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The measuring and control system for improved model based diastat filling quality

Jure Rejc [a,*], Franci Kovačič [b], Anton Trpin [b], Danilo Rejc [b], Miran Štrus [b], Pavle Obid [b], Marko Munih [a]

[a] *Faculty on Electrical Engineering, University of Ljubljana, Tržaška 25, 1000 Ljubljana, Slovenia*
[b] *ETA Cerkno, Platiševa 39, 5282 Cerkno, Slovenia*

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ABSTRACT

The article describes the development and testing of a measurement and control system in industrial environment. This system enables fast and accurate membrane expansion measurements. The membrane is part of the sensor system called diastat, which is filled with a special oil. The diastat is part of mechanical capillary thermostat. To demonstrate the right selection of the measurement equipment and data processing methods, several tests and analysis were performed: the dynamic response of the diastat membrane during filling, measuring accuracy, nonlinearity and temperature stability of the measurement system with integrated distance sensor and the most important verification measurements with reference control procedures in manufacturing process. It was demonstrated that a number of novel approaches need to be introduced enabling installation of the measurement and control system in the production of the thermostat diastats.

1. Introduction

The article describes the design, development, tests and evaluation results of the measurement and control system needed for control of filling procedure of a product called the diastat. The funder (project partner) for this development project was ETA Cerkno company from Slovenia. The diastat is a part of the mechanical capillary thermostat (Fig. 1) filled with a special oils. The implementation of the presented system was necessary to overcome problems with proper diastat filling and resulting quality of their products.

The main reason is to improve the quality of the manufactured products, to meet the requirements of international standards, such as the ISO standard, and to decrease the quantity of false products. These are present due to inadequate input materials or deficient manufacturing (Vacharanukul & Mekid, 2005). The following categories are often incorporated in the manufacturing production processes: computer aided manufacturing (Golnabi, 2003), various measuring systems (Rejc, Činkelj, & Munih, 2009) and automated visual inspection (AVI) systems (Chin & Harlow, 1982; Rejc et al., 2011). When these systems are introduced into the production, they need to work flawlessly in a longer time period (Nurminen, Karonen, & Hätönen, 2003).

The approach presented in our system belong to the first and second category. Several measurements are influencing the control system. The entire system consists of oil temperature control, oil pressure regulation and very accurate membrane expansion measurements.

In the field of industrial measurements, several parameters are often observed, such as pressure, temperature, distance, viscosity, mass or velocity. The most frequent in industry is distance measurement. The literature (Thiel, Pfeifer, & Hartmann, 1995) states that the most frequent distance measurement range is from 0.1 m to 40 m where contact micrometers (Zeitouny et al., 2011), calipers and incremental probes are mostly in use. In the class of contactless sensors, ultrasound, inductive (Sydenham, Taing, Mounsey, & Wen-Xin, 1995) and capacitive sensors (Zhu, Spronck, & Heerens, 1991) are dominant. Very accurate (Xing et al., 1987) distance sensors based on laser light are also being installed. The working principle can be triangulation (Ji & Leu, 1989), conoscopic holography (Spagnolo, 2006) or interferometry (Bapna, Verma, & Joshi, 1992).

Beside the distance measurement also temperature and pressure measurements are of upmost importance in industrial environments. Temperature can be measured through direct contact with the measured object or with observation of heated or cooled material (Childs, 2003). We can find several temperature measurement methods that differ in their speed and accuracy. In industry most frequently used temperature sensors are thermocouples, resistance temperature detectors and integrated temperature sensors (Campbell, 1970; Liu, Ma, & Yang, 2011). In the field of pressure measurements the capacitive pressure sensors (Kumar, Kumar, Jain, & Kashyap, 1999) are most frequently used, but also other measurement principles can be found (Harada, Ikeda, Kuwayama, & Murayama, 1999), for instance the piezoresistive measurement approach.

The most important part of our investigation was to enable very accurate distance measurements. Therefore, the developed mea-

* Corresponding author.
E-mail address: jure.rejc@robo.fe.uni-lj.si (J. Rejc).

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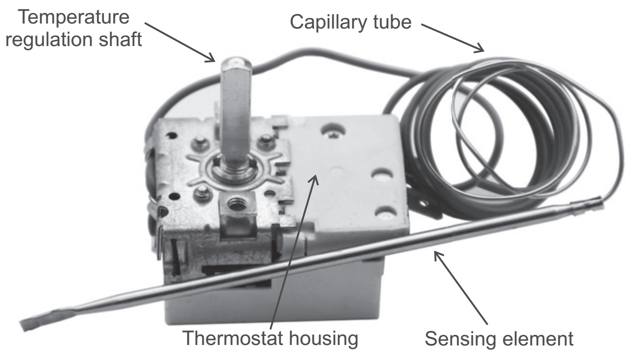

Fig. 1. Capillary thermostat.

suring system with the integrated distance sensor was verified in detail. Comparative measurements were performed by using a certified contact micrometer and real objects. The entire measurement and control system performance was verified with reference control procedures in manufacturing process. The measurement approaches and test results are presented and discussed.

