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Reliability of water cooling systems on radio-frequency modulators for industrial LINAC accelerators

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ABSTRACT:

High frequency power provided by high-voltage modulator designed with vacuum tubes, serves to accelerate the electron beam in the section formed by copper cavities. Some of the remaining power is dissipated in the cavities and metallic components of the modulator such as PFN, tubes, power supplies. These components are cooled by a circulation of water and forced ventilation. The importance of regulating the temperature of the cooling water is to maintain the same temperature in the cavities and in high power components. This is an important factor in maintaining frequency tuning. The design and sizing of the cooling system must take into account many factors like ambient temperature, the nature of the water used, the power generated by the accelerator and other important factors. Based on a history of our Linac accelerator, this work will focus on the cooling problems that may affect reliability of radiofrequency modulator installed on hot-cavity accelerator.

ELECTRON BEAM ACCELERATOR:

Tunisian electron beam accelerator installed in 2009, is a Linac CIRCEIII machine, with vertical position, from « Linac-Technologies company » in Orsay -France,. It's a design from the old CGR &THOMSON companies..

The electrons are produced in vacuum, by thermoïonic effect in the gun with low energy (about 80 KeV), then the modulator supplies pulsed high voltage to the electron source and the klystron and controlled by a Thyratron. The beam has a small size, so to cover the width of the volume of the products, it is necessary to scan the beam , for this purpose an electromagnet is used, in which a variable current is passed with 5 Hz frequency.

The accelerator has this caracteristics:

Beam Av. Power : 5kW (Extensible to 10Kw)

Beam Energy:(5Mev; 7,5 Mev; 10 Mev)

Frequency (klystron) :2,998 GHz; **Répétition rate** : 50 to 300 Hz

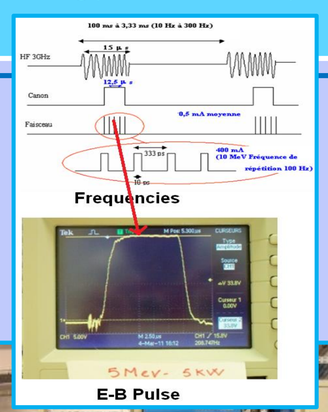
Beam Current : 10 MeV: 200 mA; 7,5 MeV: 300 mA ; 5 MeV: 400 mA

Capacity of production (sterilisation of pharmaceuticals): 2,16m³/h (minimum dose in every point of the product 25 Kgy)


PRIMARY COOLING SYSTEM


SECONDARY COOLING SYSTEM


10 MEV E.BEAM ACCELERATOR &MODU




Control & H.V pannels

THE COOLING SYSTEM:

A cooling system consisting of two compartments: the first is installed outside the building (Gaz to water system), and the second is inside (water to water system), this is to ensure stable temperatures of 21 ° C in components of the accelerator, and to keep them continuously cooled.

High temperature of components are cooled by a circulation of glycolic water in the primary system and deionized water in secondary system. The two system communicate with two plates heat exchanger with this characteristics:

