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DEVELOPING THE ACCELERATED TESTS FOR ELABORATION OF THE MANUFACTURING TECHNOLOGY OF HIGH-RELIABLE IPRTs

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Abstract – Metrological assurance of sensors embedded in the equipment and intended for long use in industrial automated systems is an important problem. In this paper attention is attracted to the importance of the experimental accelerated tests of the sensors, which should be based on the analysis of physical and chemical processes in the sensor as main sources of the sensor instability. The purpose of the tests is to elaborate the manufacturing technology of high-reliable sensors. The principles of developing the plan of the tests were suggested and an illustration was given on the widely used sensors - platinum resistance thermometers.

Keywords: metrological assurance, sensors, accelerated tests

1. INTRODUCTION

Automated systems used in modern manufacturing processes, nuclear plants, Navy and Air industries employ a great number of industrial process sensors, which are often embedded in the equipment and can not be removed for subsequent verification according to the standard specifications. Metrological control of such sensors is an important problem. This problem is usually solved by developing automatic validating systems and, if possible, intelligent self-correcting systems to diagnostic and correct the drift of the sensor characteristics during the use. However, we should keep in mind that for ensuring the highest reliability of the measurement results it is also important to increase the reliability of the sensor itself. This paper is aimed to attract attention of those people who work at developing long-life high-reliable automated systems to the physical properties of the process sensors. Actually, if even we employ an excellent in-build control device to gather information on the sensors drift, there is a risk that in some short time we will have all the sensors out of the accuracy tolerances because of their instability, and the aim of long-time reliability of the equipment will not be attained.

As a general rule, the design of the sensor is subject to fast renovation. It is difficult to estimate the effect of the technology and manufacturing technique on the long-term stability of the sensor from the real measurement data obtained during the full time of the sensor in service. In some applications the useful life of the sensor is required to be ten years or more. So, to judge about the design and technology, and to predict the behavior of the sensor for years special accelerated tests have to be performed during the construction. In this paper we suggest an approach to developing the quality control tests for the sensors of the highest reliability.

2. PRINCIPLES OF DEVELOPING THE ACCELERATED TESTS FOR PROCESS SENSORS

The main idea of our method of developing the accelerated tests is that the tests should be based on the analysis of the physical and chemical processes occurring in the sensors under the working conditions and on the analysis of the main sources of instability. Thus, the analysis should include the following steps:

- selection of the most dangerous processes which can cause a large increase of the measurement error and estimation of the possible trend of the error caused by each process at the working conditions,
- analysis of the design and manufacturing technology and detection of all possible defects in the sensor design and construction, which can initiate the dangerous processes,
- suggestion of the necessary treatments and test procedures, which do not lead to destruction of the sensor, but help to initiate the acceleration of the processes causing the instability;

The analysis does not only help to reveal the weakest points of the sensor design and technology. When a manufacturer wants to improve some element in the design or change a technological operation, he should make the special tests for the estimation of the results of the changes. Our method will help to choose the required treatments for the tests, and will help to analyze the test results. It is important to note that the recommendations on the improvement of the technology are valuable provided that the manufacturing process is quite stable and does not include any uncontrolled procedures.

The principles for developing the special accelerated tests suggested in this paper can be applied to any process sensor. It this work we apply our method to one of the most popular temperature sensor – industrial platinum resistance thermometer (IPRT).

3. DEVELOPING THE ACCELERATED TEST PROCEDURE FOR PRTS

The matter of fact, the physical and chemical processes in platinum resistance thermometers have been under investigation mostly for high-accurate standard platinum resistance thermometers. These thermometers are not suitable for industrial measurements because of their fragility, low resistance to vibrations, high cost. However, many of the important processes occurring in standard and industrial PRTs are similar. Some of the scientific publications in thermometry were devoted to industrial thermometers. From the results reported in those papers [1], [2], [3] and from our own studies we selected the following processes which might cause the instability of IPRTs:

- mechanical strains in the platinum wire,
- contamination of the wire by impurities coming from the sheath and insulating materials at temperatures above 500 °C,
- oxidation of the surface of the wire at temperatures of about 300-350 °C,
- growth of big grains in the pure platinum at high temperatures, which might result in breaking the wire,
- electrical leakage in the sensor insulation.

Each of these processes results in a special trend of the thermometers resistance. Plastic deformation of the wire or defects in its surface causes the resistance to increase. Mechanical elastic strains will usually lead to a hysreresis in the resistance, when the temperature changes from low to high values. Oxidation of the platinum will appear as a small constant increasing of the resistance at middle range temperatures. Electrical leakage in the insulation will result in shunting the sensing element and decreasing the measured resistance.

