IMPROVED DESIGN FOR 0.6-OHM HTPRTS: REDUCING THE LEAKAGE ERROR AND INCREASING THE STABILITY

Natalia P. Moiseeva

D.I. Mendeleyev Institute of Metrology, St. Petersburg, Russia

ABSTRACT

The improved design for Russian HTPRTs includes an additional platinum lead which is used as an active guarding electrode to eliminate the insulation leakage error. The idea is to block the leakage through ground and to keep the quartz insulation batteries fully charged by applying a bias voltage to the fifth lead with respect to ground, not removing the regular grounding of the bridge. The increase in the HTPRT resistance at the silver point was found to be up to the equivalent of 6 mK. It was also shown that the application of a positive voltage between the measuring leads and the fifth lead while the HTPRT is in the furnace at about 1000 °C could help to improve the HTPRT stability.

1. INTRODUCTION

The combination of platinum and quartz in a high-temperature platinum resistance thermometer results in some phenomena, which might have an effect on the accuracy of the thermometer. Berry studied insulation properties of quartz at high temperatures [1] and found that the quartz insulation of a PRT possessed an extremely nonlinear voltage-current characteristic which allowed a very little leakage current to flow in one direction presumably due to properties of the insulation batteries. This discovery made it possible to suggest a method to reduce both dc and ac leakage temperature errors in all quartz-insulated PRTs above 700 °C by operating the thermometer measuring system at a dc bias of about +6.4 V above ground.

In papers [2, 3] we investigated the effect of the voltage between thermometer leads and ground on the stability of HTPRTs. It was found that a positive voltage applied to the leads at a temperature above 900 °C might improve the stability of the HTPRTs. On the contrary, operation with a negative potential on the leads with respect to ground, or with the leads grounded, had a harmful effect on the thermometers. Contamination of the platinum and deterioration of the quartz was observed at a negative bias on the leads.

The new model of an HTPRT was developed to investigate properties of the quartz insulation at high temperature and to suggest a new method for reducing the insulation leakage error in HTPRTs. The thermometer is constructed similarly to all other 0.6-Ohm HTPRTs, but it includes the fifth lead which is embedded in the sensing element quartz support and goes in parallel to the other leads over the full length of the thermometer. The idea of using the fifth lead in an HTPRT is not new in thermometry. The additional lead serves in some HTPRTs as a passive internal guard. For Russian HTPRTs, the use of the redundant lead is the first experience. Besides, in our method the fifth lead serves as an active guarding electrode.

2. INSULATION LEAKAGE CIRCUIT MODEL

The insulation resistance of an HTPRT was investigated in great details by Berry [1, 4], Evans [5] and other scientists. From those studies we can derive some conclusions on the main sources of the electrical leakage, which should be reflected in the leakage circuit model. The first leakage path is the leakage directly between the thermometer leads through the insulating quartz parts, such as the sensing element quartz support, quartz tubes and disks. The second path is the leakage between the leads of the thermometer through ground, which is recognized to give the largest income to the total insulation leakage error. The leakage circuit model is shown in Fig.1.

