NOISE AND INTERFERENCE IN THERMOMETRY RESISTANCE BRIDGES

Valentin Batagelj [1], *Jovan Bojkovski* [1]

[1] University of Ljubljana, Faculty of Electrical Engineering, Laboratory of Metrology and Quality, Trzaska 25, SI-Ljubljana, Slovenia, valentin.batagelj@fe.uni-lj.si; jovan.bojkovski@fe.uni-lj.si

Abstract − This paper analyses the influence of interference from non-ideal laboratory environment on the resistance-bridge operation. Interference can be either the result of thermal emf, electromagnetically induced voltage or harmonic distortion of the power supply voltage. Interference is manifested as the increased measurement dispersion or even as non-negligible change in the measured resistance.

Thermal emf is the voltage generated by the temperature gradients on junctions of different metals. Resistance bridges are cancelling this effect by using either alternating current or DC current reversal.

Electromagnetic interference is air transmitted interference that generates induced voltage in the thermometer, connecting cables and/or bridge circuits. This effect results not only in unstable bridge operation and increased noise, but can also produce an offset in bridge readings.

Ideally, AC power supply voltage would be pure sine with constant frequency, phase and amplitude, but in practice it is often distorted. Higher order harmonics and/or subharmonics may interfere with the bridge operation.

Experiments with interference sources were conducted on the DC resistance bridge MI6010 and the AC resistance bridge ASL F900. The results were compared and advantages and not only disadvantages of AC and DC principle were outlined, but also some practical recommendations for the reduction of interference are given based on practical observations and experiments.

Keywords: resistance bridge, noise, interference

1. INTRODUCTION

International temperature scale ITS-90 is in large part defined using the resistance thermometers, so in order to accurately measure the temperature, it is necessary to accurately measure the electrical resistance with resistance bridges. Resistance bridges used in thermometry are high accuracy measurement instruments that work on the physical limits of resistance measurement. Detailed analysis of the resistance measurement reveals several uncertainty sources [1,2], where in normal operating conditions the dominating source is the bridge nonlinearity. Bridge nonlinearity is a well-researched phenomenon with and special procedures and devices for its evaluation were developed, [3]. On the other hand, there are several other uncertainty sources, which may in certain condition represent a much higher and especially more unpredictable uncertainty contribution, especially if the measurement conditions are not perfect. Evaluation of interference from the laboratory environment is therefore essential even for the top level measurement laboratories with near-perfect laboratory conditions.

2. MEASUREMENT SETUP

Evaluation of the impact of interference and noise was performed on two high-accuracy resistance bridges:

• AC bridge ASL F900 is based on measuring the resistance with alternating measurement current, [4]. The measurement current flows equally through the standard resistor and the resistance thermometer. The voltages produced, which are in the exact ratio to the resistances, are applied to the precision ratio transformer. The microcontroller adjusts the transformer ratio until it is equal to the ratio of the applied voltages (resistances). The declared accuracy of the bridge is 0,02 ppm (part per million). The bridge was used with measurement current 1 mA, measurement bandwidth 0.2 Hz, frequency 75 Hz, source impedance 100 Ω and gain 105. Measurement interval was 12 s. Standard resistor was Tinsley 5685 with nominal resistance 100 Ω.

• DC bridge MI 6010 is based on measuring the resistance with direct measurement current [5]. The measurement currents through the standard resistor and resistance thermometer are adjusted in the inverse ratio as the underlying resistance, so the voltage drop on both resistances is the same. Both currents are then applied to the current comparator which adjusts the turn ratio until the ampere-turn balance is detected. The declared accuracy of the bridge is 0.05 ppm. The bridge was used with measurement current 1 mA and current reversal time 6 s. Measurement interval was 10 s. Standard resistor was Tinsley 5685 with nominal resistance 25 Ω.

Both resistance bridges were placed on the same table inside the primary thermometry laboratory. Standard resistors were placed inside the oil bath with temperature stability of ±2 mK. Resistance thermometers and standard resistors were connected directly to the bridges in order to eliminate any potential influence of the switching units. Bridges were connected to the computer using the GPIB communication interface and custom-made measurement

software was used to acquire measurements and to analyze the results.

The measurements were performed on three different standard platinum resistance thermometers (SPRTs) immersed in the triple-point-of-water cell. The first SPRT is a Hart Scientific model 5681 quartz sheath thermometer, the second is the Tinsley model 5187 SA quartz sheath thermometer and the third is the Rosemount model 162CE metal sheath thermometer. All SPRTs have nominal resistance of 25 Ω with sensitivity of approximately 10 K/Ω.

