Temperature Control of Liquid Working Medium Operated Heating Plates

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Abstract: *It is extremely important to be able to produce the right quantity and quality of meat under large-scale conditions. In addition, due to rising energy prices and environmentally conscious thinking, there is an increasing focus on operating with the highest possible energy efficiency and using renewable energy sources. In pig farming, contact heating plates used in piglet nursery are typically using either liquid as working medium or they directly using electric heating solutions. The thermal utilization of solar energy provides an opportunity to reduce the energy needs of liquid working systems from fossil fuels. The main problem with this solution is that the temperature of the heating plates inside the barn can vary depending on the load and other environmental parameters, due to the central control, which impairs the comfort of the animals. This paper examines the possibilities of controlling contact heating pads with liquid as working medium. A block-oriented modelling framework is used for the mathematical models that were validated on a small-scale model.*

Keywords: *Agriculture, Control, Heating, Modelling*

1. INTRODUCTION

It is extremely important to be able to produce the right amount and quality of meat. For this reason, animal husbandry must take place on a large-scale level. Production must be carried out in a sustainable way, considering animal welfare guidelines.

The current Hungarian regulations 39/2018. (XII. 13.) dictate the condition for obtaining the animal welfare subsidy is the creation of the conditions necessary to avoid fighting and burnout, as well as the establishment of a suitable microclimate in accordance with clauses c) and e) of the first paragraph of § 5.

Even more important is the cooling of the body surface, which is extremely dangerous to the health of the animal, which can be one of the consequences of cold floor surfaces or the combined effect of sweating due to overheating of the contact plates and drafts, which can cause catarrhal stomach and lung disease.

Since the phenomenon of burnout (ear and tail chewing) can be associated with high stress levels (Johnson et al., 2018), one of the causes of which is the sensitivity of the pig to temperature and other factors, and the appropriate microclimate condition includes the appropriate temperature. So, the issue is important from both an animal welfare and an economic point of view.

In pig housing, a type of stable called a pig farm is used to increase the comfort of the piglets by means of various heating techniques (Barótfi et al., 1979). One of these is the use of contact heating plates, which can be liquid-working or direct electric heating. Boilers powered by gas or biogas (Tóth L., 2021) are often used to supply the above-mentioned solution with a liquid working medium, in some cases using solar thermal energy.

The main problem with the use of these systems is typically the uneven temperature distribution between the heating plates placed at several points within the pig farm. This is because these systems can be considered as high time constant systems that are difficult to control under changing conditions (sheet contamination, airflow, etc.). For this reason, farmers often opt for more expensive electrical solutions.

1.1. Literary background and foundation of the research

According to literature sources, it is becoming more and more common in both industry and agriculture today they use solar energy for heating purposes (Xie et al., 2019). In my experience, solar thermal underfloor heating systems that used in pig farms are often unable to maintain the expected temperatures due to the large time constant (Kull et al., 2019) and various parameters (Lu et al., 2020). That is why it is typical for farmers to operate more expensive electric underfloor heating they choose instead of systems that directly use the energy of the Sun. Both the domestic and international literature deals in detail with the control technology sub-area that is optimal for renewable resources and solar systems.

The first use of solar energy for hot water production dates to the early 1900s, when prehistoric collectors similar to today's versions appeared in England and America. Their spread was accelerated in particular by the 1973 oil crisis. Today's biggest users of the solar collector technology is China and the European Union (Varga, 2017). The technical devices that collect the radiant energy of the Sun and utilize it thermally is called a solar thermal collector (Véghely, 2012). Today, it is an extremely current and evolving research sector. A not so popular research area, however, is the thermal utilization of solar energy in temperature-sensitive areas such as pig husbandry, where the comfort of piglets is the primary consideration (Johnson et al., 2018), which adversely affects animal development.

There are several solutions for the mathematical description of dynamic systems, of which the differential equation methods (Nagle et al., 2012), which are to be used in the time domain, the transfer functions (Paraskevopoulos, 2002), which provide a solution in the operator domain, and the state space models (Shumway et al., 2011). All these description methods can be applied in a block-oriented modeling approach.

