment results in gas desorption
   Or
   Beam hits surface and results in gas desorption

2. Local vacuum could be worse and could go into RF breakdown regime

3. With largely available RF power and stored EM energy, plasma heated up and expansion. Usually with flash of X-ray emission and drastic Q-drop.

The detailed mechanism is not well understood, but there are reports that say probably related with field emission and/or multipacting (also beam stimulated).

If the filed is sufficiently high, there are lots of examples of electric breakdown or sparking, arcing, etc.
Multipactoring

Resonant electron loading → strongly depends on geometry and field distribution

Multipactoring condition

1. Resonant trajectory
   (insensitive to the initial energy)

2. \( \text{SEY}(E) > 1 \) (Physical surface condition)
Let’s assume, Electron starts from \( x=0 \) with ‘0’ energy at \( t=0 \)

If the electron arrives at \( x=g \) when the \( t=1/2f=T/2 \), resonance condition is satisfied.

In general \( t=(2n-1)/2f=(2n-1)T/2, \ n=1, \ 2, \ 3, \ 4, \ ... \)
Equation of motion

\[ a = \frac{eE_0}{m_e} \sin \omega t \]

Integration for \( v \)

\[ v = -\frac{eE_0}{m_e \omega} \cos \omega t + C = \frac{eE_0}{m_e \omega} (1 - \cos \omega t) \quad (\because v=0 \text{ at } t=0) \]

actually secondary electron energy at birth is about 1-3 eV

Integration for \( x \)

\[ x = \frac{eE_0}{m_e \omega^2} \sin \omega t + \frac{eE_0}{m_e \omega} t \quad (\because x=0 \text{ at } t=0) \]

Resonance condition, \( x=g \) at \( t=(2n-1)/2f \)

\[ g = \frac{eE_0}{m_e \omega} \frac{(2n - 1)}{2f} = \frac{\pi e E_0}{m_e \omega^2} (2n - 1) \rightarrow E_0 = \frac{m_e \omega^2}{\pi e} g \frac{g}{(2n - 1)} \]

Gap voltage \( V_g=E_0 g \) (no transit time yet)

\[ V_g = E_0 g = \frac{m_e \omega^2}{\pi e} \frac{g^2}{(2n - 1)} \]
Transit time factor (TTF): since the field is changing while the electron moves, the effective voltage or field seen by the electron should be taken into account.

\[ E = E_0 \sin \omega t \]

The energy gain becomes: \( KE = E_0 (TTF) g \)

In this parallel plate geometry, the transit time factor for the particles in resonance condition is

\[ TTF = \frac{2}{\pi (2n - 1)} \quad n = 1, 2, 3, 4, \ldots \]

The electron impact energy in resonance condition (again let’s assume the secondary electron at birth is ‘0’, actually it is about 1-3 eV)

\[ KE = E_0 g = \frac{2m_e \omega^2 g^2}{\pi^2 e (2n - 1)^2} \quad \text{in eV} \]

Ex. \( f=500\text{MHz}, \text{gap}=0.02\text{m} \rightarrow n=1, \text{impact energy}=2915 \text{ eV} \)
\( n=2, \text{impact energy}=324 \text{ eV} \)
\( n=3, \text{impact energy}=116 \text{ eV} \)
Multipacting in general

MP is mostly at low electric field side.
  during ramp-up
  beam pipe (stray field region)
  window, iris, couplers
  equator sides of cavity, etc

How to avoid:
Careful analysis during design stage & simplify the design (avoid resonances)
Reduce Secondary Emission Yield
  Keep the surface clean (no contaminant, gas, particulates..)
  RF conditioning reduces
  Baking, discharge cleaning,
  Surface coating (Ti, TiN)
  DC biasing
*Detuning
  Slight change of VSWR: sometimes helps when MP happens in the transmission line (waveguide, window, coupler, etc.)
*Over-coupling (lower time constant)
  to pass MP region quickly especially in pulse machine
  *very limited range of control
Field emission (FE)

Fowler Nordheim Law

\[ j \propto \frac{(\beta E_s)^2}{\varphi} \exp \left[ -\frac{a \varphi^3/2}{\beta E_s} \right] \]  
Shape factor \( \beta \) (could be >100), work function \( \varphi \), etc.

