Liquid Nitrogen Level Detection for the Safe Opera-tion of Onboard Cryostats of HTS Maglev Vehicles under Vibration Condition

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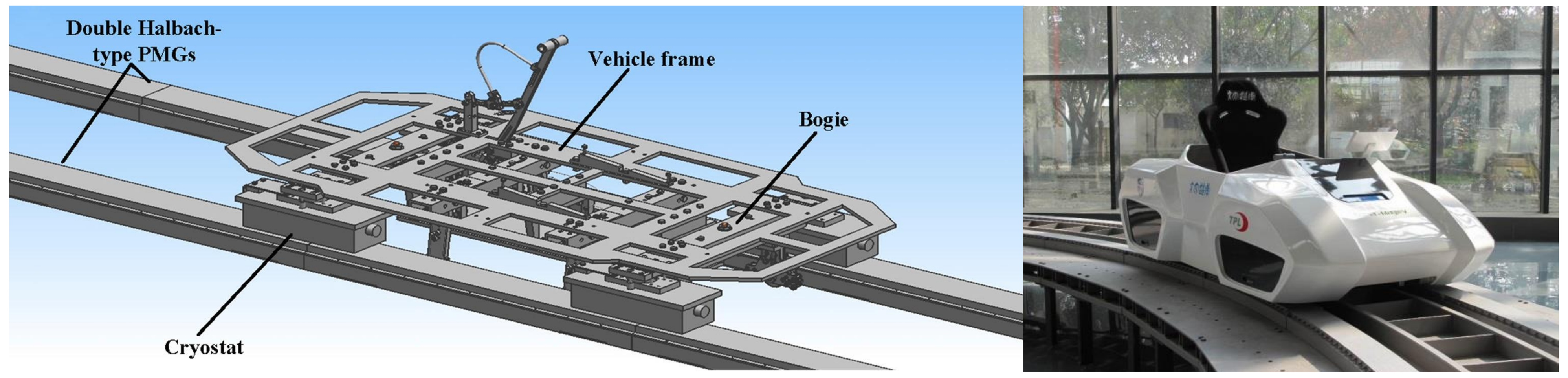
Background



The liquid nitrogen (LN2) cryostat (also called as dewar), which was used to store LN2 coolants for onboard high-temperature superconducting (HTS) bulks, is an important component of the HTS maglev vehicle. Immerged in LN2, the HTS bulk can keep the superconducting state and robust levitation force to ensure the safe operation of HTS maglev vehicles.

Abstract

For the safe operation of high-temperature superconducting (HTS) maglev vehicles, the liquid nitrogen (LN2) level of the onboard cryostat should be monitored in real-time during the whole running process. The previous LN2 level detection method was proposed by using platinum resistance sensors as testing equipment to estimate the liquid level by threshold value judgment. However, the fluctuation of LN2 level causes great disturbance for the liquid level detection during the running vehicle, which leads to the false level. To eliminate the interference caused by LN2 level fluctuation, the state estimation theory of using particle filter algorithm was employed to process the test data. The real-time measurement results illustrate that this method is able to meet the requirements of the LN2 level detection with good precision, and a simple hardware is valuable for the practical application of the HTS maglev vehicle.

