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INRIM and NIM Cooperation on the Temperature Amplifier

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Abstract In August 2006, a scientific cooperation agreement between the Italian National Research Institute of Metrology (INRiM) and the National Chinese Institute of Metrology (NIM) was signed. The cooperation will last at least 3 years and has several goals in the field of contact thermometry. First of all, the Chinese Thermometry Division intends to have a temperature amplifier (TA) operative in its laboratories. The cooperation will begin with the manufacture of two new gas-controlled heat pipes by INRiM for NIM: one for lower temperatures and the other for higher temperatures, up to the silver fixed point. The know-how required for the use of those devices will be transferred from INRiM to NIM, since some young Chinese researchers will spend several months working in the Gas-Controlled Heat Pipes Laboratory of INRiM, learning all working principles of the TA and of the involved devices, such as the pressure controller, pressure lines, heater control, and cooling systems. Next, the heat pipes will be filled at INRiM with the working fluids (mercury and sodium) and sent to NIM. NIM will manufacture part of the required accessory devices, such as furnaces, pressure lines, and cooling systems, while a new pressure controller will be manufactured at INRiM for NIM. The acquired and assembled new devices will allow NIM to cooperate in several research activities related to contact thermometry, such as phase transition studies, new temperature standard proposals, and calibration capabilities evaluation. The paper reports all details of this cooperation, the first results achieved, and those expected.

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1 Introduction

The Italian National Research Institute of Metrology (INRiM) and the Chinese National Institute of Metrology (NIM) are both active in research activities related to temperature metrology and temperature scales. The NIM is interested in employing the scientific and technical experiences of INRiM in the field of thermometry concerning the realization and implementation of the International Temperature Scale of 1990 (ITS-90) and research and studies related to metrology of temperature and the definition of the kelvin. The INRiM has a long-established experience in the design, construction, and characterization of gas-controlled heat pipes (GCHPs), and has developed its second generation of the temperature amplifier (TA).

In August 2006, researchers from INRiM were invited to spend some weeks at NIM in Beijing. Discussion immediately followed and a draft of a scientific agreement was prepared. The subject of the agreement is scientific and technological cooperation in the thermometry area and, especially, concerning the proposal and application of the TA as a temperature standard and its use as a calibration facility. A schematic schedule of the agreement is reported in Fig. 1.

2 Starting Activities

As previously agreed, in January 2006, two researchers from NIM, Jianping Sun and Xiaoke Yan, joined the "GCHPs" Group at the INRiM Laboratory, and measurement activities started using the new prototype of the TA. After a short period devoted to learning methods and techniques on the use of the TA, the measurement activities started in cooperation with the staff of INRiM, in the GCHP laboratory. The devices employed in this measurement campaign are the same used for the iMERA—Euromet 772 project [1] and involve a mercury GCHP as a low-temperature reference and a sodium GCHP for temperatures up to the silver freezing point. Since the mercury GCHP had already been characterized [2], the activities have been mainly concentrated on the characterization of the new sodium GCHP at higher temperature. This new GCHP has been connected to the same pressure line as the mercury GCHP in order to realize, for the first time, temperature amplification using all the new apparatus: new GCHPs, a new pressure controller, a new pressure line, and new acquisition and control software.

All investigations previously carried out at INRiM were limited by the capabilities of the involved pressure controller used for the first TA. The new pressure controller recently developed at INRiM allows the extension of the pressure range, both at lower and at higher pressures. The pressure control is now achievable at the level of a few ppm in the whole range from <400 Pa to more than 400 kPa.

First, investigations on the TA at very low pressure (<1,000 Pa) were carried out by NIM researchers. During the experiment, first, it is necessary to find appropriate

2006		
	August	Visit of two INRiM Researchers at NIM Cooperation draft proposed
	November	INRiM - NIM Cooperation Agreement Planned
	December	Agreement signed
2007		
	January	Two NIM Researchers start working at INRiM
	February	Contract signed
		Mercury GCHPs manufactured at INRiM for NIM
	March	The two Researchers back at NIM
	July	Sodium GCHP manufactured at INRiM
	September	NIM GCHPs Filling and checking at INRiM
	November	The two GCHPs delivered at NIM
2008		
	March	Pressure controller for NIM GCHPs manufactured at INRiM
	June	Pressure controller for NIM GCHPs delivered at NIM
	August	Temperature Amplifier assembled at NIM
	September	Comparison measurements start at NIM
2009		⇓

