How Voltage Spikes Affect the Accuracy of Reading Convector Rated Heat Flux

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Abstract. The authors hereof have analyzed the standards and past research in heating systems. The paper considers the circuitry of test bench electrification and instrumentation. It describes an experimental setup and an automatic system to control the temperature of the heating circuit; the system is based on a Honeywell MVC80 controller and uses an HD-4022.10U a TRIAC solid-state relay. Control voltage curves are presented. The paper provides generalized data obtained in a series of tests of Lider PS10000 SQ-E voltage regulators (0.5% regulation accuracy) and a CHBT-200003 voltage regulators (3% permissible voltage deviation). The system has been tested to measure the rated heat flux of a KCK 20-1,049 convector by water-and electricity-based methods; effects of voltage spikes on the measurement accuracy are discussed herein.

1. Introduction

The heating system of a building is intended to make stay in such building comfortable for residents/workers while being energy-efficient. For the user, the most important part of the system is the heater, as it must meet the most fundamental requirements to water-tightness, strength, hydraulics, and most importantly, heating [13].

Decree of the Russian Government No. 717 [6] prescribes compulsory certification of heaters; to that end, a heater must pass a series of standardization and certification tests. Heater testing is currently regulated [1]. Export-oriented manufacturers also seek to comply with the European standards [2]. Using modern instruments in testing improves the accuracy of measurements; such instrumentation can be automated [9].

Tests intended to determine the rated heat flux of a heater are exposed to numerous physical factors that affect the measurement accuracy, including the effects of hydraulics pertaining to internal corrosion [17, 18], the temperature parameters [19], and the voltage quality as regulated by [1], Clause 4.4.8 Electric boiler and pump must be connected to a source of regulated voltage with a maximum deviation of 0.1%. This kind of accuracy is difficult and costly to attain, whether for VAC or for VDC [20]. The new revision of GOST R 53583 will have the requirement changed to Clause 5.4.6 Electric boiler and pump must be connected to a source of regulated voltage with a maximum deviation of 2%.

The new revision of GOST R 53583 is intended to enhance the heater testing methodology by taking the advantage of the new developments in instrumentation, automatic controls, and state-of-the-art heating system production, design, and operation [12]. Whether voltage regulation accuracy...
requirements has to be adjusted, or any other amendments have to be made to the GOST is a question discussed by other researchers, too [14–16].

2. Materials and methods

The problem is to optimize the metrological characteristics [7, 8] of a test stand so that interlaboratory tests will have a ±1% accuracy of rated heat flux measurement. This research is to find how voltage spikes affect the accuracy of reading the rated heat flux. To that end, it is necessary to:
- carry out rated heat flux tests with two voltage regulators (0.5% and 3%);
- find how the regulation accuracy affects the rated heat flux.

The test stand is placed in a climatic chamber and consists of:
- a closed (non-ventilated) 2.5 m tall chamber sized 3.3 x 3.3 m in plan view (internals only); the internal surfaces of the chamber are water-cooled to maintain the temperature conditions suitable for the tested heater;
- a water cooler and circulator;
- a heating circuit with a circulating pump;
- instrumentation and controls.

The test stand is equipped with a regulated-voltage power supply that uses a Lider PS10000 SQ-E 0.5% voltage regulator; it also has a backup power supply that uses an CHBT-20000/3 voltage regulator, 3% regulation accuracy. Switching is manual.

Figure 1 presents the power supply circuitry of the test stand. Power equipment: circulating pump (CP), electric boiler with a tubular heater (TH). As shown in the figure, the pump is connected to a regulated power source via a variable-frequency drive (VFD). The boiler uses a Honeywell MVC80 controller (a PID controller), which controls the boiler via an HD-4022.10U TRIAC solid-state relay (SSR). The relay is series-connected to the power circuit and takes commands from the PID controller, which depend on the readings of the heated water temperature $t_1$. Passthrough voltage peaks when the boiler is heating up. The controller delivers a control voltage of 0 to 10 V to the relay, which is further reduced by the PID control algorithm.

The temperature is controlled by an LT-300 laboratory thermometer, which has a maximum permissible absolute error of ±0.05 °C; the resolution is 0.01 °C. Voltage supplied via the SSR is controlled by a HIOKI 3334 wattmeter, 0.1 accuracy class. The measured parameters are voltage, current, active power, total power, power factor, frequency, mean values (sampled 5 times a second). The TH is an active (resistive) load, meaning that $\cos \varphi = 1$; active power corresponds to the total power and heat flux of the heater, which is defined as the difference of heat losses and input electrical power.