Measurement setup was scrupulously investigated and optimized to obtain the measurement results close to the performance limits of the measurement instruments. Special attention was given to the cables for connection of resistance thermometers and standard resistors to the bridge. Various bridge settings were tested and the bridge gain of the AC bridge was calibrated according to the manufacturer procedure. Standard resistors were placed inside the oil bath with temperature stability of a few mK. All cable connectors and thermometer heads were thermally isolated to reduce the effect of thermal emf. Special line for mains voltage was established. All devices in the laboratory, which were not used in the experiment, were switched off.

With all given precautions, the best achievable performance from the point of view of noise and interference was obtained. The performance was evaluated by observing the dispersion (standard deviation) of the resistance readings during one hour of measurements. For the DC bridge, the theoretically achievable dispersion is stated by the manufacturer, [5] and for the used bridge parameters equals to 1.64 μΩ (0.066 ppm). The actual achieved dispersion was approximately 1.7 μΩ, which is close to the expected value. For the AC bridge, the manufacturer and the literature don't explicitly state the theoretically achievable dispersion. The actual achieved dispersion was approximately 0.55 μΩ. These two dispersion values represent typically obtained results, some measurement sets showed also slightly better or worse performance, which could be attributed to random causes. The ratio between achievable dispersions of both bridges is approximately 1:3, which is in good agreement with the declared accuracies.

3. THERMAL EMF

Thermal emf is the voltage generated by the temperature gradients on junctions of different metals. Resistance bridges measure the voltage drop caused by the measurement current on the measured resistance. The thermal emf is superimposed to this voltage drop and may cause erroneous measurements. Resistance bridges are cancelling this effect by using either alternating current or DC current reversal. Thermal emf is added to the voltage drop in the positive current swing and subtracted from the voltage drop in the negative current swing, so the thermal emf is cancelled from the measured mean voltage. This method is very effective if the thermal emf is stable or is at least changing much slower than current direction. AC bridges should be more immune to thermal emf with 25 (or

75) reversals per second, compared to one reversal per 12 seconds with the DC bridges.

To evaluate the effect of thermal emf, all the thermal isolation, which is used to protect the cable connectors and thermometer heads, was removed. As expected, the dispersion of readings with the DC bridge increased by a factor of 2 to approximately 4 μΩ with no change in the mean value. The AC bridge dispersion showed only a small increase to 0.7 μΩ, which is acceptable in most measurements.

In the second experiment, a draft was created by moving a hand in front of the cable connectors. The dispersion of readings with the DC bridge increased to 5 μΩ, while the AC bridge showed no further deterioration.

In the third experiment, cable connectors and other parts of the measurement setup were heated using the hot air from the hair drier. As expected, the DC bridge reacted violently and the dispersion increased to more than 200 μΩ. Surprisingly, the AC bridge showed no further deterioration.

4. ELECTROMAGNETIC INTERFERENCE

Electromagnetic interference is air transmitted interference that generates induced voltage in the thermometer, connecting cables and/or bridge circuits. To evaluate the effect of electromagnetic interference, three experiments were prepared based on the actual problems that were noticed during laboratory work.

4.1. Electrostatic discharge

Electrostatic discharges are small sparkles that may occur in conditions of low relative humidity, when a person touches a grounded metal object. Static electricity is caused by friction of materials, such as unsuitable clothes or shoes with floor or chairs. Electrostatic discharge may affect the operation of electronic equipment and in worst case even cause permanent damage.
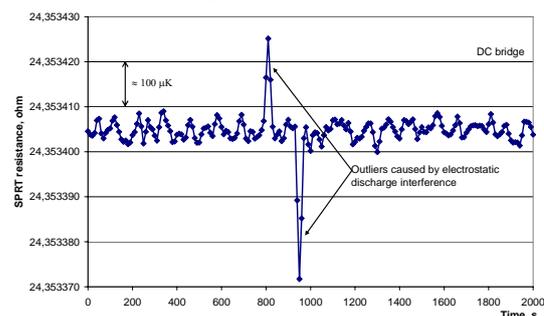

Fig. 1. Spikes in DC bridge resistance readings due to electrostatic discharge.

To evaluate the effect of electrostatic discharge, a person was creating friction between shoes and plastic floor. After sufficient static electricity was accumulated, it was discharged with a spark against the grounded metal frame of the table. The operation of the bridges was observed during the discharge. The AC bridge showed no noticeable reaction, while the DC bridge consistently reacted with a characteristic spike in the readings, as presented in figure 1.