Heating power : 114 KW

Flow rate : 19 m³/h

Gaz (refregirant) :R407C

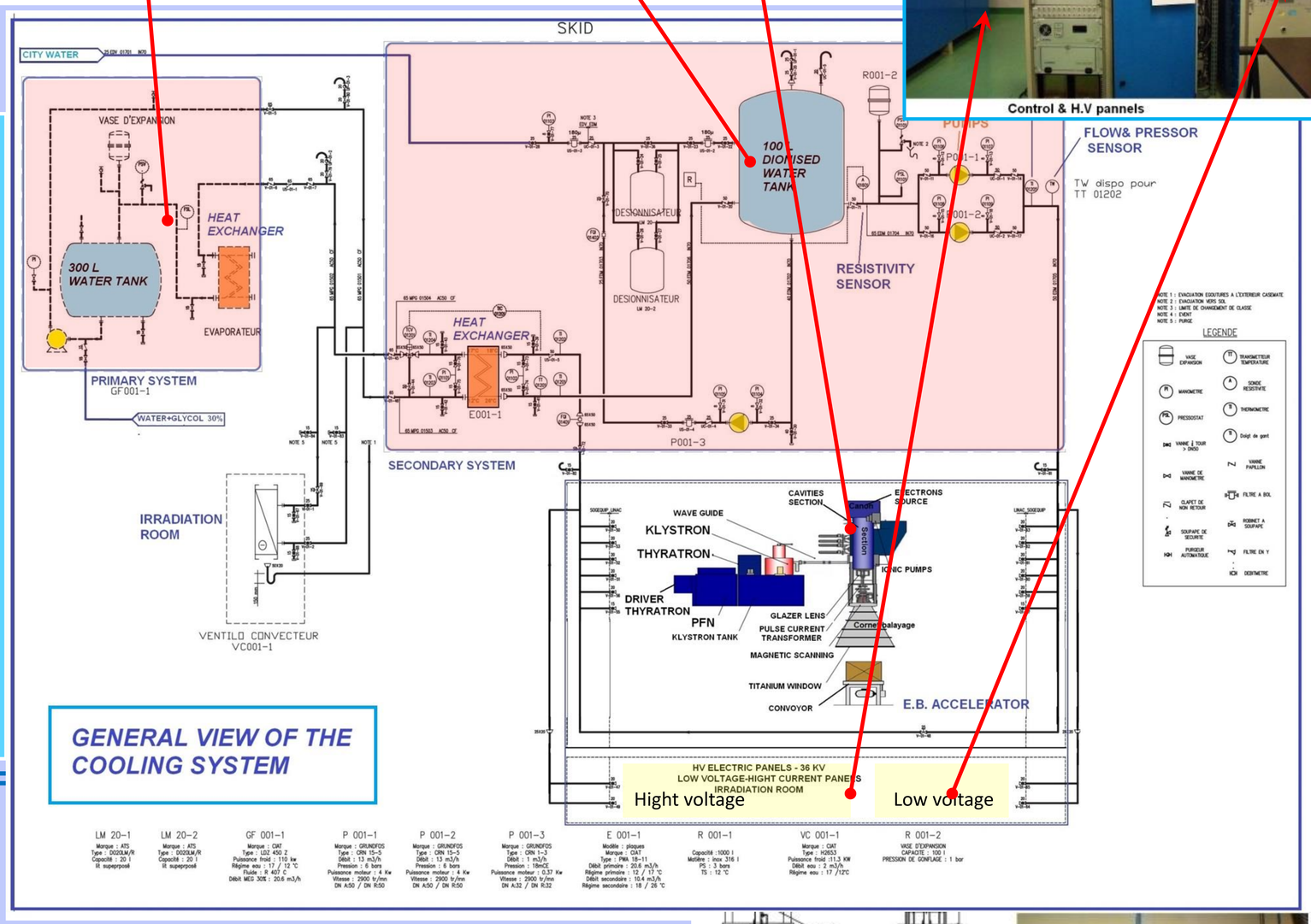
Dionised water : minimum 500 kΩ/cm

Malfunctions which appeared during warranty :

Many Stops of the accelerator due to alarm of Gaz default "Gel/R407C" in the primary water cooling circuit. It was necessary to visit roof in order to press "Reset" button and then wait for 15 minutes for heating gun of vacuum tubes. First time this failure appeared in 2010. Besides of this defect also another of the primary cooling system appeared , who consist of water temperature instability (22-24 degree in the secondary water cooling circuit instead of 21degree) .

Both of these defects stopped accelerator during the guarantee period nearly every day.

The supplier delivered the primary water cooling system to provider. They replaced gas, pressure regulator , sensors and controllers .

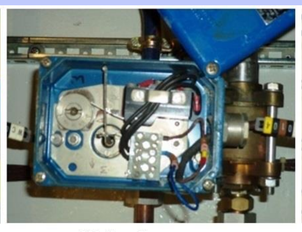


GENERAL VIEW OF THE COOLING SYSTEM

CLASSIC PROBLEMS:

- Oxidation on pipes and fittings
- Degradation of rubber seal, Plexiglas and polymer components due to the presence of radiation in the section room
- Degradation of tube welding's and solders in bimetallic parts

