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AUTOMATED CALIBRATION BENCH FOR CALIBRATION OF RADIATION THERMOMETERS

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Abstract – In order to improve and optimize the procedure for calibration of radiation thermometers, an automated calibration bench was developed. Manual calibration with the help of special stands is time consuming and less reliable compared to automated calibration. The developed calibration bench has 5 degree of freedom (DOF) (3 translation joints and 2 rotation joints). For each axis we have used motorized movement control by means of a stepper motor. Stepper motors control circuit has built-in microcontroller, which controls the speed and direction of rotation of the stepper motors and communicates with the PC. The user interface is implemented as a virtual instrument in LabVIEW programming environment.

Keywords: calibration bench, automation, non-contact temperature measurements

1. INTRUDUCTION

Accurate and repeatable positioning of radiation thermometers is an important part in calibration by comparison of radiation thermometers. Such calibration consists of positioning the reference radiation thermometer and calibrated thermometer in front of the blackbody and comparing their readings. Determination of temperature stability and homogeneity of the blackbody cavity is important, too. In such cases, automated calibration bench replaces manual positioning, which results in better repeatability and accuracy, reduced operator workload and reduction of possible operator errors.

In this paper a custom-made calibration bench with 5 DOF is presented. It is an upgrade of automated system for measuring temperature profiles [1], which had only one DOF. The mechanical part of calibration bench consists of simple mechanical solutions composed of mostly standard commercially-available components. The bench is controlled by an embedded microcontroller, which drives five stepper motors and communicates with a PC. The user interface is implemented as a virtual instrument on a PC.

With the developed automated calibration bench we are able to perform reliable and repeatable positioning of radiation thermometers during a calibration process [2]. The automated calibration bench is also used for evaluation of blackbodies with a radiation thermometer. The temperature drop could be caused by an inaccurate initial position of the radiation thermometer (alignment with the axis of the blackbody's cavity) and/or the size-of-source effect [3, 4], which is especially critical close to the aperture of the blackbody’s cavity.

2. AUTOMATED CALIBRATION BENCH

Automated calibration bench is composed of two main parts, which are framework and the central moving part. Framework is mainly made of standard aluminium profiles, easily available on the market. Structure of the calibration bench is presented in Fig. 1. The workspace of the system is 2800 mm in direction of the x axis, 500 mm in direction of the y axis and 300 mm in direction of the z axis.

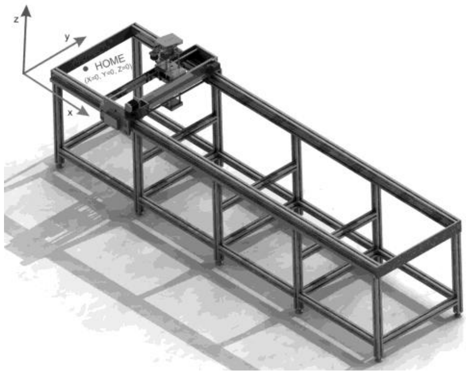

Fig. 1. Automated calibration bench

The central moving part is composed a little bit more complicated because of transmissions, pinions and motors. Its frame is built of custom made aluminium parts, to obtain best performance, as seen in Fig. 2. This part is mounted on linear guides and it is travelling along the x axis in a range of 2800 mm. It can be seen the top of the mechanical system on which could be with screws simply mounted one radiation thermometer or special holder which permit mounting three radiation thermometers at the same time.

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This holder is used for mounting at the same time a reference radiation thermometer and a calibrated thermometer.

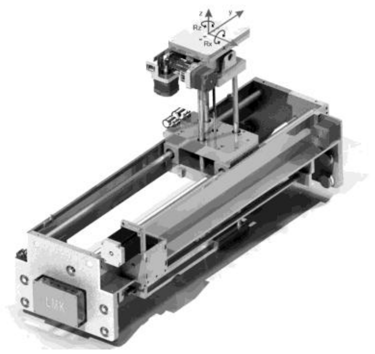

Fig. 2. Central moving part of the calibration bench

2.1. Translation of the top of the calibration bench in x, y and z direction

Essentially the automated calibration bench is a Cartesian mechanism with two additional rotary joints. It has 5 DOF, 3 prismatic joints and 2 rotary joints. Structure is presented in Fig. 3. All the joints are electrically driven by means of the bipolar stepper motors, one for each joint.

