The construction of digital twin for reliability of liquid level volatile products

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Abstract. Due to the lack of air tightness and environmental stress, the liquid level volatile products will gradually volatilize, which will affect the performance and reliability of products. Due to the small volume, complex working environment, strong acidity of electrolyte and various electric environments, it is difficult to monitor the liquid level in real time, so it is impossible to predict the remaining life of such products. In view of this, this paper proposes a scheme to estimate the liquid level information and predict the remaining life of volatile liquid level products through reliability digital twin. First, a set of test device is designed to control the environmental factors of liquid level volatile products in real time and collect the information of liquid level height. Then, according to the product working environment and liquid level data collected by the test device in real time, a general mathematical model of liquid level volatile of products is fitted. According to the model, the twin mapping of this kind of products in virtual space can be built, which can make them have liquid level volatile products surplus life prediction ability. Finally, the digital twin real-time collects the actual use data of the product, and continuously evolves the remaining life prediction model of the product through learning, so as to improve the prediction accuracy and better guarantee the reliable use of the product.

1. Introduction

Liquid level volatile products generally refer to the products containing volatile liquid. With the use or time accumulation, the liquid capacity will gradually reduce due to the lack of air tightness and environmental stress, and affect the product performance and reliability. [1] The most typical liquid level volatile products are battery products. [2][3] In general, liquid level volatile products have the characteristics of small volume and complex working environment. [4] Due to the strong acidity of electrolyte and all kinds of electric environment, it is difficult to set up liquid level sensor to monitor the liquid level in real time. [5] Because the liquid level information can't be known in time, the battery's lack of liquid will occur from time to time. In light of this, the circuit or system can't work normally. [6] In serious cases, it may lead to the change of the circuit's voltage resistivity, which may lead to serious safety problems. If the liquid level information of the product can be controlled in real time, it will also help to predict the remaining life of the product and replace the failing battery in time, so as to ensure that the product can play its intended function. Therefore, there is an urgent need for a method to predict the electrolyte level and its remaining life in real time by monitoring the working environment stress of this kind of products, so as to improve the efficiency of maintenance support and ensure the sustainability of product reliability.
Digital twin is a kind of simulation process that makes full use of physical model, sensor update, operation history and other data. It can reflect the whole life cycle process of the corresponding physical entity, and the twin can reflect and predict the real operation of the object through simulation experiments, so as to assist the staff to make decisions. [7][8] Therefore, it is feasible to use digital twin technology to realize the monitoring and prediction function of liquid level reliability information of liquid level volatile products.[9] Recently, more and more people begin to use digital twin to study reliability issues. For example, by using digital twin model, Millwater, H gives out a method to do the computation of the probability-of-failure, the remaining useful life, and the effects of inspections and repairs of the airframe.[10] And, to do the fault diagnosis in distributed photovoltaic systems, Jain Palak develops a digital twin that estimates the measurable characteristic outputs of a PV energy conversion unit (PVECU) in real time, thus perform the fault diagnose by generating and evaluating the error residual vector.[11]

However, at present, digital twin technology has two shortcomings. First, at present, this technology pays more attention to the monitoring of processing technology or physical characteristics of complex products. For example, Sun[12] used digital twin technology in the paper "Research on some key technologies of digital twin system of aircraft general assembly line", and provides solutions for various key links involved in aircraft general assembly; Zhang[13] established a perfect workshop management and control system through digital twin technology; but the research on digital twin of product reliability is still in the exploration stage. Secondly, at present, the prediction model of digital twin model is not perfect, and there is no systematic model evolution theory. For example, Liu Kui[14] proposed in the paper "application exploration of digital twin in the field of aeroengine reliability" that in the product operation and maintenance stage, the model can be modified by collecting real-time and off-line collected data and feeding back to the twin engine and twin environment, It is feasible to complete the simulation of engine running state, failure prediction and reliability evaluation, but no detailed scheme has been put forward.

In order to solve the problems above, this paper proposes a method to construct the reliability digital twin of liquid level volatile products. In the 2nd chapter, a typical product reliability digital twin experimental device is designed to simulate the working environment of liquid level volatile products, monitor and record the changes of environmental parameters and liquid level information of the test piece in real time; in the 3rd chapter, the construction method of reliability digital twin of typical liquid level volatile products is introduced, and the data collected by the experimental device in the first chapter is used as the input to establish a typical product twin model. The 4th chapter introduces the reliability digital twin evolution method of the measured data, which can collect the work and liquid level information of the real product through the maintenance and measurement, and input it into the twin established in the second chapter, so that the twin can realize the evolution function and improve its liquid level prediction ability. The conclusion is given in the last chapter.