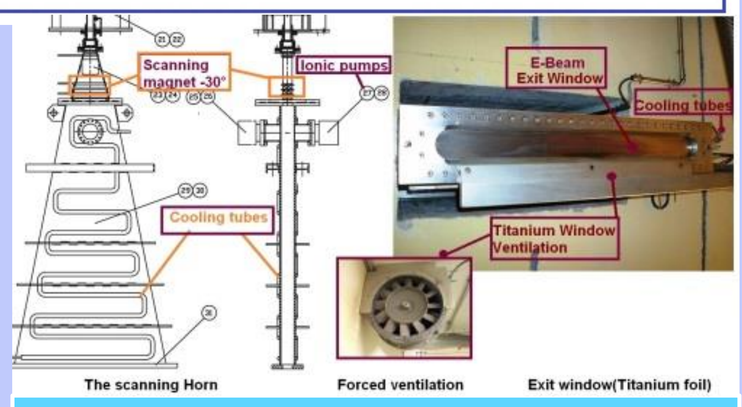

Temperature Sensor


Water flow sensor


'clarinet' water distribution

SWITCHES AND SENSORS :

- Mechanical flow switch are not very reliable for detecting the needed flow of water to cool enough components.
- External 'Thermocouple' probe attached to copper cooling tube does not give accurate temperature value, internal sensors are suggested in this type of configuration, because temperature of air with air conditioners disrupts the measure of true value.



The scanning Horn — Forced ventilation — Exit window(Titanium foil)

TITANIUM WINDOW:

The exit window of the beam must be cooled by forced ventilation in addition to the circulation of the cooled water to avoid blackening and embrittlement of the titanium foil which is subjected to the force of the vacuum.

CASE OF PFN INTERNAL WATER LEAK:

- The PFN is composed of a 20 'self/capacitance' sets, charged through a resonant circuit with 32KV(the double of the rectified high voltage) . The PFN is discharged by a Thyratron in the primary of a pulse transformer: a first output is applied to Klystron (135 kV), a second output is applied to the Canon (90 kV). Thyratron trigger pulses come from platinum trigger, controlled by the electronics modulator command.

1- PFN Characteristics

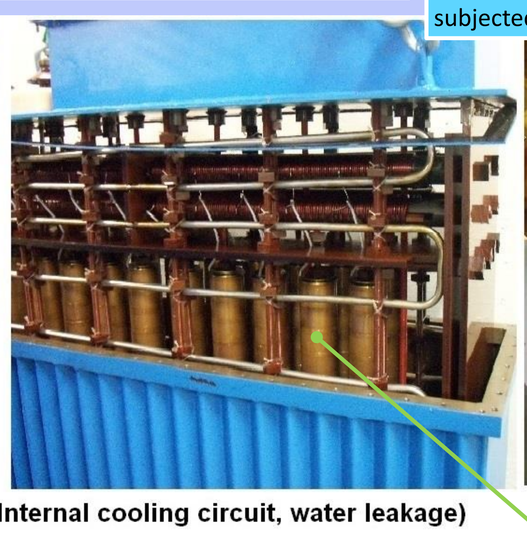
- Pulse width at- 3 dB : 14,5µs
- Pulse width at 95 % : 13 µs
- Pulse width at 50 % : 15, 5µs
- τ rise time (de 10 to90 %) : 0,7µs
- τ down (de 90 à 10 %) : 1,5 µs

- Puissance crête : 12 MW
- Puissance max : 120 kW
- Peak voltage of klystron : 135 kV
- Stability of pulse (Jitter) : <1%
- Top pulse ondulation : ± 4 %
- PFN Energy : 180 J

- Total Capacity : 0,38 µF
- Total Inductance : 146µH
- Impedance : Zc = 19,5 Ω
- Charge voltage :32 kV
- Energy in Pulse (10 MeV) : 35 à 37 joules

2- PFN default due to Cooling circuit

The interface between cooling system who is waterproof and high voltage isolant oil, cause d problems of leak in welding points, who is the case of our PFN default. The internal water leak is undetectable by eyes in short period, because the level of leakage is very low and takes a lot of time to generate a detectable default (a few months).



Pulse Forming Network (Oil tank, Internal cooling circuit, water leakage)

PFN -HV polymer film capacitors (every capacitor 19nF)shown in the below photo's, was damaged due to the presence of cooling water in the isolation oil. this problem is invisible but it creates at the beginning many disturbances in the current security (circuit breakers, thermal relays ...)


PFN Damaged H.V capacitors