The spike always consists of three outlier readings, forming a triangle in either positive or negative direction. The value of the outliers is least five times outside the expected dispersion, so they are easily detectable and can be removed from the result analysis.

4.2. Electromagnetic interference from electric devices

All electronic devices emit a certain amount of electromagnetic interference, which may in some cases reach levels that affect measurement instruments. Especially critical are some switched-mode power supplies for laptop computers, computer monitors, motors, etc.

To evaluate the electromagnetic interference from electronic devices, a classical CRT computer monitor was placed near the resistance bridges. After the monitor was switched on, the dispersion on the AC bridge increased to 3 μΩ, as presented in figure 2. Although the mean value of readings did not change, the measurement became practically useless. The DC bridge showed no noticeable reaction.
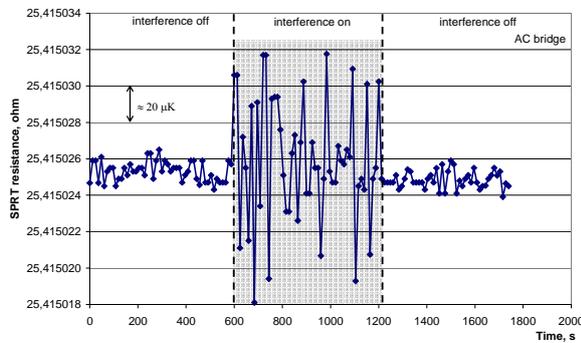

Fig. 2. Effect of electromagnetic interference from CRT monitor on AC bridge.

4.3. Electromagnetically induced voltage

Electromagnetic interference may induce voltages in wires that form closed circuits. This is especially problematic in high-frequency signals which emit electromagnetic waves like small antennas. Although this may appear as an unlikely and abstract event, it was encountered in the laboratory equipment. One of the commercial calibration furnaces has a RS232 communication interface, which was not internally grounded and consequentially produced high-frequency oscillations. The oscillations had a shape of short burst with 20 μs intervals and frequency of approximately 5 MHz. After the cable was properly grounded, the signal disappeared.

The effects of the described interference were reflected on both resistance bridges as both the increase of dispersion and the change of the measured resistance. The effect was investigated with three different SPRTs and the results are presented in table 1. The results show that the change of measured resistance correlates with the self-heating constant of the SPRT. This implies that the interference induced the voltage in the thermometer cables and/or bridge circuitry, which produced enough electric power to heat up the

sensing element of the SPRT. To verify this theory, the bridge measurement current was checked and in presence of interference, the value of the current was increased, but due to the high frequency of the interference it is difficult to measure it accurately.

The results in table 1 show that the AC bridge is more susceptible to this type of interference. The interference causes a large increase of dispersion, but also a small decrease of measured value, which explains the negative change at the SPRT with the smallest self-heating. The change of measured temperature is in worst case approximately 0.6 mK, which is completely unacceptable in SPRT measurements. Fortunately, the increased dispersion is a good indicator that the measurement may be faulty.

The measurements with the DC bridge show a smaller change of measured temperature, but the bridge is almost immune to this interference and it is therefore more difficult to realize that something is wrong, as can be seen in figure 3. The measurements with the interference present appear normal and are similar to measurements with the slightly increased measurement current. If the interference is constantly present, it may be very difficult to notice it, especially because the measurement current is normally measured as the DC current.
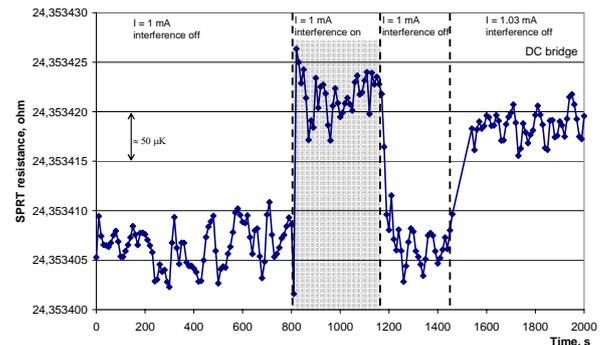

Fig. 3. Heating of sensing element by induced voltage in DC bridge with Tinsley SPRT.

5. AC POWER SUPPLY

Ideally, AC power supply voltage would be pure sine with constant frequency, phase and amplitude, but in practice it is often distorted due to non-linear electrical loads. Higher order harmonics and/or subharmonics may interfere with the bridge operation and cause instable operation.