Fig. 1 Timetable of the first activities carried out under the cooperation between INRiM and NIM

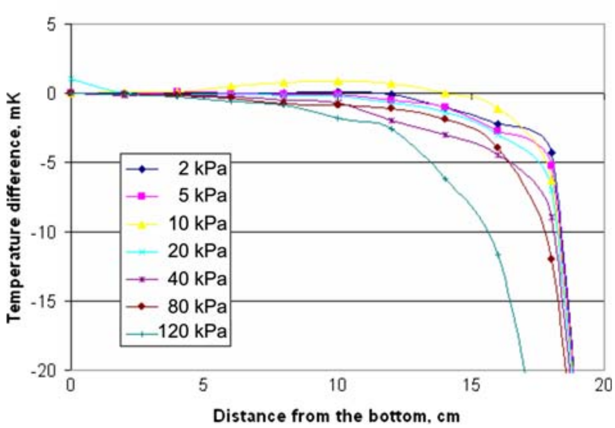

Fig. 2 Temperature uniformity in the mercury GCHP at different pressures

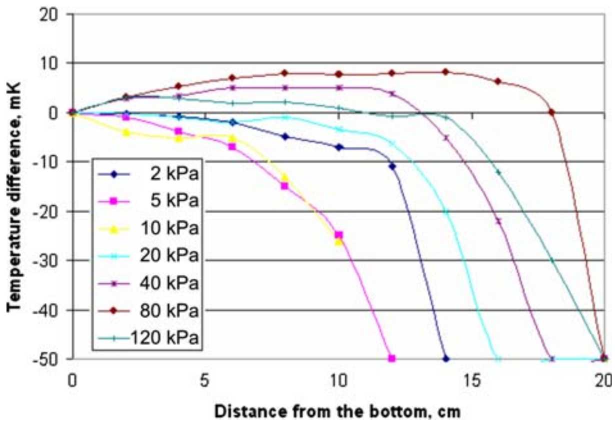

Fig. 3 Temperature uniformity in the sodium GCHP at different pressures

heating powers for the mercury heat pipe and sodium heat pipe in order to obtain good temperature uniformity along their thermometer wells. When the temperature uniformities along the thermometer wells in the sodium heat pipe and mercury heat pipe meet the experimental needs, the dedicated controlling systems are used to control the set-point value, using an SPRT as a pressure sensor in the mercury GCHP [2,3]. Temperature data (stability and uniformity) are then recorded for both low and high temperatures, using the same SPRT for the mercury, while an HTSPRT in the sodium GCHP records the higher temperatures. The immersion profiles obtained under pressure control in mercury and sodium GCHPs at several pressures are shown in Figs. 2 and 3.

Automatic measurements on the TA are carried out with the computer-aided control and data acquisition systems. With these acquired data, the temperature stability of the mercury heat pipe and the sodium heat pipe has been evaluated from 400 Pa to 200 kPa, corresponding to temperatures ranging from 150 °C to 410 °C in the mercury

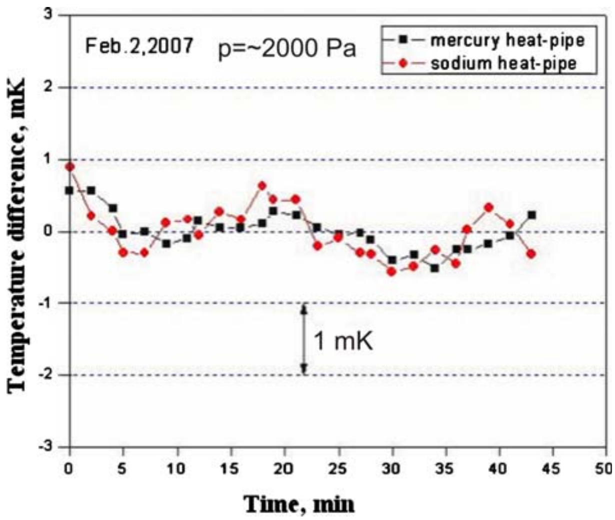

Fig. 4 Temperature stability in the mercury and sodium GCHPs at 2,000 Pa

GCHP and from 480 °C to 1,000 °C in the sodium GCHP. An example of the stability achieved at ∼2,000 Pa is reported in Fig. 4.