Theoretical limit \( \sim 1 \text{ GV/m} \), reality \( \sim <10 \text{ MV/m} \)
Mild FE: system may be operable. Vacuum could be worse (operation would be difficult). Could kill valve o-rings. Especially in superconducting cavity, limit achievable gradient, lower Q, make system unstable, etc.
Sometime big burst of field emitter could make surface defects.
Field emission and its enhancement

- **Model**
  - Protrusion-to-protrusion
  - Modification of constant and shape factor in FN equation by absorbed gases and other contaminant
  - Activation of field emitter at elevated temperature by changes of the boundary layer
  - Insulator enhanced; from the distortion of electric field

- **Complexity**
  - Function of size, shape, kinds of particle, charge, substrate status, wettability, temperature, processing history…….. (statistical distribution, hard to control, larger surface will statistically have more field emitter)
Kilpatrick criterion

Old criterion on RF breakdown but still in use

In late 1950s, W. Kilpatrick analyzed for RF breakdown free condition.

\[ f(MHz) = 1.64E^2 \exp\left(-\frac{8.5}{E}\right) \]

\( E: \) breakdown electric field \( \frac{MV}{m} \)

This estimation is based on the old system especially vacuum system. It is a pretty conservative criterion. Usually RF system is designed and operated at the factor between 1 and 2.
Vacuum
When there is no leak and pumping is good, outgassing still exists.
Outgassing

1. Desorption: gas release from the surface. Final state of all outgassing mechanism. Bonding mechanisms can be either physical or chemical. In general chemical bonding is stronger. Desorption rate increases with temperature. Desorption is accelerated by photons, electrons and ion bombardment.

2. Vaporization: phase transition of material to the gas. Materials with higher vapor pressure can evaporate in vacuum and/or at elevated temperature.

3. Diffusion: dissolved gas in the bulk material moves to the vacuum surface. Hydrogen have high mobility in the bulk material.

4. Permeation: absorbed gas from outside diffuses through the bulk material and then desorbed from the vacuum surface.
Reducing Outgassing

Polishing: reduce the effective surface area and the adsorption capacity

Heating: baking or firing
150-300°C baking is very helpful to get rid of water but not enough for hydrogen. Any metal is a large reservoir of hydrogen. During the heat treatment CO and CO2 are often emitted in addition to hydrogen.
Firing temperature: 500°C for OF Copper, 1000°C for Stainless Steel

Gas discharge cleaning

Photon or electron bombardment/showering

Coating
OFH copper degassing at 500°C

Stainless steel

E. Hoyt, SLAC-TN-64-5, Jan (1964)
Beam related issues
Central challenge at the beam power frontier is controlling beam loss to minimize residual activation.

- 1 W/m at 1 GeV proton beam for hands-on maintenance.
Mis-Steered beam: Copper damage

Electron beam

Electron stopping in the material

Simulation for SNS linac beam dump window using CASINO (electrons stripped from H-)

Electron trajectory

Energy distribution

Energy deposition vs. depth
Proton/Ion beam stopping

Bragg curves for 90 degree incidents

7.5 MeV

22.8 MeV

90 degree beam

Cu

22.8 MeV Proton

Depth (mm)

Energy Loss (eV/mm)
Thresholds or Criteria to protect structure (example)
Thermal: below melting temperature
Mechanical: below mechanical stress limit (ex 70 % of yield, 50 % of tensile strength..) due to thermal gradient, also including fatigue effect and fractural toughness

Mostly mechanical threshold comes much earlier
In this example the peak temperature is < 200 C when the peak stress reaches the mechanical threshold

Usually MPS analysis is done with pretty conservative assumption
Ex. SNS DTL (2.5 MeV DTL 1 input energy, 7.5 MeV DTL output energy)
Time to reach the mechanical stress threshold

7.5 MeV, $\sigma_r=4$ mm

2.5 MeV, $\sigma_r=4$ mm
MPS delay from the fast interlock system

RF system
When a fault condition is detected in a unit of the system (arc, cavity field, forward power, reflected power, circulator power, klystron reflected power, etc.)