Several measurement instruments in the laboratory showed abnormally high noise, which was attributed to power-supply voltage distortion. To reduce the impact of this interference, a separate (instrumentation) power line was drawn directly to the faculty power transformer and only measurement equipment was connected to it. Measurements of total harmonic distortion (THD) showed that normal power-supply voltage has the THD in range between 3% and 5%, depending on the time of the day. The THD measurement on the instrumentation line showed an improvement, but was still between 2% and 3%, which implies that the majority of the distortion comes from the

high-voltage power line. Nevertheless, the use of instrumentation line created a noticeable improvement in measurement results with most measurement instruments.

The AC bridge works with the frequency of 25 Hz or 75 Hz, so the frequency specter of the power supply voltage was measured. The specter shows the presence of both 25 Hz and 75 Hz components, which sporadically appear at certain hours of the day and where found to be correlated with increased dispersion of measurements with the AC bridge. A special power-supply filter was therefore developed, which would produce power-supply voltage with minimal amount of the 25 Hz and 75 Hz subharmonic components. The filter consists of the 6th order band-pass RC active filter based on operational amplifiers, which filters the power-supply voltage. The filtered voltage is then amplified with a power amplifier and transformed to 230 V with a 12V/230V output transformer. This setup ensures that the filtered voltage is synchronized with the power-supply voltage, so the bridge can phase-lock the measurement current to reduce interference. Both the normal and instrumentation line have substantial subharmonic components, while with the filtered voltage the subharmonics are lower than the noise floor of the measurement. The filtered voltage has high harmonic components, which are the consequence of the distortion in the output transformer, but they don't interfere with the bridge operation.

To verify the effect of power-supply distortion, measurements with both bridges were performed using normal, instrumentation and filtered voltage. The DC bridge showed little dependence on power-supply voltage and actually the measurements using normal line were slightly better than the other two. The AC bridge showed more dependence on power-supply voltage. The best dispersion achieved with normal line was 0.7 $\mu\Omega$, with instrumentation line it was 0.6 $\mu\Omega$ and with the filtered line it was 0.55 $\mu\Omega$. The difference in best achieved dispersion is not large, but when using the bridge with normal and instrumentation line, it has sporadic bursts of larger dispersions exceeding 1 $\mu\Omega$. These bursts were often found to be correlated with the increased level of subharmonics in the power-supply.

6. CONCLUSIONS

The experiments have shown that both the AC bridge and the DC bridge are susceptible to interference and noise. The DC bridges are more susceptible to thermal emf and to electromagnetic pulses, such as electrostatic discharges, switching of large electric loads, mobile phones, etc. The AC bridges are more susceptible to electromagnetic interference from electronic devices and interference from the power-supply voltage. The installation of a high-accuracy resistance bridge is therefore not a straightforward procedure and requires a lot of fine-tuning and experimentation.

The impact of interference on measurement results is through higher dispersion of results and through the change in the measured resistance. Higher dispersion can be to some extent compensated by averaging a larger number of resistance readings. However, higher dispersion should not be disregarded, as it can also be an indication that interference is influencing with bridge operation and producing a change in measurement results. Probably the most problematic case is when the interference is not manifested through higher dispersion, but it is changing the measurement result, as is the case with DC bridge and electromagnetically induced voltage. Such interferences are often difficult to notice and may have large implications on the measurements of highest accuracy.

One solution to reduce the possibility of corruption of results due to interference is to use both DC and AC bridge for the measurements of highest importance, such as intercomparisons. The operating principle of both bridges is very different, so the effect of interference is demonstrated in different ways. If both bridges produce the same results, it is very likely that the measurement was performed correctly.

REFERENCES

[1] G. F. Strouse, K. D. Hill, "Performance Assessment of Resistance Ratio Bridges Used for the Calibration of SPRTs", *8th Temperature Symposium*, pp. 327-332, Chicago, USA, Oct. 2002.

[2] S. Rudtsch, G. Ramm, D. Heyer and R. Vollmert, "Comparison of Test and Calibration Methods For Resistance Ratio Bridges", *Tempmeko 2004*, pp. 773-780, Cavtat, Croatia, June 2004.

[3] D. R. White; "A Method for Calibrating Resistance Thermometry Bridges", *Tempmeko '96*, pp. 129-135, Torino, Italy, Sept. 1996.

[4] ASL, *F900 Precision Thermometry Bridge*, Operator's Handbook

[5] Brown D, *Resistance measurement systems w/ sub ppm accuracy from 1 μΩ to 1 GΩ*, http://www.mintl.com/documents/resmeassysts_000.pdf