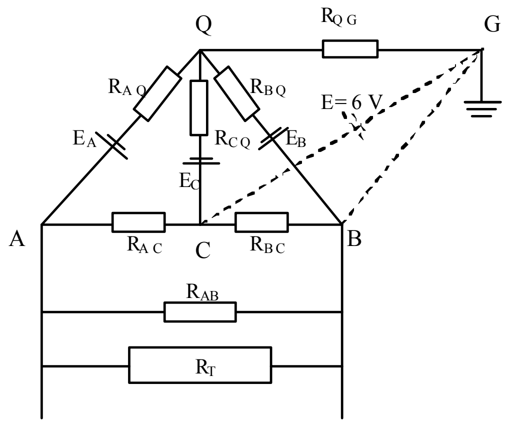

Figure1: The leakage circuit model

The two pairs of current-potential HTPRT leads are designated the A and B leads. R_{AB} is the insulation resistance directly between these leads across the quartz support and the separating disks. An important element of the leakage circuit, introduced and investigated by Berry [1] is the insulation batteries E_A and E_B, which provide the standing dc voltages on the leads A and B with respect to ground when the HTPRT is in an ac powered furnace at a high temperature. The fifth lead of the HTPRT is designated C. It also produces the standing dc voltage E_C. The point Q represents some common quartz surface, such as the HTPRT quartz sheath, which is connected to ground through the resistance R_{QG}. The resistances between this common surface and the leads (they can be interpreted as the internal resistances of the batteries) are designated R_{AQ}, R_{BQ}, and R_{CQ}. The insulation resistances between the fifth lead and the other leads are designated R_{AC} and R_{BC}. R_T is the resistance of the sensing element. The dotted lines refer to the temporary connections, which were being placed and removed during the investigation.

The investigation of the HTPRT insulation leakage was performed at the freezing point of silver, for realization of which we used an ISOTECH model 17705 ac powered high temperature furnace, grounded through the power line. The standing voltage measured with a Solartron 7081 digital voltmeter was about +1.5 V between the fifth lead and ground, and +0.6 V between the other leads and ground. A special experiment was designed to study the ability of the insulation batteries to lose and regain the charge. We applied the voltage of 6 V from a constant voltage source between ground and the fifth lead (the fifth lead was connected to the negative side of the source) for about 30 min, then we removed the voltage and monitored the change of the standing voltage with time. The graph obtained is shown in Fig.2.

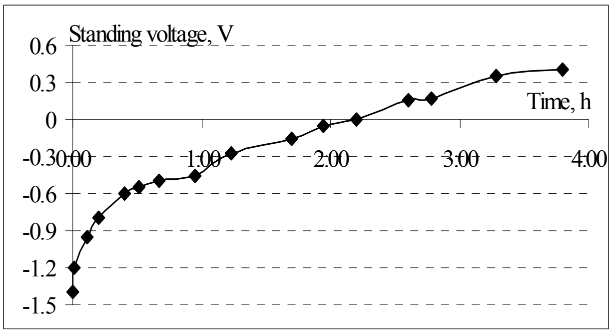

Figure 2: The change of the standing voltage with time after removing a negative bias.

3. MEASUREMENTS AT THE FREEZING POINT OF SILVER

All measurements of the HTPRT resistance in this work were made with a Guildline model 9975 DC bridge. In this bridge, while making measurements, one of the thermometer leads is automatically connected to the circuit common, and, in the regular mode of the bridge, the circuit common is connected to ground. In the schema in Fig.1 this connection is shown as the dotted line BG. As soon as the thermometer quartz parts and the furnace materials lose their good insulating properties at high temperatures, we have electrical loops in the measuring circuit through ground. It was concluded previously in some papers on HTPRTs, that the leakage through ground caused the largest error in the HTPRT resistance value in the situation when one of the thermometer leads was grounded though the bridge. To estimate this error, we can simply disconnect the circuit common of the bridge from ground and observe the change in the readings. Obviously, the leakage error will depend on the temperature, on the nominal resistance of the sensor, and on the thermometer design. For this 0.6-Ohm HTPRT at the freezing point of silver we obtained the difference between the resistance values measured with the grounded and ungrounded bridge of about the equivalent of 4.4 mK. Actually, this is the error in the calibration results that one might obtain in the silver freezing point when using the regular bridge ground connections. With this HTPRT we can also assess the effect of the ground loops on the temperature error by connecting the fifth lead to ground, thus providing an additional leakage path. The HTPRT resistance at the Ag point after the fifth lead was grounded was observed to decrease by about the equivalent of 1 mK.

Usually the fifth lead in an HTPRT is used as an internal guard connected to the positive potential post of the bridge for eliminating the error caused by the drop of electrical potential between the leads. When we connected the fifth lead of our HTPRT to the positive post of the bridge we observed an increase in the resistance values of about the equivalent of 1 mK. It should be noted that if we eliminate the ground loop by disconnecting the bridge from ground, we will still have an error in measurements coming from the electrical leakage between the leads through the grounded furnace parts. However, as our experiment showed, the use of the internal guard in that case is less effective, the increase in the readings was only about 0.2 mK. In Fig.3 we show the difference between the temperature readings at the Ag point caused by the different bridge connections described above.