The graph in Fig. 4 is important since it clearly shows for the first time that the new prototype of the TA is operating correctly. This means that the inner surfaces of both GCHPs have been "treated" for a sufficient time by the liquid/vapor flow, and this results in a uniform covering layer of liquid metal inside the GCHPs. The simultaneous and identical temperature fluctuations are therefore due only to the pressure fluctuations during this first control attempt. The fact that both GCHPs show the same behavior, as reported in Fig. 4, represents a fundamental result for the research on the temperature amplification. The time response in both the GCHPs, moreover, is similar and quick, as expected when the working fluids are uniformly surrounding the inner surfaces of the GCHPs, and the thermometer well surfaces, in particular. This consideration gives further confirmation to the construction and design of those GCHPs that, as reported, are both brand new and tested in the TA configuration for the first time. Two identical GCHPs will be produced and delivered to NIM.

In addition, since the experimental results on dT_{Na}/dT_{Hg} are very important to assess the temperature amplification relationship $T_{Na}(T_{Hg})$ between the sodium heat pipe and the mercury heat pipe, measurements on the dT_{Na}/dT_{Hg} relation at low pressure were conducted in the following way. First, while keeping a stable pressure in the pressure line, the resistances of two SPRTs in the sodium heat pipe and the mercury heat pipe were recorded. Second, the pressure inside the heat pipes was slightly increased or decreased by means of the electromagnetic valves. Third, the resistances of two SPRTs were measured once they were in thermal equilibrium at the new pressure. Finally, the corresponding temperature changes were calculated to obtain the relation dT_{Na}/dT_{Hg}. Similar measurements were carried out throughout the whole pressure interval previously reported.

Table 1 Summary of first measurement activities by NIM researchers on the TA operating in the INRiM Gas-Controlled Heat Pipes Laboratory

Date	Pressure (Pa)	Hg stability	Hg immersion profile	Na stability	Na immersion profile	Other
19 January 2007	1,000	X	X			
24 January 2007	<1,000	X	X			dT_{Na}/dT_{Hg} evaluation
2 February 2007	2,000	X	X	X	X	
6 February 2007	5,000	X	X	X	X	
7 February 2007	10,000	X	X	X	X	
9 February 2007	20,000	X	X	X	X	
14 February 2007	40,000	X	X	X	X	
1 March 2007	80,000	X	X	X	X	Uniformity among the six wells in the Na GCHP
5 March 2007	120,000	X	X	X	X	dT_{Na}/dT_{Hg} evaluation

A summary of the measurement activities carried out in the first months of 2007 is reported in Table 1.

3 Cooperation on Software Development

During the three months of common activities at INRiM, both NIM and INRiM researchers worked together in the implementation and improvement of the existing software for the TA. The software for the acquisition and control of pressure and temperature was developed at INRiM in the last year [4]. This package was dedicated to all the I/O processes involved in the whole control algorithm, such as bridge readings, pressure readings, electro-valve actions, real-time controls at the level of a few milliseconds, PID controls, data storage, etc. Since the pressure controller is the key to the whole system, the software directly operates in a continuous dialog with the microcircuits and the dedicated electronics specifically developed [5].

This software has been successfully used for testing the capabilities of the innovative pressure controller and for the characterization of the mercury GCHP. When both the sodium and the mercury GCHPs were connected together and work on the TA started, a new situation had to be faced by the software. As might be expected, the two GCHPs constantly interact with one another and temperature or pressure changes in one of the two causes a consequent change in the other, changes due, for example, to a cold SPRT immersion, or to a change of the power. In those circumstances, the software has to be improved in order to better “understand” the complex behavior of the TA and take the appropriate actions, in order to achieve better control. NIM and INRiM staff worked together to improve several algorithms and increase the capabilities of the whole system. The main activities included the contemporary data acquisition with different kinds of SPRTs and HTSPRTs, with multiple graphs online showing fine-tuning of the PID constants. This last procedure turned out to be relevant in order to improve the temperature stability inside the GCHPs; the PID control must take into