2. AIM OF THE RESEARCH

The research aims to investigate control algorithms that can perform robust temperature control of systems with large time constant. My goal is to connect a heating auxiliary thermal solar system formed from a network of liquid contact heating plates used in piglet housing to a small sample model with the possibility of:

- different control algorithms (On-Off, PID, model-based, adaptive model-based, artificial neural network),
- various actuators (pump, throttle).

The validation of the mathematical models happened in the experimental laboratory of the Institute of Technology, Department of Mechatronics.

3. MATERIAL AND METHOD

In this chapter, the experimental methods and tools used to achieve my research goals will be presented, including the small-scale system created for the experiments and the parts that make up the system.

3.1. Block-oriented modeling

The mathematical models of the studied system were created in a block-oriented way. MATLAB + Simulink software package was used as a framework due to the currently active university license (Tóth J., 2021).

MATLAB is a product of The MathWorks, Inc. MATLAB is a programming language and the development framework that supports that language. This software package is widely used for numerical calculations (Ashino et al., 2000), as a tool for linear algebra, mathematical programming, and other subjects (Stoyan, 2008), also the transfer functions and state-space models used in process control applications (Simulink User's Guide, 2015). MATLAB is an excellent prototyping language, i.e. an algorithm for designing a calculation, suitable for testing, as it has both linguistic and visualization tools, however, this convenience comes at the expense of speed. MATLAB is an interpreted language, so a program written in it is not converted into computer instructions, such as in the C language, but is executed line by line. The so-called Toolboxes are available for the MATLAB software package, which extend it the scope of use. Toolboxes are function libraries created for solving a special task, such as image processing, statistics, and curve fitting. The simulations were carried out in MATLAB R2019b.

The Simulink software package is a toolbox of the MATLAB system. Simulink is a block-oriented modelling framework used for simulating dynamic systems. The framework includes the basic units, one of which is the solar energy recovery mathematical models describing the system can be constructed, the vast majority of which are ordinary differential equations. The Simulink system includes a numerical solver for the Runge-Kutta and the Dormand-Prince algorithms (Ashino et al., 2000) which most frequently appear in an engineering application, i.e., a perfect choice for the models in this research.

3.2. Small-scale model

The small-scale model is a two-circuit solar thermal utilization suitable for Hardware-in-the-Loop (HIL) simulations for the validation of mathematical models. To model the solar collector, an electric heater was used to precisely control the amount of energy representing the heat energy input of a solar collector. Figure 1 is a schematic diagram of the small-scale model, while Figure 2 shows the actual experimental system.