→ It truncate or turn-off the RF in < 1-2 us.
At the same time it sends the signal to MPS system

→ The signal passes through the MPS chains

→ abort beam (usually source beam truncation from front-end)

Abnormal beam from the Source

→ Abnormal beam transportation

→ Beam loss monitor detects the fault condition
At the same time it sends the signal to MPS system

→ The signal passes through the MPS chains

→ abort beam (usually source beam truncation from front-end)

Typical MPS delay that uses fiber optic cables and passes through the chain: 15-30 us
Errant beam

off-energy beam generated anywhere in the accelerator and transported to the downstream in a fault condition
Since the errant beam is off-energy beam, it is mostly lost while transported through the linac, which results in beam trips caused by excessive beam loss.

Errant beam hits cavity surface: desorbs gas or particulates and there’s a non-zero chance for creating an environment for arcing/discharge

Dedicated MPS line for the fast interlock system could reduce the MPS delay down to 5-6 us.
Ion source/LEBT is one cause of errant beams

Normal ion source pulse
~ 33 mA
Low current pulse causes beam loss in SCL
Ion source/LEBT errant beam example

- DTL4 RF waveform
- Drop in beam current beginning in the MEBT
- HEBT BCM01 was not working for this case
Example: Odd beam from front end

Previous normal pulse
RF Truncation in NC structure

Abnormal RF pulse with beam

Normal RF pulse with beam

370 useconds in CCL

22 us full beam lost in the SCL

348 useconds in HEBT

Normal RF pulse with no beam
Layout of dedicated MPS

- Wideband current transformers:
  - 1 GHz with 1 ms droop time constant
  - Nearest one before and after SCL
  - Long cable lengths (500-1200ft)

Amplifiers and attenuators to counter induced noise on long cables
Understanding of the system is the most important aspect for the safe operation and equipment protection

• Let’s take an example with klystron for machine protection point of view.
  – how they are designed or fabricated
  – Klystron is a high power rf source where many accelerator related components are in place such as electron gun, beam acceleration, RF coupling, beam bunching, maintain high vacuum, DC high voltage, beam dump, RF window, cooling, beam focusing, etc.

• And then discuss about how to protect it.
• Since there are many analogies, this example will help expanding the idea for other equipment.
Klystron
Klystron

- History

The klystron as first described by the Varian brothers. *J. appl. phys.*, 10 (1939), 324.

- A few hundred MHz ~ tens of GHz
- A few hundred W ~ several tens of MW
- Typical efficiency RF power/DC power: 50-70 %

US patent No. 2242275, Russell H. Varian, May 20, 1941
Klystron is a RF amplifier.
Electron beam starts from cathode and accelerated by the pulse or DC voltage. (DC beam, not bunched yet)
Beam passes through the input (bunching) cavity that is excited by low power RF/microwave. When beam passes through the input cavity, bunching process starts. While drifting the beam tube, bunching develops. When bunched electron beam reaches the output (or catcher) cavity where the bunching is maximum, bunched beam induces RF current in the output cavity. The amplified RF is extracted through the output coupler. Beam is dumped on collector.
Electron Gun

Dispenser cathode
- Operating temperature: 1100K-1500K depending on application
- Current density: A few tens A/cm²
- Typically <2 A/cm² or much lower
- BaO, SrO, Al₂O₃ impregnated into porous tungsten + many artistic additions
- Very sensitive emission characteristics
- Need very careful treatment & handling
- Lifetime is function of temperature (or emission current density)

→
1. Failure of emission: poisoning or depletion of oxide or impregnant.
2. Failure of heating mechanism: heater short or open circuit.