What defects of construction can initiate and accelerate these processes? We analyzed the design of platinum sensors developed at one of Russian industrial companies, and detected the following weak points of the construction:

- possible defects of the platinum coil winding, which might result in shortening the coil or developing strains in the platinum,
- possible poor adhesion of the sealing glaze to the ceramic and the wire, which might allow wet air or contaminants to penetrate inside the sensor and decrease its insulation resistance,
- possible defects in the leads welding, which might result in a breakage of the electrical circuit at fast temperature changes,
- insufficient purity of the constructing materials, which might contaminate the platinum wire at high temperatures.

And in the last step of developing the accelerated test procedure for IPRTs, we have to choose the test treatments, which are permissible for the construction, but cause the dangerous processes to reveal themselves. Obviously, it follows from the analysis given above, that an important treatment for the PRTs must be exposure of the sensors to high and middle-range temperatures. Then, it should be fast temperature changes, so called thermo cycling, and, of course, mechanical vibrations.

It is important to note, that procedure of developing the accelerated test for commercially produced sensors should include some initial experimental tests, which are intended to support or reject our choice of the test procedures. We took for the experiments eight sample sensors and investigated how the treatments at different temperatures could affect their resistance. Each treatment was followed by the measurement of the resistance at 0 °C.

In the first experiment five sensors were heated at a temperature of about 600 °C in an annealing furnace by cycles of 9-12 h each with slow cooling to room temperature. Then the sensors were kept in the furnace at the same temperature for a long time of about 58 h, and then we made several 0.5-hour thermo cycles between 20 °C and 600 °C. Unfortunately, one of the sensors was destroyed after the fist two cycles. The graph showing the behavior of the other four sensors is presented in Fig.1.

From this experiment we see, that the fastest change in the resistance occurs during the first 30 h of treatment at 600 °C. Then the drift became much smaller. All of the thermometers exhibited a decrease of the resistance at 600 °C. Most probably, it can be explained by removing some strains of the wire developed during the construction of the sensing element. Another reason could be the oxidation of the impurities in platinum. From this experiment we can see that it is very important to add some additional anneal to the technological procedure performed at the plant. The positive result of the test is that we did not observe any increase in the resistance, which demonstrate that the sensor is well protected against contamination of the wire at high temperatures, and, obviously the insulating materials used in the construction are of a very high purity

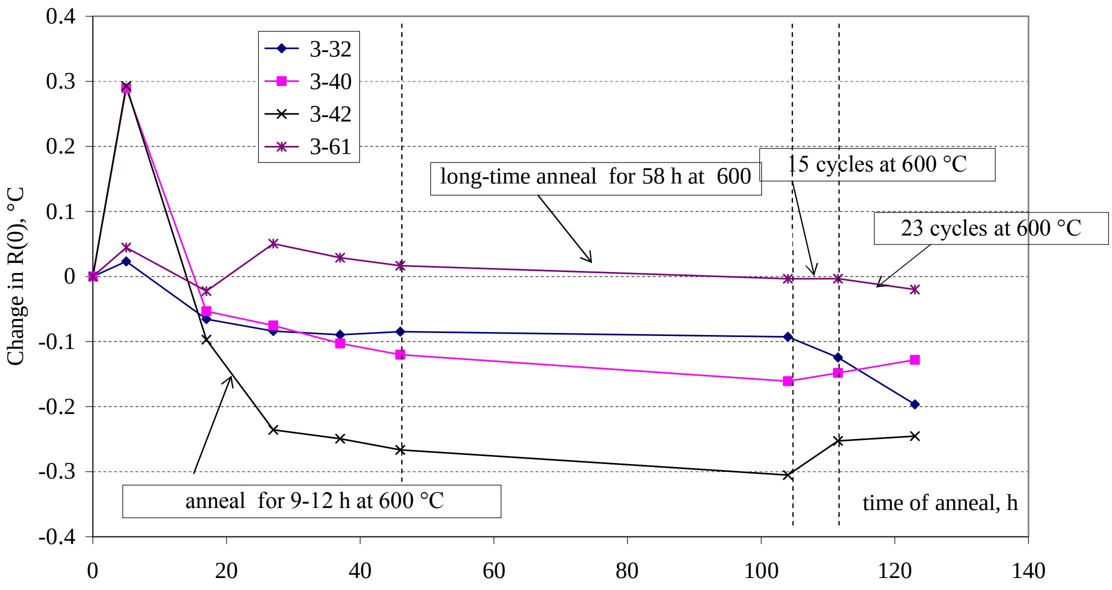

Fig. 1 Investigation of IPRT stability at 600 °C

The change of the long-time exposure to short time cycling results in increasing the instability of the resistance, which might be related to developing strains in the platinum coil. This test for reliability revealed the most stable thermometer # 3-61. Probably it would be useful to try to analyse the difference in the manufacturing process of the sensors and find out the reason of this phenomenon.

So, the experimental study supported our initial suggestion on including in the test plan for IPRTs treatments at high temperatures and thermal cycling between low and high temperatures.