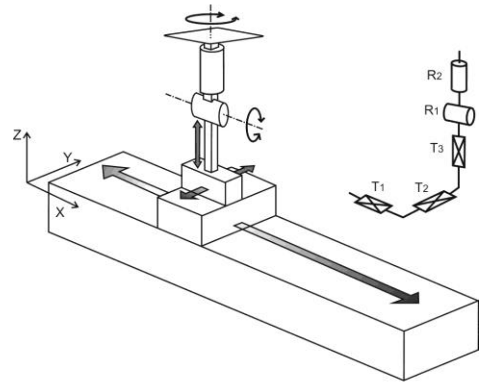

Fig. 3. Calibration bench structure and joints representation

The translation along x axes is presented with translation joint T1, the translation along y axes is presented with joint T2 and translation along z axes is presented with translation joint T3, Fig.3.

In the direction of the x axis the rack and pinion system is used to transform the rotation of the stepper motor to the translatory movement of the central moving part. In this direction it is a large distance, almost 3000 mm, therefore we could not use a ballscrew, due to bending under its own weight. The stepper motor used for translatory joint T1 is mounted on central moving part. This motor is driven in a full step mode and it has 400 steps per revolution. With one step of motor can be achieved the translatory movement of 0,02 mm in the x axis direction. The rotation of the motor is transmitted through toothed gears and belts to the pinion which is rotating on the rack, making the central part moving. The racks are mounted on the both sides of main framework in direction of x axis in order to obtain better mechanical performance.

The translatory movement in the direction of y axis is realized by a screw and special nut, which transform the rotation of the stepper motor in the translatory movement of the joint T2. The nut is made of such a material that there is no backlash. This motor is driven in a full step mode and it has 200 steps per revolution. With one step of motor can be achieved the translatory movement of the joint T2 of 0,005 mm in the y axis direction.

For the translatory movement of the vertical prismatic joint T3 in direction of z axis is used the stepper motor with the same characteristics and the same holding torque like for the prismatic joint T2. It has been also used a screw and a nut for transformation of the rotation of the stepper motor in the movement of the joint T3. With one step of motor can be achieved the translatory movement of the joint T3 of 0,005 mm.

All the joints of the calibration bench can be moved simultaneously, but with different velocity. The speed of each axis is preset and saved to the microcontroller unit (MCU).

2.2. Rotation of the top of the calibration bench around x and z axes

At the end of prismatic joint of the z axis (T3 joint) are added 2 rotary joints R1 (rotation Rx) and R2 (rotation Rz), for end effect orientation, Fig. 3. Two rotation joints enable positioning of the top of the mechanical system at different angles related to the main x and z axes. Maximum rotation of the joint R1 is 11,5° and of the joint R2 is 20,2°. Rotation angles around the x axis and around the z axis are presented in Fig.4. In our case requirements for minimum angles rotations were 10,0° for R1 and 20,0° for R2, but it should be of any other value. The rotation of the joint R1 is from the level position 4,8° upwards and 6,7° downwards. With the current position of the top, a 9,8° rotation to the right and a 10,4° rotation to the left is possible in confront to the central axis of the top platform. The angles of rotation R1 upwards and downwards and rotation of R2 to the left and to the right are not equal, because of mechanical limitation which is set with fixation of home switches.

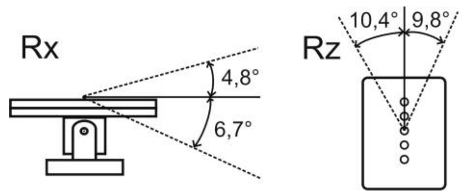

Fig. 4. Rotation of the top of calibration bench around the x and the z axes

The two used stepper motors are of the same type with the equal holding torque. The special custom made screw is mounted on the motor spindle. On the other side it is made a special half of nut, which teeth are positioned in radius to make possible the movement, rotation of the joint. The rotations of the stepper motors are directly transformed into rotation movement of the joints. The friction between the screw and teeth holds the top platform in place when the windings of the stepper motors are not energized. The advantage of this mechanical solution for rotation of rotary joints is no backlash.

2.3 Stepper motor interface of the calibration bench

To drive the stepper motors of the calibration bench it is needed the interface. Stepper motor interface consists of microcontroller board and of five stepper motor driver boards, Fig 5. Each joint has one stepper motor and each motor needs one driver board.