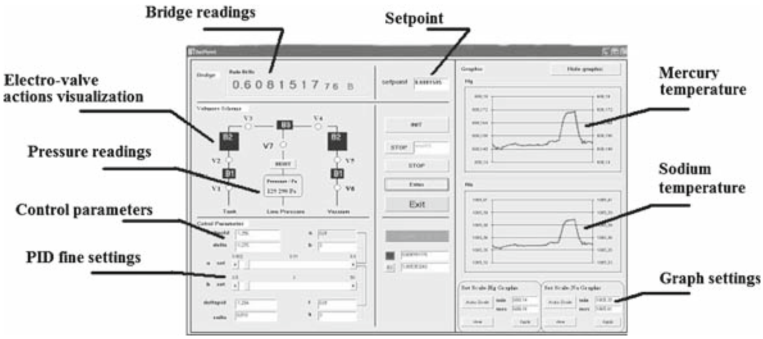

Fig. 5 One of the several virtual panels involved in the acquisition and control process for the temperature amplifier

account further delays due to the above-mentioned continuous interaction between the GCHPs. Another fundamental improvement has been the addition of a function that allows the set point to be changed without stopping the control process. This function is specifically interesting when temperature steps and response times are investigated or if temperature ratios in the heat pipes are to be evaluated, without stopping the control and the acquisition. This process is not so easy to be obtained since the system has to reset many of the control parameters when the set point is changed and, at first, it risks confusing the effect of a control sequence with the change of set-point value. Special care and "self-learning" processes have therefore been implemented by both INRiM and NIM researchers. This software can now be easily used for several functions, both for the TA study and use and for the control of any of the GCHPs, and also for calibration purposes. The main features of the resulting improved software are as follows:

– Easy-to-use panels and windows
– PID algorithm improved
– Multiple graphs visualization
– SPRT and HTSPRT parameter settings and changes during the control
– Control parameter fine-tuning improved
– Totally automatic set-point control
– Manual panel for completely manual control of any component (bridge, pressure sensor, electro-valves)
– Multiple file data storage
– Set-point changing available also during fine control

One of the several virtual panels is shown in Fig. 5.

The so-called "self-learning" processes represent an interesting feature of this system. After several measurements and control observations, INRiM and NIM researchers decided to implement special subroutines to allow the system to easily adapt the control process to different conditions. Since the same pressure controller and the same software will be used in the NIM laboratory, where a different pressure line will be assembled and different buffer volumes will be present, the decision was to try to find "intelligent" and "self-learning" algorithms, to give to the software the possibility to automatically reach its best performance in different situations. These processes are based on evaluating the effect of different sequences of opening and closing electro-valves, directly measuring the corresponding temperature change, when the whole TA is operating. In this way, the pressure values, the volume dimensions, and the pressure-line characteristics are all included in the evaluation of the control parameters and in this kind of retro-active evaluation. The software automatically memorizes the effect of electro-valve opening/closing sequences at different temperatures, achieving fine-tuning in the evaluations of the control constants. This is mostly important when more than one GCHP is operating, since the induced temperature effect, due to the pressure control from one GCHP affecting the other(s), may cause control malfunctioning. The process demonstrated its ability to also evaluate this situation, and take it into account, resulting in a correct delay evaluation for the set-point control maintenance. This principle has been previously checked manually; then, the process was implemented for automatic evaluation of the involved values and actions. During the control, the software automatically decides how many and which kind of sequences are better to keep the set point, taking into consideration any delay in the temperature response time. As a test and first application, the software has been installed in the GCHPs' control line at the LNE-INM/CNAM laboratory in Paris. Under significantly different conditions, and operating with different working fluids, different GCHPs, and a different pressure line, the controller and this software reached the best capability achieved in the INRiM GCHPs Laboratory. A paper will be presented on this result and on the evaluation of the pressure controller performance, against a commercial one.

4 Conclusions

The agreement signed by INRiM and NIM represents promising scientific cooperation in temperature metrology. Since the first activities started, the potential of this cooperation has been demonstrated. The studies on the new prototype TA have been speeded up, thanks to the presence of the NIM researchers at INRiM. At the same time, a new TA is being manufactured for NIM, both for research and for calibration purposes. The characterization of the high-temperature sodium GCHP has been completed and good knowledge in terms of power distribution and control capabilities has been obtained. The software has been implemented taking into account the suggestions arising from the daily experiences in the laboratory. Fundamental knowledge has been transferred to NIM researchers: this will allow them to assemble their own TA and all the requisite dedicated devices at the NIM laboratories, after the new GCHPs and the pressure controller are completed at INRiM.

The cooperation agreement has a three-year duration that can be extended if the parties decide to continue the common studies. Further activities will be carried out on in the following years, aimed at the assembly of the TA in the NIM laboratory and on parallel studies by means of this apparatus. Independent measurements will enforce the proposal of a new standard for contact thermometry [6]. Other studies will be carried on under this cooperation in the field of noise thermometry and acoustic thermometry, with mutual assistance between the two research groups.

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