2. Design method of reliability digital twin experimental device for typical products

Due to the difficulty of monitoring typical liquid level volatile products such as batteries, it is necessary to design a set of experimental device, which can simulate the temperature change, humidity change, container surface area change of typical products and the comprehensive change of the above factors, and can collect the temperature, humidity and liquid level signals in real time, after digital processing, it can be transmitted to the computer to generate the experimental database as the input data of the digital twin. When the twin model of the experimental device has enough ability to simulate and predict the liquid level information, the twin model of the real product can be established.

The device designed in this paper can be used to simulate the process of liquid volatilization. By controlling the temperature, humidification and other operations, we can change and monitor the temperature data and surface water vapor pressure in real time, and it will set up a liquid level monitoring sensor to monitor the change of liquid level in real time. When the influence of liquid surface area on the evaporation rate is investigated, the experimental can be realized by changing the containers with different diameters. The schematic diagram of the device is shown in the figure below,
which can output the information of liquid level height, liquid temperature and surface water vapor pressure in real time, and provide input information for the construction of liquid level volatilization model and the evolution of digital twins of liquid level volatilization.

![Diagram of experimental device](image)

**Figure 1** Diagram of experimental device

As shown in Figure 1, the container on the left side of the experimental bench is equipped with test liquid, and the container is equipped with temperature sensor and liquid level sensor. The lower end of the container is equipped with a low-power heater. The right side is equipped with humidity sensor and air humidification device. The external connection of energy and data bus can realize the real-time acquisition of all kinds of sensor data and the programming control of the experimental platform. The device can simulate the volatilization of typical liquid level products under different environmental conditions.

a) Simulation scheme of working environment temperature change

As shown in the figure, the container contains a temperature sensor, which can collect the liquid temperature information in real time, connect with the low-power heater under the container through the data bus, and control the heater switch through the real-time temperature data, so as to realize the temperature control of the experimental device.

b) Simulation scheme of humidity change in working environment
As shown in the figure, there is a humidity sensor above the device, which can collect the environmental humidity information in real time, connect with the air humidifier at the right end of the device through the data bus, and control the humidifier switch through the real-time humidity data, so as to realize the humidity control of the experimental device.

c) Simulation scheme of liquid surface area change
   Prepare multiple containers with different diameters to simulate the volatilization process of products with different liquid areas.

d) Multi factor comprehensive change simulation scheme
   It can simulate the work of liquid level volatilization products in many kinds of complex environment, and output the real-time change of temperature, humidity and liquid level height.

3. Construction method of reliability digital twin of typical liquid level volatile products

Combined with the above experimental device, a reliability digital twin construction platform of typical liquid level volatile products is built in the computer. The platform enables users to input the three-dimensional structure of the product cavity, real-time work task events of the product, and collect the environmental information in real time through the environmental sensors arranged outside the product, so as to automatically generate the digital twin of the product liquid level for the whole process of using. Digital twins include liquid level volatilization model, physical model of the product, and also can record the task process experienced by the product, and establish real-time data acquisition interface of environmental temperature, humidity, wind speed, container cross section and other parameters, which is connected with the temperature sensor, humidity sensor and wind speed sensor of the product entity, and can collect all kinds of environmental information experienced by the product in real time, and receive those to the twins for processing.

3.1. Liquid level volatilization model

The typical product liquid level volatilization model contained in the digital twin should include the following functions.

1) Prediction of liquid level based on measured environmental parameters

   Consider the environmental parameters related to the evaporation rate, such as temperature, humidity, wind speed, gas-liquid contact area, etc. Through the experiment platform built in the 2nd chapter, we can test each single variable, and the mathematical relationship between the evaporation rate of liquid level and each environmental variable can be established:

\[ \Delta = f(T, E, S, V) \]

   Wherein, \( \Delta \) represents the liquid level volatilization rate;
   T represents Kelvin temperature;
   E represents surface water vapor pressure;
   S represents the gas-liquid contact area;
   V represents the surface wind speed.

   Considering the coupling of multi parameters, the mathematical relationship between the volatilization rate of liquid level and various environmental variables can be determined and the mathematical model of liquid level volatilization can be established by fitting the experimental data.

   After the model is established, the real-time data received by the environmental sensor is brought into the model for calculation, and the product level height information estimation can be obtained.

2) Fitting of environmental stress distribution and prediction of stress parameters in the future

   Fitting of environmental stress distribution and prediction of stress parameters in the future according to the accumulated environmental temperature, humidity, wind speed, gas-liquid contact area and other information in the task record, combined with the task profile, through the least square method and other algorithms, we can match with the common distribution model, use the model...
evaluation criteria to select the model with the highest degree of simulation, and use the model to predict the environmental stress distribution in the future.