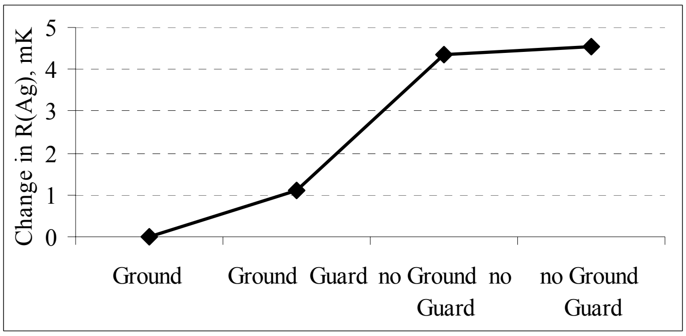

Figure 3: Effect of the different circuit connections on the measurements at the Ag point

The matter of fact, the use of a grounded measuring instrument has many advantages over the use of an ungrounded instrument. The proper grounding protects the measuring system from electrical shock, reduces noises and disturbances, assuring a better stability and reproducibility of the readings. However, in this case, it is important to find a method to eliminate the error from the leakage through ground. One way was suggested by Berry. He involved a voltage source in the insulation circuit, placing it between the circuit common and ground. It is important, that while the alumina insulation had an approximately linear volt-ampere dependence, the quartz showed extremely non-linear characteristic which was explained by charging the insulation batteries. With our new model for an HTPRT, we can take advantage of the fifth lead being involved in the leakage circuit. The idea is to keep the insulation batteries fully charged by applying a voltage between the fifth lead and ground. The positive point of the voltage source was connected to ground, and the negative point to the fifth lead. In Fig. 1 this connection is shown as the dotted line CG. The effect of the voltage between the fifth lead and ground on the value of resistance measured by the bridge is shown in Figs. 4, 5. The voltage was increased in steps from 0 to 9 V, and then decreased in steps from 9 V to 0 V.

In the experiment shown in Fig.4 the increase of the voltage was slow; the time interval between the steps was about 5 min.; the decrease of the voltage started immediately after the value of 9 V was reached. In Fig.5 the steps were made with 1 min interval; the exposure of the HTPRT to the highest voltage was about 20 min. Comparing these two pictures, one can see that the hysteresis is larger for the faster process, which shows that charging of the insulation batteries goes faster then discharging. When the batteries are fully charged, a voltage of about 4 V is sufficient to keep the resistance at the highest value. It is interesting that the dependence of the resistance on the bias voltage at small voltages from 0 to 1 V differs from that at the other voltages. Especially in the return process, it appears that the resistance at 1 V is smaller than that at 0 V. An explanation to this is likely in the properties of this particular insulation circuit. It should be noted that the value of 6 V, obtained in this study as sufficient for saturation of the insulation batteries and elimination of the ground leakage is not universal. It will depend on the temperature and the furnace. Measurements, made at the Al point showed that voltages as high as 15 V had no effect on the HTPRT resistance. We should expect that at the Au point the voltage ensuring the ground leakage protection will be less than 6 V.

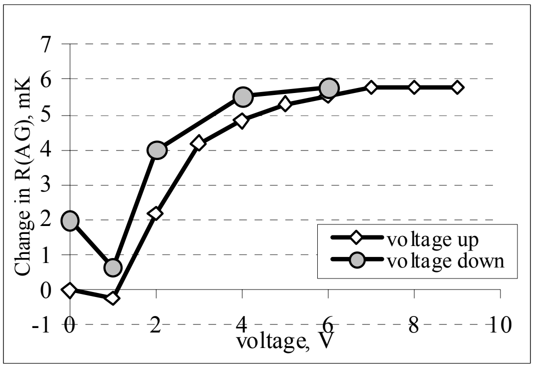

Figure 4

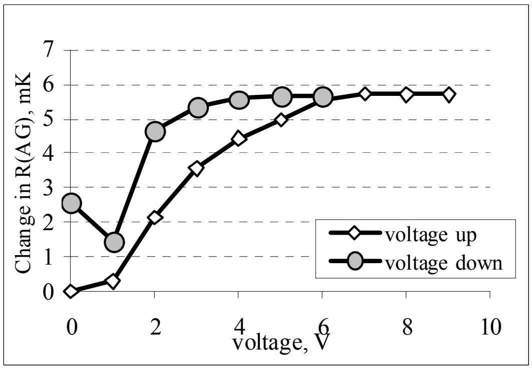

Figure 5

The effect of the voltage between the fifth lead and ground on the HTPRT resistance at the freezing point of silver

