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# Automation of Superconducting Cavity Cooldown Process Using Two-Layer Surrogate Model and Model Predictive Control Method

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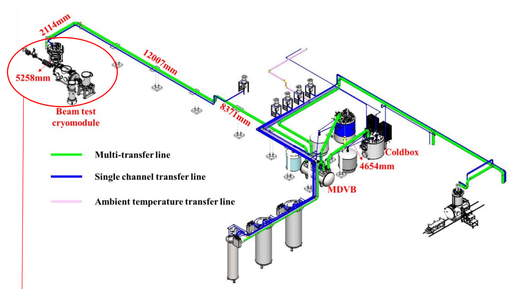
## Abstract

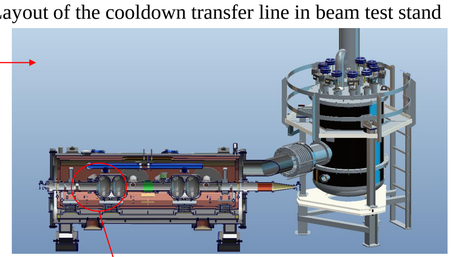
**Superconducting cavities need to be gradually cooled from ambient temperature (300K) to the superconducting temperature (4.2K or below) during the test and operation. The temperature difference on the cavity must be strictly limited during the cooldown process to prevent excessive thermal stress on the surface of the superconducting cavity. In this paper, 3D numerical simulation, 1D pipe and 0D tank model with artificial neural network (ANN) were combined to generate a two-layer surrogate model that can balance computational accuracy and speed, and a model predictive control(MPC) approach was also built on the basis of this model, to improve the automation and cooling efficiency of the superconducting cavity cooldown process.**

## CFD Simulation Model

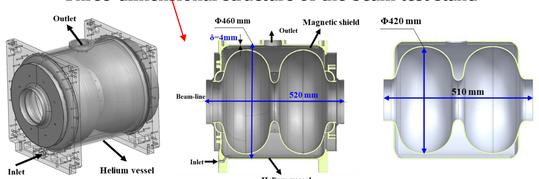
**1ST Stage:**
- **Model simplified and CFD calculation**
- **Generating small dataset for the first layer surrogate model**