3) Residual life prediction

We can bring the predicted value of the environmental stress parameter into the liquid level volatilization model, and calculate the time when the liquid level of the product is close to the failure threshold, which is the predicted residual life of the product.

All kinds of parameters in the volatilization model can be estimated in real time through the common estimation methods such as maximum likelihood estimation or EM algorithm after accumulating the environmental parameters, task profile and real liquid level changes of the product. This kind of parameter estimation method can calculate and process the cumulative time series, so the more data is accumulated, the higher the accuracy of parameters obtained by fitting and the stronger the estimation ability of the model. After a certain amount of volatilization data has been accumulated through experiments, a general volatilization model of liquid level can be obtained by data fitting for the use of reliability digital twins.

3.2. Reliability digital twin structure of typical liquid level volatile products

After the liquid level volatilization model is completed, the reliability digital twins of typical liquid level volatilization products can be further constructed, which includes the following parts:

a) Product 3D model. The lightweight model of products can be directly obtained from CAD tools as the basic type of reliability digital twin

b) Data interface. It can receive the environmental information detected by the environmental sensor arranged on the product surface in real time, or the product information input by the staff manually;

c) Liquid level volatilization model. As the core of the digital twin, it takes the data received by the data interface as the input, integrates the three-dimensional product model, and outputs the real-time product level and residual life estimation.

The twin's data interface can receive three types of data:

- Three-dimensional structure of product entity
- Environmental information collected in real time by environmental sensors arranged outside the product
- Staff manually input task profile

Through the liquid level volatilization model established in the previous section, the real-time environmental information of the received product is used to estimate the liquid volatilization and liquid level height, simulate the change of liquid level, and predict the future environmental information by fitting, then calculate the expected time of the product liquid level falling to the failure threshold through the liquid level volatilization model, which is the expected remaining life of the product. Raise an alarm when the liquid level is close to the failure threshold.

Through the first part of the establishment of a typical product reliability digital twin experimental device, to verify the ability of the platform in sensor information collection, task model distribution and simulation, liquid level height estimation, residual life prediction. The virtual real interaction structure is shown in Figure 2.
Figure 2 Reliability digital twin virtual real interaction structure of typical liquid level volatile products

4. Digital twin evolution method of liquid level based on measured data

Because there are many parameters in the liquid level volatilization model that will affect the prediction ability of the model, it is necessary to compare the estimated value of the liquid level change obtained from the calculation of the real liquid level information and the liquid level volatilization model, then correct the parameters in the model in real time through the parameter estimation method, and do further learning optimization so as to improve the accuracy of the liquid level volatilization model. Furthermore, the simulation and prediction ability of reliability digital twin is enhanced, and the evolution of digital twin of liquid level is realized. The structure block diagram is shown in Figure 3.

We have obtained the general model of liquid level volatilization through the experimental device. The digital twin will receive the real-time input from the external environmental sensor of the product and estimate the liquid level information through the general liquid level volatilization model included. In the later use of this kind of products, firstly, maintenance personnel can carry out on-the-spot maintenance according to the prediction results, reduce the maintenance frequency while ensuring the reliability of the product; secondly, they can further collect the real liquid level information after the product fails, input it into the digital twin of the product, and further evolve the product life prediction model through learning, fitting and other methods to improve the prediction accuracy.
5. Summary

In this paper, a digital twin method is proposed to solve the problem that the liquid level information of volatile products is not convenient to monitor and the remaining life is difficult to predict.

In view of the current situation that it is difficult to monitor the product liquid level information, we propose a design method of a typical product reliability digital twin experimental device in Chapter 2, which can control the product environmental information (such as temperature, humidity, wind speed, etc.) in real time by setting various sensors, control devices and signal interfaces, and record the product liquid level information, output the above information in real time through the data interface. This scheme provides the possibility for the preliminary construction of digital twins.

In view of the current situation that the liquid level information of liquid level volatile products is difficult to predict, we propose a reliability digital twin construction method of typical liquid level volatile products in Chapter 3. Through the experimental device in Chapter 2, we carry out the liquid level volatile experiment, first get the general liquid level volatile model of this kind of products by fitting. Then, according to the specific product, after inputting the 3D structure of the product, arranging the environmental sensors on the surface of the product, and inputting the task profile, the exclusive reliability digital twin is automatically generated, so that the digital twin has the ability to predict the liquid level and the remaining life of the product after collecting the environmental information.

In view of the current situation that the prediction of the residual life of liquid level volatile products is not accurate, in Chapter 3, we propose a digital twin evolution method of liquid level based on the measured data. This method can input the actual liquid level information obtained from the maintenance and inspection of the real products to the digital twin. By comparing the output of the model with the real liquid level data, the twins can adjust the parameters, modify the model, improve the prediction ability of liquid level and remaining life, and realize the evolution of digital twins.
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