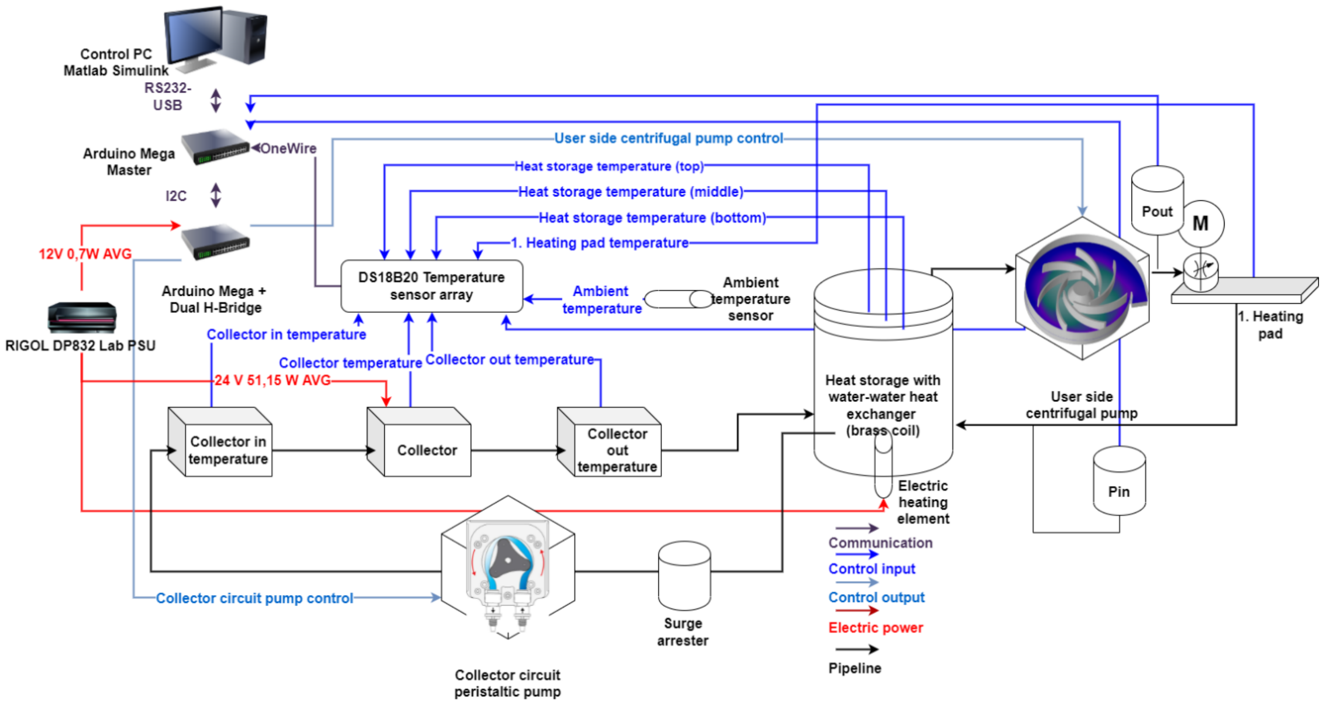

Fig. 1. *Block diagram of the designed small-scale system*

The model is designed to make room for further improvements that may be required based on measured data (Tóth J., 2021). The small-scale model uses seven DS18B20 digital temperature sensors which are able to set up as 10 or 12 bit output resolution, one for heat storage unit, one in the collector unit, one each for both the collector inlet and outlet points, one on the surface of the heating bench, a sensor for measuring the ambient temperature, and one for the return branch of the user-side. The pressure transmitters used to test the pressure conditions are integrated in the user-side placed on the inlet and outlet sides of the throttle valve. The type of pressure sensors is My1220 which have a measuring range of 0-10 bar and an output voltage of 0.5-4.5 V. The sensor has an analog output, so the resolution depends on the used ADCs resolution, which in this case 10 bits.

The pump responsible for circulating the heat transfer medium in the collector loop, operates on the principle of a volume displacement and it is a peristaltic pump. Since the pump is operated with an on-off controller, the flowrate is either 0 or 0.354 liter/min.

The circulating pump of the user circuit is a centrifugal pump. The pumps flowrate depending its load and driving motors regulation is between 0 and 0.23 liter/min. The reason to use different working principle pumps is that the output flowrate of a positive displacement pump is easily calculable and it is sufficient to model a steady flowrate in the collector circuit. This solution has been validated in preliminary research. In the main focus of this research however stands the user circuit, in which centrifugal pumps are used in practice. Both pumps are driven by brushed, permanent magnet DC motors. A polypropylene plastic container (1 liter in volume) insulated with a roof insulation material (1.35 W/m^2K) was used as a heat storage. The storage tank is equipped with a copper tube coil as a water-to-water heat exchanger between the storage- and heat transfer medium used in the collector circuit.

During the measurements, the temperature rise of the heating cycle was examined. An average of 51.15 W was used to heat the collector circuit, and the pump speed of the collector circuit was 316 rpm, expressed as a mass flow of 0.0059 kg s^{-1}.

The measurements also revealed that the system is operating at a significant loss. To explore the location of the losses, thermal camera images were taken as shown in Figure 3, showing a 50-50% image in the visible light as well in the infrared range.