![Figure 1. Test stand power supply circuitry.](image)
3. Results and discussions

To find how the voltage stability would affect the accuracy of measuring the rated heat flux of a КСК 20-1,049 convector, the research team carried out two series of tests using 0.5% and 3% regulators per GOST R 53583-2009, see Table 1. Tests used two methods: water-based and electricity-based, for more reliable results; measurements were taken every 10 minutes. Final measurements of the heat flux $Q_m$ are shown in Table 2.

Table 1. Rated heat flux of a convector: test report.

| Parameter                        | 0.5% regulator | 3% regulator |
|----------------------------------|----------------|--------------|
|                                  | 10 min. | 20 min. | 30 min. | 10 min. | 20 min. | 30 min. |
| **Water-based method**           |         |         |         |         |         |         |
| absolute pressure, MPa           | 0.10152 | 0.10152 | 0.10152 | 0.10152 | 0.10152 | 0.10151 |
| chamber temperature, °C          | 20.02   | 20.02   | 20.03   | 20.03   | 20.03   | 20.03   |
| water temperature, °C            | 91.21   | 91.20   | 91.19   | 91.21   | 91.19   | 91.20   |
| water temperature, °C            | 88.82   | 88.82   | 88.82   | 88.81   | 88.82   | 88.82   |
| heat transfer medium flow, l/h   | 383     | 383     | 383     | 383     | 383     | 383     |
| temperature drop, °C             | 69.99   | 69.99   | 69.98   | 69.98   | 69.98   | 69.98   |
| actual heat flux, kW             | **1.0285** | **1.0241** | **1.0195** | **1.0325** | **1.0194** | **1.0239** |
| **Electricity-based method**     |         |         |         |         |         |         |
| test time, min                   | 10      | 10      | 10      | 10      | 10      | 10      |
| wattmeter readings over test time, kW | 0.1975 | 0.1978 | 0.1967 | 0.1976 | 0.1975 | 0.1976 |
| actual heat flux, kW             | **1.0233** | **1.0245** | **1.0180** | **1.0232** | **1.0226** | **1.0237** |

Table 2. Final measurements of the heat flux $Q_m$.

| $Q_m$, kW | Abs. error, kW | Rel. error, % | $Q_m$, kW | Abs. error, kW | Rel. error, % | Difference, W |
|-----------|----------------|---------------|-----------|----------------|---------------|---------------|
| 1.0241    | 0.004          | 0.41          | 1.0257    | 0.007          | 0.46          | 1.6           |
| 1.0219    | 0.002          | 0.21          | 1.0231    | 0.005          | 0.25          | 1.2           |

Test results: difference between 0.5% and 3% regulators. The difference is 1.2 W for the electricity-based method (0.04%) and 1.6 W for the water-based method (0.05%).

The next step is to process the experimental data by a method that is applicable to most normally distributed readings [5]:

1. Determine the number of necessary measurements;
2. Test for normality;
3. Find the regression line parameters;
4. Errors of regression line coefficients.

Figure 2 shows the voltage spikes as read by a HIOKI 3334 wattmeter for 0.5% and 3% regulation over 30 minutes; the dotted lines are regulator-specific voltage regression lines calculated by least squares [10, 11].
Table 3 presents deviations from the mean voltage.

**Table 3. Deviations from the mean voltage.**

| Parameter                        | 0.5% regulator Lider PS10000 SQ-E | 3% regulator CHBT-20000/3 |
|----------------------------------|-----------------------------------|---------------------------|
| Maximum value, V                 | 221.2                             | 230.8                     |
| Deviation, %                     | 0.21                              | 2.89                      |
| Mean voltage over 30 minutes     | 220.73                            | 223.92                    |
| Minimum value, V                 | 220.2                             | 218.1                     |
| Deviation, %                     | -0.24                             | -2.78                     |
| Root-mean-square deviation       | 0.342                             | 4.392                     |

Figure 3 shows PID controller-generated curves of control voltage changes (0 to 10 V) as experienced by the TRIAC when connected to a regulated (TH) load. Apparently, a voltage rise in the mains reduces the TRIAC control voltage (the spikes correspond to the PID controller trigger points). The temperature $t_1$ remains constant at 91.2±0.01°C in both cases, as it is maintained by the controller, see Table 1. Apparently, changes in the supply voltage only affects the TRIAC control voltage but not the final TH temperature.
4. Conclusions

1. The applied power supply circuitry can control the power equipment of a test bench (the boiler, the pump) automatically while preventing voltage spikes from negatively affecting the measurement accuracy. Total error of the test series did not exceed 0.5% for the water-based method, or 0.25% for the electricity-based method as long as tests complied with metrological requirements.