2. Diastat

The diastat is one of the components in the capillary thermostat, used in everyday life for temperature regulation in household appliances (European standard, 2003; Peffer, Pritoni, Meier, Aragon, & Perry, 2011). Capillary thermostats differ in dimensions and performances. The project partner produces 6 different types of capillary thermostats, covering the temperature ranges from −5 °C to +550 °C.

The diastat consists of a membrane, capillary tube and a sensing element (Fig. 2), filled with a special oil as a heat-mechanical transducer. The oil expands with the temperature rise. Larger oil volume results in the membrane expansion that is pushing the capillary thermostat switch. Switching occurs when the membrane expansion is sufficiently large. The user predetermines the desired switching temperature with the capillary thermostat regulation shaft. This switching temperature can be also fixed in advanced by the manufacturer. The filling oils differ in viscosity and chemical properties. The details regarding the oil characteristics will not be part of this article.

The quantity of thermostat types that project partner manufactures is top grade in comparison to the number of diastat families. There are several thousands different diastat types and millions are manufactured every year. The types of diastat differ in all three component parts. The connection between the membrane and the sensing element is provided by the capillary tube. It is very thin with the outer diameter of 1 mm and inner diameter of 0.5 mm. The length varies from 470 mm to 1550 mm. Apart from the capillary tube, also the sensing element is not built into the thermostat housing. The outer diameters of the sensing element differ from 3 mm to 6 mm and the lengths between 73 mm and 201 mm.

The membrane is the most important part of the diastat. Its design enables the conversion of changes in oil temperature into linear membrane expansion. The membranes differ in radius, from 20 to 26 mm, and also in a membrane part that asserts force on the thermostat switch. This part can be made of ceramic as a ceramic button or from metal as a metallic button (Fig. 3). These differences do not influence on the thermostat performance.

3. The diastat filling procedure

Each diastat is filled with oil. The filling procedure of approximately 90% of manufactured diastats is performed on rotary filling machines (Fig. 4). The quantity of ceramic button membranes diastats that are filled on rotary machines is three times larger than those with the metallic button. In production hall six rotary machines are situated, each with 48 filling heads. The filling procedure is as follows. The workers manually position the sensor element of the diastat into the filling head, while the capillary tube and membrane hang freely in the air. The rotary machines rotates with a cycle time of cca. 2.5 s. With each cycle the diastat moves from one procedure phase to another, where the duration of the phases can be several cycles. In the first two phases several diastats are in vacuuming process, sucking out all the air and checking if the diastat does not leak. Follows the longest phase where the diastats are filled with oil. The machine is under pressure pushing the oil into the diastats and expanding the membranes. In the final phase each diastat sensor element is taken out from the filling head. This procedure can be skipped for those diastats that are filled with low viscosity oils. Finally, the tip of the sensor element is mechanically pressed and electrically welded to close the diastat.

The other cca. 10% of the diastats are meant for special purposes, where regulation tolerances are very narrow. As it is difficult to assure these tolerances with the use of rotary machines, these diastats are filled manually. This procedure lasts about 2 days. Due to long manual filling procedure the partner aimed to transfer some of these special diastat types for filling on the rotary machines after our project with the measurement and control system is implemented.

4. Influence of diastat filling on quality of the thermostat temperature control

Industrial environment requires very accurate distance measurements. The expansion of the membrane during filling can range from 0.07 mm to 0.5 mm, depending on the diastat type. The expansion of a kitchen oven thermostat diastat membrane for 0.01 mm represents a difference in temperature of 3 °C. These two facts require the measuring accuracy of the implemented measuring system within the range of 5 μm, corresponding to ±1–2 °C error for calibrated thermostat.

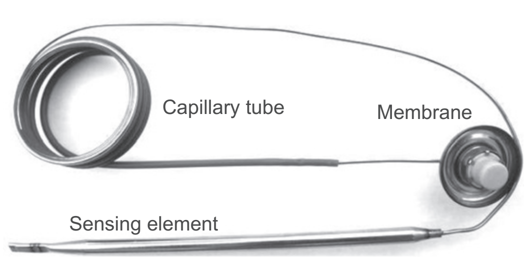

Fig. 2. Diastat.

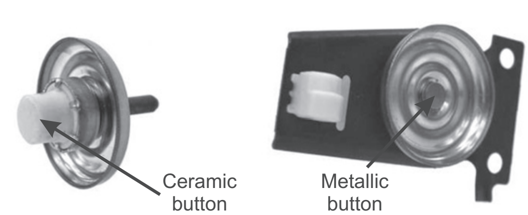

Fig. 3. Two different types of membranes.