Have to keep good vacuum, clean condition, & adequate cathode temperature

High voltage
400 kV (ex. S-band 80 MW tube)
130 kV (ex. 700-800 MHz, 5 MW tube)

→ DC Arcing/discharge
Cathode

E-guns are mostly running in the space charge limited regime

**Space charge limited regime**: when electron emission density is large enough at a certain cathode-anode voltage, electric field at the cathode surface becomes zero. And emission current vs. voltage $\rightarrow$ Child-Law:

$$I = PV^{3/2}$$, $P$: Perveance (geometric factor)

If **temperature is not high enough** (if some area of the cathode does not reach the space charge limited condition), the emission characteristic becomes very sensitive with temperature (temperature limited regime) thus beam quality and optics change.

If **temperature is too high**, cathode life time gets short.
**Magnetic field**

Cathode is immersed in magnetic field
Confined flow focusing
Failure in magnet or magnet power supply
Running at a wrong field → could be catastrophic

**Collector**

Designed to have fairly uniform power density
High power klystrons
  ex 1.3 MW CW: ∼2 MW DC beam dump
  cooling failure → catastrophic
  vacuum failure → catastrophic
  : vacuum firing (minimal outgassing at high power beam bombardment)
Output coupling and Window

Typically iris or loop coupling

Window:
One of the limiting factors for peak and average power.
Adequate power handling: low loss RF dielectric material.
Good match over the frequency band of the klystron.
Trapped mode near operating frequency:
  electric breakdown, instability of RF
Main danger in high peak power window:
  Multipacting
  high VSWR
Multipacting on cavities in klystrons

As mentioned in the previous page, MP is possible in windows and output circuit.

In addition, the cavities in the klystron is, of course, the possible MP region.

It could be dangerous or could result in instability.
Couplers
Power Coupler

Function: Deliver RF power
Coupling $\Rightarrow Q_{ex}$

Concerns: Transmission loss
Thermal stability
Mechanical stability
Simplicity
Reliability
Cost
Multipacting

Frequency
Power needed
Coupling Types
Cooling
Window

SNS Fundamental Power Coupler
Power couplers
For SRF cavities

Coaxial

Waveguide

SNS power coupler

TTF3 coupler (ILC)

CEBAF WG coupler

Cornell CESR WG coupler
Coupler conditioning
Multipacting simulations

SNS Choke window

One point MP at outer conductor

- 1.3 GHz
- 50 Ohms
- 61.6 mm


* G. Devanz, CEA Saclay, SFP Meeting in Roscoff in 2000
SNS MP examples: e-probe, radiation

Radiation detector signal
ex. Mostly from multipacting around power coupler

Processing in a mild condition and DC biasing help.
Arcing on the window: vacuum leak

550 kW, 805 MHz
Coaxial window crack

5 MW, 805 MHz
Window failure

Possible discharge evidence
MP in the notch type HOM coupler

Figure 3: Curved leg of the HOM F-probe fractured from HOM can.
T. Khabiboulline et al, PAC07

56MHz QWR for RHIC
SLAC-PUB-15753

Simulation for ILC, FNAL

10 MeV/m
28 MeV/m

Figure 7: Resonant particle trajectories at the HOM coupler. Top-left: $E_{peak} = 72$ kV/m; Top-right: $E_{peak} = 93$ kV/m; Bottom-right: $E_{peak} = 102$ kV/m; Bottom-left: $E_{peak} = 344$ kV/m.
Again in order to avoid MP

One can carefully design the RF geometry to avoid MP. If the surface is not clean enough, still there are chances especially if geometry is complex. Analysis may not cover all details. Also if geometry is complex, cleaning would be very difficult.

Usually MP could be processed out by careful conditioning/processing. But not always. If there’s not enough diagnostics (blind conditioning), arcing or catastrophic failure could be followed.

When arc detector detects an arc or e-probe shows abnormal signals, careful conditioning would be required (a single arc could damage surface). Conditioning at short pulse, low duty helps (sometimes very time consuming). Initial conditioning without DC biasing is preferable if possible.
SNS Examples
Interlocks/RF permission

LLRF system collects all permissions from other systems.
Ex. Cavity Partial Quench
Discussion & Question