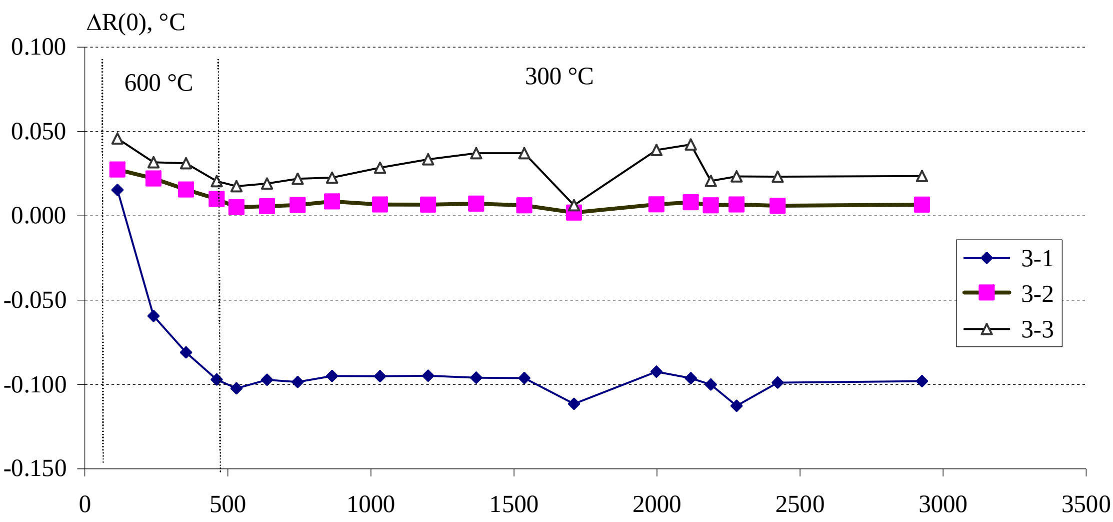

Fig.2 Investigation of the effect of long-time treatment at 300 °C

The second experiment was designed to see how the middle range temperatures would affect the thermometer stability. We annealed three sensors at 600 °C for about 400 h, then the temperature was changed to 300 °C and the thermometers were soaked at this temperature for 2500 h. The change in the resistance at 0 °C measured after the treatments is shown in Fig.2. One can see from the graph, that the change of the treatment temperature had a strong effect on the thermometer stability. After continues decrease in the resistance we obtained stabilization or even an increase in the resistance. The probable reason for the increase in the resistance is a slight oxidation of the platinum at 300 °C. PRT # 3-3 seems to be more capable to oxidized, which can be related to some leakage in the capsule sealing. The drops of the curves in the middle part of the graph we are going to explain by a sudden overshoot of the furnace due to a controller fault. Incidentally, the temperature was increased to 500 °C and we obtained a decrease of the resistance again. It is interesting that this overshoot did not affect the behaviour of the most stable thermometer # 3-2. This experiment showed that some drawbacks of the technology could be detected during the accelerated tests and appropriate measures should be taken to improve the reliability of the construction.

In this paper we did not make experiments on the effect of vibrations or on the effect of penetrating moist on the sensor. However, we are sure that such experiments must be done by the manufactures during the accelerated tests. The experiments described above demonstrate the necessity to include in the test plan treatments at high and middle temperatures and thermal cycling. The tests should help to judge about the reliability of the sensor. They are very important at the stage of improving the manufacturing technique.

4. CONCLUSIONS

The task of ensuring the high long-time reliability of the complicated equipment in industry is very closely connected to the problem of ensuring the proper work of the process sensors embedded in the equipment.

Very often the only solution of the problem is considered to be in developing special control intelligent systems intended to continuously gather information on the sensor characteristics during the fool time in service, analyse it and estimate the uncertainty of the measurements. In this paper we tried to show that there is the second action required for ensuring the long-time reliability of the system. To make really reliable equipment with useful life time of ten years and more we have to use very reliable sensors in the measuring systems.

We suggest that the special accelerated tests have to be performed in the stage of developing the design and manufacturing technology. These tests must be developed for each type of sensors and should be based on analysis of the physical and chemical processes in the sensor. For each of the processes we should estimate the trend of the measurement error. The analysis of the construction should be focused on detection of possible defects, which could accelerate the dangerous processes. The metrological analysis of the test results will help to elaborate the design and technology in order to increase the reliability and life time of the sensors.

In this paper we give an example of developing the accelerated test procedure for one of the most widely used sensors – industrial platinum resistance thermometer. However, this method of elaboration of the test plan can be applied to any process sensor.

The understanding of the sensor behaviour for a long time of operation at the working conditions will also be helpful, and even necessary for developing the self-diagnostic systems. Estimation of the change in the characteristics of the sensor with time will give the opportunity to construct self-correcting apparatus.

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