2. 0.5% and 3% regulators caused a difference to emerge: 1.2 W (0.04%) when using the electricity-based method, or 1.6 W (0.05%) when using the water-based method. This means that a 3% regulator can be used without deteriorating the accuracy of KCK 20-1.049 convector rated heat flux measurements too much.

References

[1] State Standard R 53583-2009 2010 Heating devices Test methods (Moscow) Standartinform Publ. 11 p
[2] DIN EN 442-2-2015 2016 Radiators and convectors Part 2 Test methods and rating (Moscow) Standartinform Publ. 79 p
[3] State Standard 31311-2005 2016 Heating devices General specifications (Moscow) Standartinform Publ. 11 p
[4] State Standard R 58065-2018 2018 Conformity assessment Rules of certification of heating radiators and heating convectors (Moscow) Standartinform Publ. 26 p
[5] State Standard 20849-94 2013 Heating convectors. Specifications (Moscow) Publishing house of standards 11 p
[6] Decree of the Government of the Russian Federation of June 17 2017 717 on the introduction of mandatory certification of heating appliances (heating radiators and convectors) The draft document was prepared by the Ministry of Industry and Trade of the Russian Federation https://www.garant.ru/products/ipo/prime/doc/71605406
[7] MI 2714-2002 2002 Recommendation GSI Thermal energy and heat carrier mass in heating systems The method of measurement The main provisions (Moscow) VNIIMS of the State Standard of Russia 24 p
[8] State Standard R 8.736-2011 2013 State system for ensuring the uniformity of measurements Multiple direct measurements Methods of measurement results processing Main principles (Moscow) Standartinform Publ. 19 p
[9] Olejnik B N, Lazdina S I, Lazdin V P and Zhagullo O M 1987 Devices and methods of temperature measurements [studies manual for secondary specialist studies institutions of the specialty "Electrotherplotechnical measurements"] (Moscow) Publishing house of standards 296 p
[10] Tkalich V L, Labkovskaya R Ya 2011 Processing the results of technical measurements Tutorial (St. Petersburg, SPSU ITMO) 72 p
[11] Bolshev L N, Smirnov N V 1983 Tables of mathematical statistics (Moscow) Science 416 p
[12] Bershidsky G A, Poz M Ya 2017 Some questions of the method of thermal testing of heating devices Ventilation. Heating. Air conditioning: AVOK 4 pp 76-81
[13] Tsvetkov N A, Zhukov A V, Krivoshein Yu O, Ivanchin M G and Tokmakov A E 2015 Improving the method of measuring the thermal power of heating devices in actual operating conditions Bulletin of the Tomsk State University of Architecture and Civil Engineering 6 pp 141-148
[14] Sasin V I, Bershidsky G A, Prokopenko B V and Shvetsov B V 2007 The current test method for heating devices - is an adjustment required? Ventilation. Heating. Air conditioning: AVOK 4 pp 46-51
[15] Sasin V I, Bershidsky G A, Prokopenko B V and Shvetsov B V 2007 The current test method for heating devices - is an adjustment required? Ventilation. Heating. Air conditioning: AVOK 4 pp 46-51
[16] Sasin V I, Bershidsky G A, Prokopenko T N and Kushnir V D 2013 Parameters of heating devices according to Russian standards AKVA-TERM 5 pp 71-73
[17] Antsiferov S A, Filenkov V M 2015 Testing of the experimental stand for determining the hydraulic resistance of a rough pipe Vestnik NGIEI 6(49) pp 10-15
[18] Antsiferov S A, Usmanova E A 2015 Analysis of the effect of internal corrosion on the operation of pipelines Vestnik NGIEI 6(49) pp 5-10
[19] Rafalskaya T A, Mansurov R Sh 2017 Evaluation of the influence of water temperature in the hot water system on the temperature of the premises Water supply and sanitary equipment 4 pp 42-49
[20] Kudinov A K, Prjadilov A V and Uzbekov K Kh 2004 Power transistor converter for charging a capacitive energy storage device Science – production 4(72) pp 54-56