In this investigation we made all of the measurements with a dc bridge, which is used at the Russian Standard of Temperature. Incidentally, at the present time the most widely used measuring instrument in the world is model F18 ac bridge, which can be operated at either 30 or 90 Hz. Though this instrument was not available for the experiments with the new HTPRT, we can make some speculations about the use of our method for ac measurements, based on some previous publications. It is known that the F18 bridge has the virtual ground, which is automatically placed on one of thermometer leads and keeps the lead at 0 V. However, in paper [4] Berry observed that after the measurements were made with a F18, the insulation resistance of a Chino HTPRT was reduced to 59% of its initial value obtained before the connection of the HTPRT to the ac system. So, the 0 V voltage on the leads might also somehow affect the insulating properties of the quartz. In paper [1] Berry showed that the insulation resistance can be increased even in ac systems by applying a positive dc bias voltage between a thermometer lead and ground. Therefore, we can foresee that our method of using the fifth active electrode in the insulation circuit will be applicable to ac measuring systems as well.

4. THE EFFECT OF THE BIAS VOLTAGE ON THE HTPRT STABILITY

It was noticed in our previous papers [2, 3], that a bias voltage applied to the thermometer leads with respect to the surroundings can affect the properties of the HTPRT. The most important observations were as follows: a positive bias results in a decrease in the HTPRT resistance, the effect is stronger for the thermometers with a lower value of W(Ga); a negative potential on the leads results an increase in the resistance and a decrease in W(Ga); a negative potential can also result in deterioration of the quartz parts in a close contact with the platinum. These three phenomena appear with different strength in different high temperature furnaces, which is likely due to the furnaces providing different leakage paths through the insulation. The exact nature of these effects is not clear. One suggestion is that a positive bias might promote the oxidation of the metal impurities in the platinum, a negative bias can cause the impurities to intrude on the quartz and destroy it.

The HTPRT investigated in this work has a relatively low W(Ga) value of about 1.118095, which however meets the requirements of the ITS-90. The study of the effect of the bias voltage on the HTPRT stability was performed in an annealing furnace at the temperature of 1000 °C. The curve of the change in R(TPW) during the initial heat treatments is shown in Fig. 6. The first treatment of the HTPRT at 1000 °C resulted in a slow increase of R(TPW). Then we tried to induce a positive potential on the platinum of the sensing element by applying the voltage between the regular leads and the fifth lead. The change in the HTPRT resistance was remarkable. The R(TPW) continued decreasing even when the voltage was removed. The total decrease of the resistance was more than the equivalent of 10 mK. After the initial heat treatments, the HTPRT was not used for about 8 months, and, as a result, the R(TPW) increased by the equivalent of 1.5 mK. During the further 50 hours of annealing at 1000 °C the HTPRT showed some increase in R(TPW) again (see Fig.7). Then we again applied the 20 V bias between the fourth and the fifth leads, which immediately resulted in a decrease in the resistance.

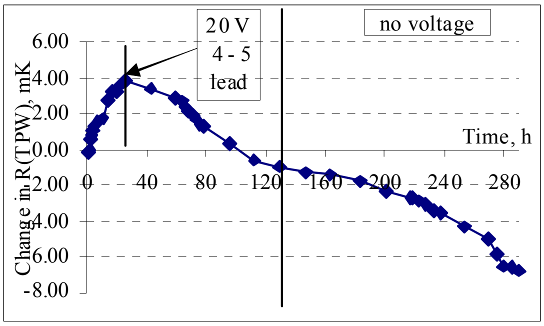

Figure 6: Effect of bias voltage on the resistance stability during the initial heat treatments