Experiment

Experimental setup

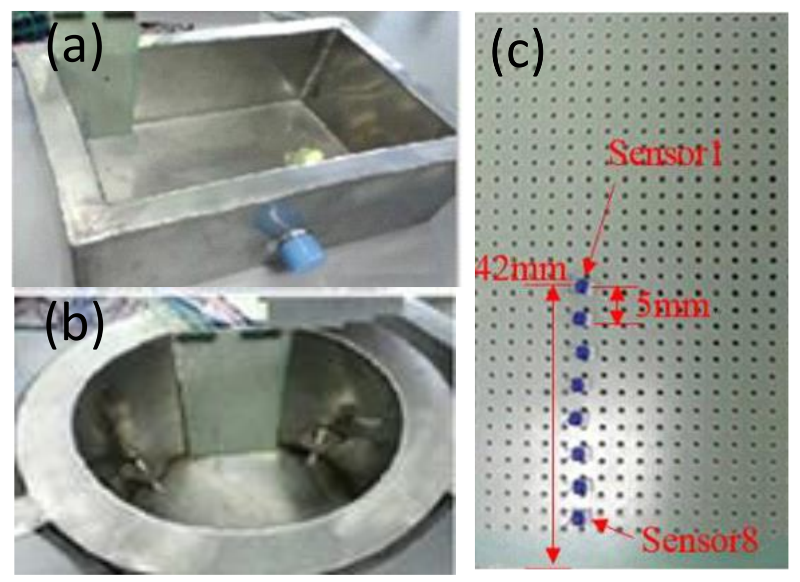


Fig. 1. Equipment used in the experiments: (a) measurement in a rectangular dewar; (b) measurement in a circular dewar; (c) the temperature ruler, in which eight PT100 platinum resistance sensors were arranged in a linear array and their serial numbers are from 1 to 8 from the top to the bottom.

$$h = h_0 + k_1 t \quad \rightarrow \quad T = T_0 + k_2 h'$$

Transform the displacement signal into temperature signal

By using the state estimation theory, we can get state transition equation

$$h'_k = h'_{k-1} + \Delta h' + w_{k-1}$$
$$T_k = T_{LN} + a \cdot h'_k + v_k$$

- **Static Evaporation Behaviors:**

In order to get basic rules about the natural evaporation characteristics, the static LN2 evaporation experiments were firstly carried out in the two dewars

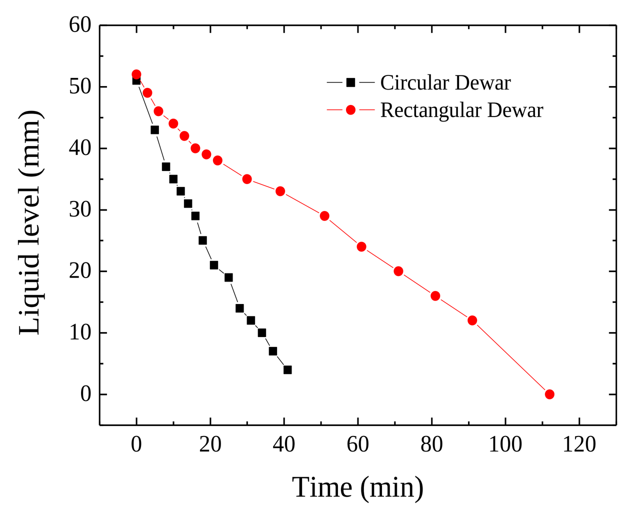


Fig.2. Relationship between the actual liquid level and time in the two dewars.