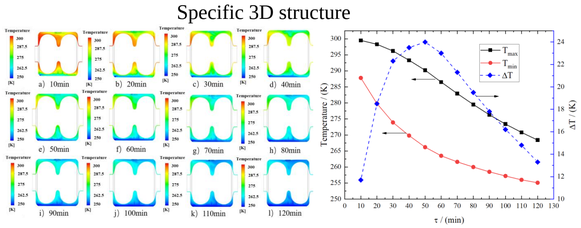

Layout of the cooldown transfer line in beam test stand



Three-dimensional structure of the beam test stand



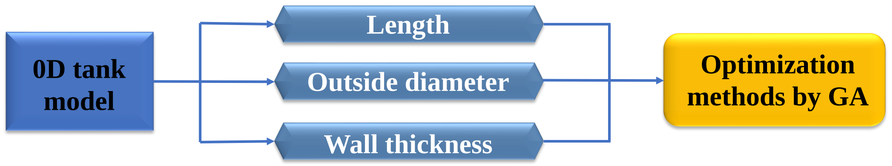

Specific 3D structure

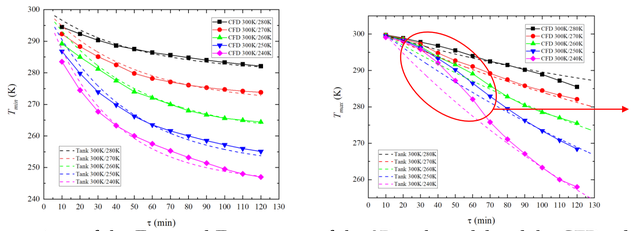



Temperature distributions at different moments

## Surrogate model for a single superconducting cavity's cooldown process

**2ND Stage #1:**
- **Surrogate model for a single cavity using tanks model**



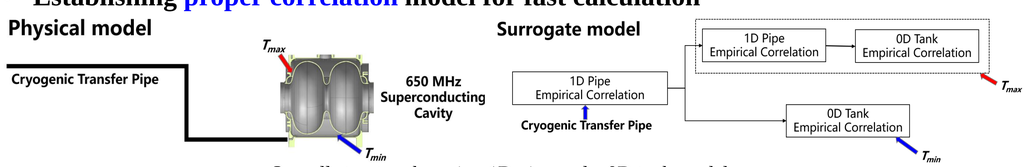

**0D tank model NOT SUITABLE (on $T_{max}$ prediction)**

Comparison of the $T_{max}$ and $T_{min}$ curves of the 0D tank model and the CFD calculation

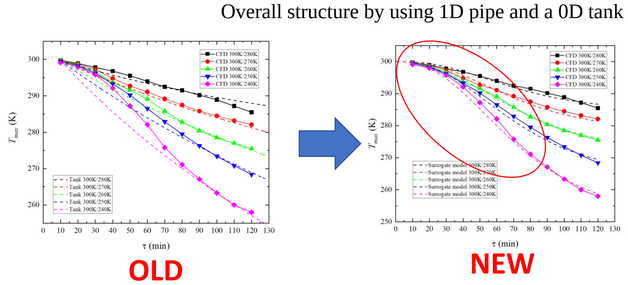
**Need New Models and further Optimization**

## Surrogate model with long transfer-lines and cavity cooldown process

**2ND Stage #2:**
- **Cavity 0D tanks model with Transfer-line 1D pipes model**
- **Establishing proper correlation model for fast calculation**




Overall structure by using 1D pipe and a 0D tank model

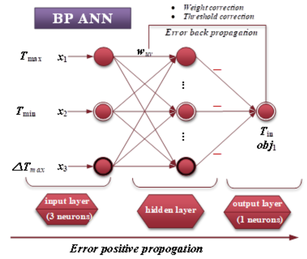



**OLD** → **NEW**

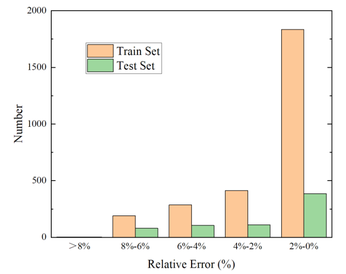
**FIT BETTER**

## MPC control method for cooldown process

**3RD Stage :**
- **Build 2-layer surrogate model MPC**



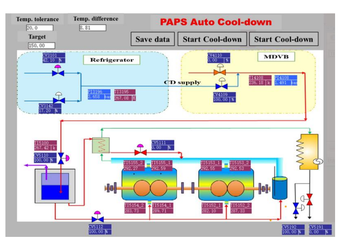

Topology of BP neural network



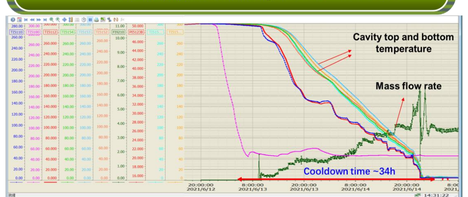

Performances of the BP neural network on the training and test sets

## Environmental test in PAPS platform

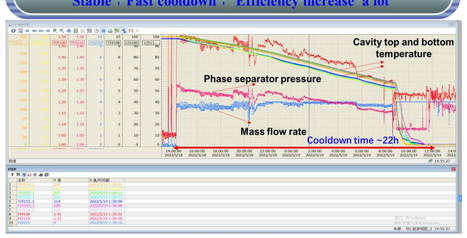
**4TH Stage :**
- **Experimental test**




**1、Former method: Manual adjustment ; Not stable**




**2、Improved method: MPC; ANN**
**Stable ; Fast cooldown ; Efficiency increase a lot**




The improved method could realize **a quick and smooth** cooldown process of the superconducting cavity, during which the temperature difference on the cavity could satisfy the requirements. Additionally, the improved automatic cooldown method was more adaptable and **saved 29% more time** than the original manual control method. It lays a foundation for the future large-scale cryogenic system or other systems with large lag and nonlinear characteristics to achieve more intelligent automation control.