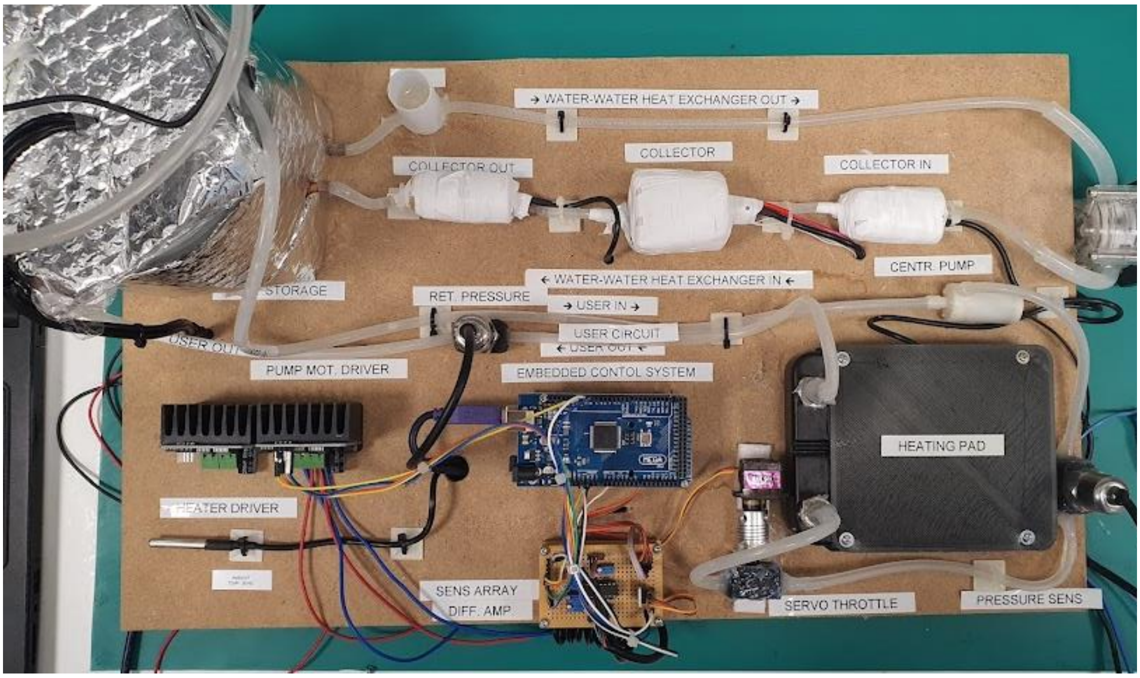

Fig. 2. The built experimental small scale system with embedded system and hydraulic circuits

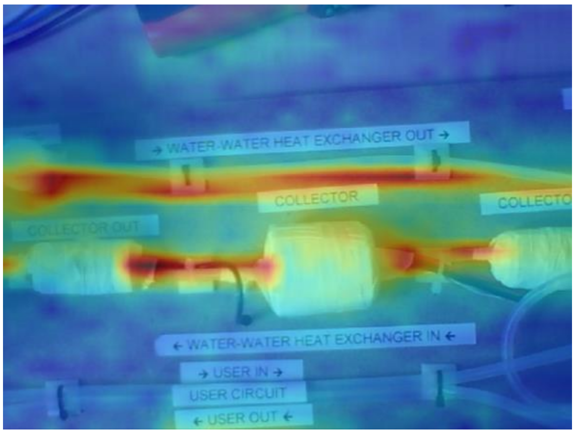

Fig. 3 Heat camera image of a small sample model (Tóth et al., 2019)

It is striking that most of the heat loss is on the surface of the pipes, so a necessary step in the development of the model may be to reduce the losses occurring here with adequate thermal insulation.

According to our calculations, 31 percent of the power invested in electricity is spent on heating the ambient air in the form of a loss, while the remaining 69 percent is used to heat the liquid in the heat storage.