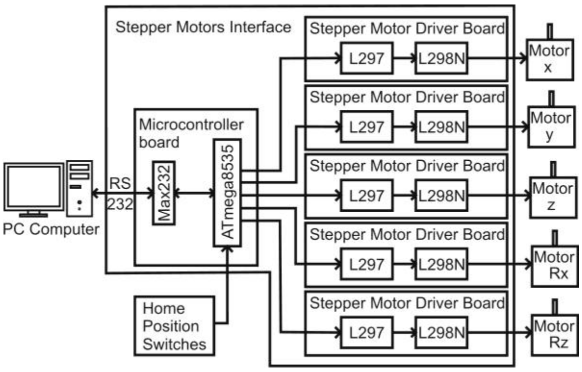

Fig. 5. Stepper motors interface

The main part of the interface is the microcontroller board for the control of the bipolar stepper motors. The microcontroller used is an Atmel ATmega8535, 8-bit microcontroller. Its main features are 8K Bytes in-system programmable flash memory, 512 Byte EEPROM, 512 Bytes SRAM, 32 general-purpose I/O lines and up to 16 MIPS throughput at 16 MHz. It has also built in serial peripheral interface for communication with a PC.

Driver board of stepper motor was done with L297 stepper motor controller in combination with an L298N bridge driver. The microcontroller generates: clock signal, direction signal and enable signal. These signals are sent to L297 IC, which drive the L298N IC bridge-stepper motor supply. This choice of ICs allows a low cost of stepper motor control system and it simplifies the software development for microcontroller.

To reduce the possibility of damage on mechanical system and measurement equipment or any other equipment during the movement of the calibration bench, limit switches were mounted at the beginning and at the end of the movement range of each axis, it means that each joint has two limit switches in totals 10 limit switches in all were used. Limit switches are needed for safety precaution in the case of calibration bench failure.

To achieve the best performance of accuracy and repeatability in the positioning of the top of the calibration bench, the home procedure was made with five optical interrupter switches, so called home switches. This type of switches has better switching repeatability compared to mechanical switches. Home position of the automated calibration bench is presented in Fig 1.

3. SOFTWARE

3.1. Firmware of the microcontroller

The firmware for the microcontroller was written in the Atmel AVR Assembly language. It was written in such a way that the load on the microcontroller was minimized. The main task of the microcontroller is to drive all five stepper motors and communicate via an RS-232 interface with the PC. Microcontroller receives commands from the PC. The main commands are: move for, go to position, go home, stop motor and stop all motors. It also replies to requests about the status information such as: moving for? (it returns the distance), movement status? (returns logical one if the top of the bench is moving in the requested direction) and many others. All instructions and requests that are sent to the microcontroller are processed in a real time. The communication between the microcontroller and the PC is achieved with the RS-232 interface.

3.2. Software of the PC

Software on the PC side is written in a LabVIEW language. Any other programming environment could be used to control the mechanical system, but LabVIEW was chosen since it is already used for measurement applications in our laboratory.

LabVIEW is development environment produced by National Instruments for creating programs in its own graphical programming language called G language. Programs written in G language are called virtual instruments (VIs). Each VI consists of user interface and a block diagram containing the actual graphical code. In LabVIEW was written a simple driver program called *LMK Calibration Bench.vi*. This program serves as a user interface and as a communication interface between PC user and calibration bench. User interface is shown in Fig. 6. Using this driver as a sub program, more complex programs for measurement algorithms could be written in a simple way with minimal effort.

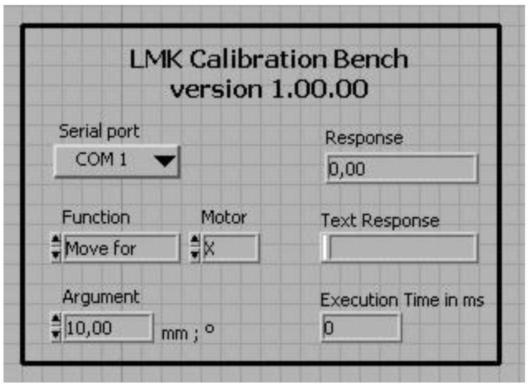

Fig. 6. Simple driver program written in a LabVIEW

4. CONCLUSIONS

The automated calibration bench that was developed for calibration of radiation thermometers proved to be very accurate and repeatable in positioning of radiation thermometers and useful in calibration process. The accuracy of translation joints is within 0,15 mm and the accuracy of rotational joints is within 0,025°. With calibration bench we could perform reliable and repeatable evaluation of the blackbody in terms of temperature stability and homogeneity, which is an important component of the uncertainty budget in the calibration of radiation thermometers.

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