Experimental Methods

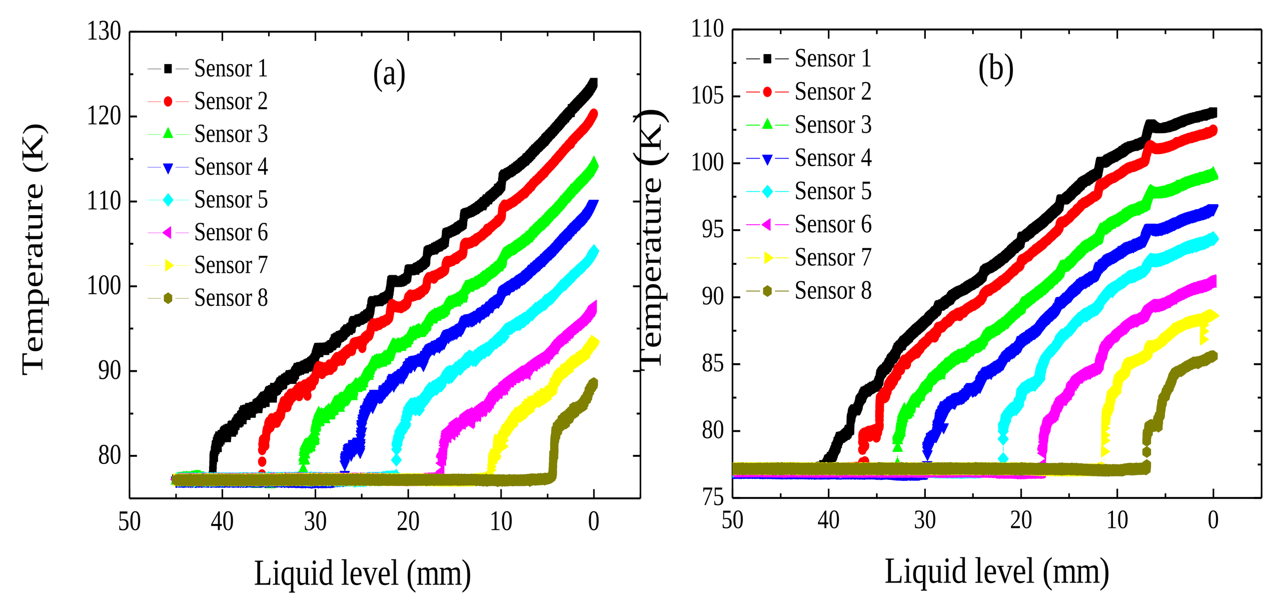


Fig. 3. Temperature outputs of eight PT100 platinum resistance sensors with the liquid level of LN2 during the static evaporation process (a) in the circular dewar and (b) in the rectangular dewar.

•State Estimation Theory and Particle Filter Algorithm

In the case of the fluctuation of the liquid level, there are random disturbances in the temperature curve, which makes the measured height of liquid level above or below the actual value. In order to solve the problem of the random disturbances, the state estimation theory of using particle filter algorithm was introduced.

$$x_k = f(x_{k-1}, u_{k-1}, w_{k-1})$$
$$y_k = g(x_k, v_k)$$

Where x_k is the state vector, u_{k-1} is the exciter, w_{k-1} is the state converting noise, v_k represents the observing noise, f is the state converting model, and g is the observing model.

Results and Analysis

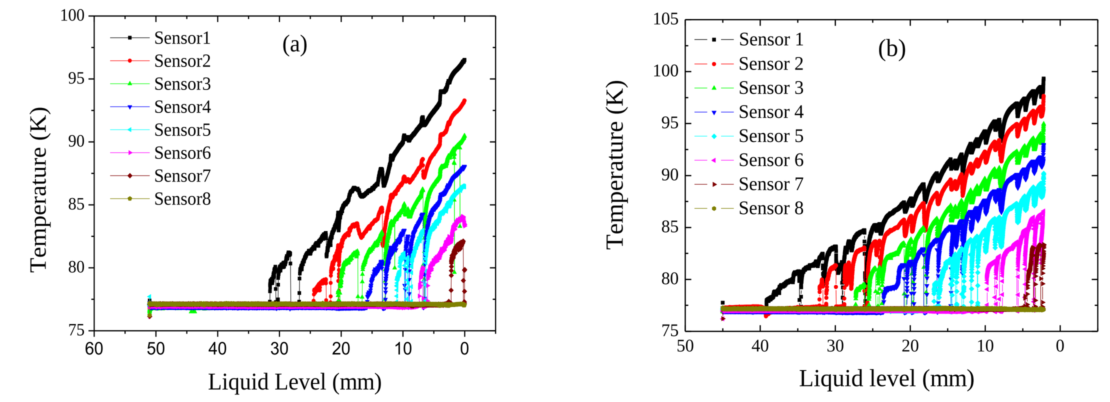


Fig. 4. Relationship between the temperature and the liquid level of (a) the circular dewar and (b) the rectangular dewar under vibration.

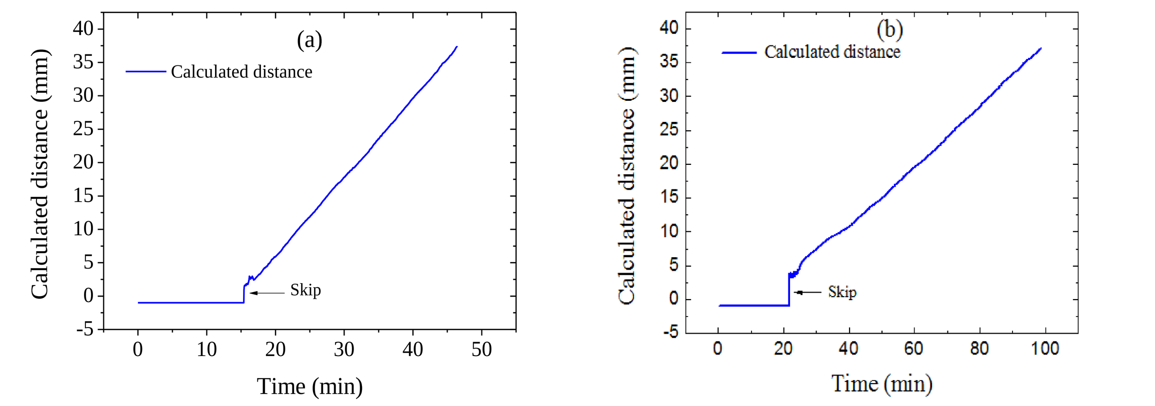


Fig. 5. Calculated distance h’ between Sensor1 and the liquid level, (a) for the circular dewar, (b) for the rectangular dewar.