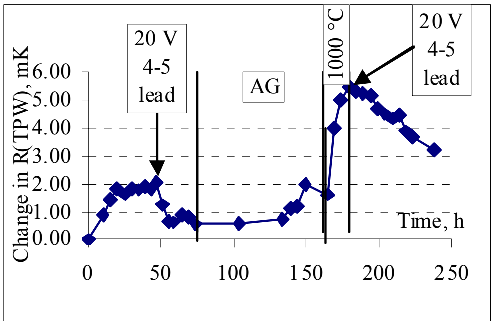

Figure 7: Effect of bias voltage on the resistance stability during heat treatments at 1000 °C and at the Ag point

After a relatively stable state was reached, we performed measurements at the Ag point. As seen from the graph in Fig.7, the resistance R(TPW) was stable within the equivalent of 1.5 mK. However, when the measurements at the Ag point were completed and the HTPRT was exposed to 1000 °C again, it exhibited a large increase in R(TPW). This increase was stopped and reversed by applying 20 V between the fourth and fifth leads. The results obtained support our previous conclusions on the effect of the voltage applied to the thermometer leads on the HTPRT stability. Through the redundant lead we can provide a potential drop in the quartz and keep the sensing element at a positive potential in a high temperature annealing furnace. So, this method might affect the shape of the stabilization curve, though the nature of the effect is not clear yet.

5. CONCLUSIONS

It was found in the past research on HTPRTs, that the major source of error at high temperatures is the electrical leakage through ground. Special guarding methods were suggested in some papers to reduce the leakage error. The improved design for Russian 0.6-ohm HTPRTs was developed to investigate the properties of the quarts insulation and suggest a new method for reducing the insulation leakage through ground at high temperatures.

The investigation confirmed the observation by Berry that a standing voltage is developed on the platinum leads of an HTPRT relative to ground when the thermometer is in an ac powered furnace at a high temperature. The source of the voltage has an ability to adsorb or slowly lose the charge when a bias voltage is applied to the leads with respect to ground. A negative or ground potential on the leads might discharge the insulation batteries, which results in decreasing the insulation resistance of the HTPRT. The fifth lead, involved in the insulation circuit, allows to keep the batteries fully charged by applying a bias voltage between the lead and ground. It is shown that the maximum increase of the resistance at the Ag point is observed at a bias of about 6 V. Further increase of the bias did not have an effect on the resistance measurements. The insulation leakage error in the Ag point eliminated by the bias was about 6 mK.

One more interesting effect was found with the new model of Russian HTPRT. In fact, a long time of using an HTPRT in the silver freezing point or in an annealing furnace may result in contamination of the sensing element by impurities, which will cause the constant increasing of the HTPRT resistance at high temperatures. It was shown that the application of a positive voltage between the measuring leads and the fifth lead while the HTPRT in the furnace at about 1000 °C, will make the resistance of the thermometer change its behavior from increasing to decreasing. So, the new model of the HTPRT might help to improve the resistance stability.

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REFERENCES

[1] Berry R.J., "Analysis and control of electrical insulation leakage in platinum resistance thermometers up to 1064 °C", *Metrologia* **32**, 1995, pp. 11-25.

[2] Moiseeva N.P., Pokhodun A.I., Mangum B.W., Strouse G.F., "Investigation of Stability of HTPRTs at High Temperature", *Proceedings of Tempmeko 99*, edited by Dubbeldum J.F. and de Groot M. J., Delft, 1999, pp. 371-376.

[3] Moiseeva N.P., " Effect of the heat treatment conditions at high temperature on the stability of HTPRTs", *Document CCT/99-03*, *BIPM Com. Cons. Thermometry*, 2000.

[4] Berry R.J., "AC and DC Insulation Leakage Errors in Platinum Resistance Thermometers up to 1100 °C", NRCC Report No 29860, National Research Council Canada, 1988, pp. 1-29.

[5] Evans J.P., "Evaluation of Some High-Temperature Platinum Resistance Thermometers", *Journal of Research of NBS* ***89***, 1984, pp. 349-373.

Address of the Author:

Natalia P. Moiseeva, D.I. Mendeleyev Institute for Metrology, Moskovsky pr. 19, 198005 St. Petersburg, Russia, tel. +7 812 3239634, fax +7 812 1130114, e-mail: N.P.Moiseeva@vniim.ru.