3.2.1. Temperature sensor

The sensor type of choice was the DS18B20, an intelligent sensor available in an industrial stainless-steel housing. The various parameters of the sensor make it extremely suitable for use in the small-scale model.

When configured for 12-bit data resolution, the maximum accuracy is 0.0625 °C.

3.2.2. Pressure sensor

In order to narrow the measuring range of the used My1220 pressure sensors, it was necessary to condition the output signal and calibrate the sensors.

The circuit shown in Figure 4 consists of a voltage tracking circuit (buffer), a differential amplifier and a low pass filter with a cutoff frequency of 1.592 Hz. The gain of the differential amplifier is 20. The differential amplifier has a voltage output of 0 V in case of ambient pressure. The sensor itself has 0.5 V output voltage value in the same situation, as the sensor is able to detect pressures lower than atmospheric pressure. With this solution it became possible to measure the examined range, which in this case is 0-15 kPa with sufficient accuracy (resolution of 14.6 Pa).

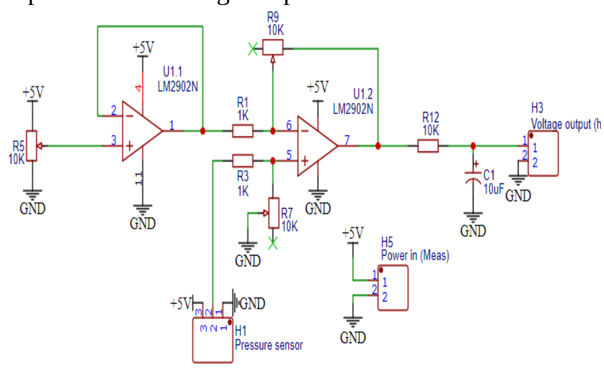

Fig. 4. Signal conditioning circuit

The sensors and the signal conditioning circuit were calibrated by measuring the equivalent water column height, since the hydrostatic pressure of a 1 m water column was 0.1 atm, i.e. 98066.5 Pa

3.2.3. The embedded system used to control and measure

The embedded system used in the small-scale model is based on the Arduino platform.

Arduino is an open-source development platform designed to program hardware with designs available to anyone. The open ecosystem created in this way allows for community developments that have made embedded computing more widely available and attractive. The platform consists of a so-called Integrated Development Environment (IDE) and a compatible Arduino board, i.e. a microcontroller platform with additional electronics. The programming environment itself is a platform-independent C / C ++ programming language written in Java. To enable the compiler to work seamlessly with multiple microcontrollers and even microcomputers with different architectures, the IDE includes hardware definition files and associated hardware-specific directory packages that allow you to manage the various memory addresses required by the various peripherals of the controllers and the register. Thus, contrary to the general misconception, Arduino is not a microcontroller, but a complex platform that allows us to program an embedded system of different architectures, designs, and performance in a unified manner (Tóth J., 2021).

The program for the cards in the small-scale model has been compiled and uploaded with Arduino IDE version 1.8.3.

The following parameters were considered when selecting the cards for the small-scale system:

- number of analog-to-digital converters, their resolution,
- number and resolution of pulse width modulation modules,
- maximum power that can be controlled per port,
- available communication modules,
- processing speed,
- number and resolution of timers,
- interrupt handlers,
- oscillator stability.

The Arduino Mega 2560 card has been selected for the small-scale system to control the pumps and read the sensors, as this card has a suitably versatile microcontroller with adequate speed and peripheral support. The most important parameter of the card is the microcontroller, which is an ATmega2560.

4. RESULTS, CONCLUSION

We successfully designed and built a small-scale system which is capable to mimic a contact heating system supplemented with solar thermal system. The small-scale model is equipped with all the necessary actuators and sensors which enables us to conduct experiments and collect data. This data will be used to identify the parameters in the block-oriented simulation models on which we are currently working, and it is able to validate our simulation in various control scenarios.

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