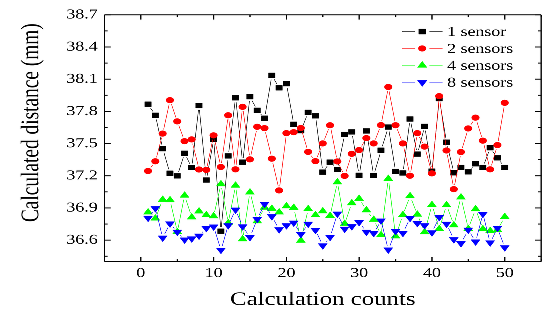


Fig.6. The distance h’ calculated by using the experimental data of 1, 2, 4 and 8 sensors, respectively. The results were calculated for 50 times repeatedly with the same data from Fig. 4(b) to check the repeatability of the calculated results. The last sampling point which is 37 mm from the liquid level in Fig. 5(b) is chosen for the examination.

TABLE I
CALCULATION RESULT STATISTICAL CHARACTERISTICS

Sensor numbers	Average Value /mm	RMSE / mm
1	37.50	0.58
2	37.50	0.54
4	36.85	1.15
8	36.71	1.30

Measurements in a covered Dewar

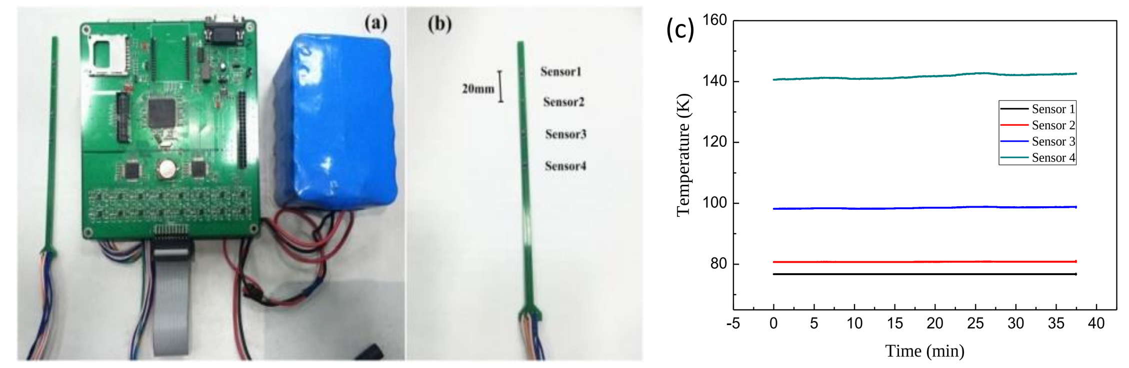


Fig.7. Equipment used in a covered Dewar for LN2 level detection: (a) the experimental facilities; (b) the strip-type circuit board with four PT100 platinum resistance sensors; (c) Temperature outputs curves in a static dewar.

Conclusion

- This paper presents a new method that using the platinum resistance sensors to measure the temperature curve, and introducing the state estimation theory which is based on the particle filter algorithm to deal with the data under vibration condition and shield the fluctuation interference.
- The test model is based on the statistical correlation among the working time, position of the liquid level, the fluctuation of liquid level and the testing data.
- According to the experimental results, the estimation method of liquid level height is feasible when measuring the LN2 level under vibration condition.
- For application, it is possible to use one temperature measuring point to estimate the liquid level; in addition, the obvious gradient of temperature in the covered dewar implies that this detection method can be applied into the real system.
- This method is able to meet the requirements of the LN2 level detection with accepted precision and the simple hardware is valuable for the practical application of the HTS maglev vehicle.

Acknowledgements

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