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# Distributed Intelligent Hierarchical System for Heat Metering and Controlling

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***Abstract** – A key factor of rational energy consumption management is the accurate measurement. Measuring and charging heat consumption are rarely worked out in the prevalent warm-water heating systems. The developed modern heat-meter device, which includes micro-controller, is self-calibrating and self-testing, it uses several correctional algorithms in order to increase accuracy after authentication. The discrete devices are connected to a local concentrator via M-bus. The concentrator collects calculated data from measured values and information about the state of the heat-meter. Consumption data and information about the work-state events are logged and stored by the measuring unit. The concentrator is connected to the central supervisory system through mobile communication channel (GSM). In this system, the meter devices respond to arising failures on the one hand with the help of their own algorithms, on the other hand based on information from the concentrator and from the center. Whereas the center is able to collect information about measuring and usage, based on requested information. This solution highly increases the thrift and the trustiness of the system.*

***Keywords** – correction heat measurement, heat flow measurement, micro controllers, hierarchical supervisor system*

## I. INTRODUCTION

In last decades saving the energy has become an important issue, due to environmental protection and economical reasons. A significant part of the energy is utilized for heating.

Nowadays there are a lot of district heating systems in Hungary and worldwide, which were built by energy wasting approach. These systems are based on fixed price service agreements. This solution contradicts the energy saving principle, because the consumers are not interested in energy saving, they always pay a fix charge.

A primary concern of nowadays heating services is to accurately measure and charge the heat consumption.

The continuous control of the whole or a part of the heating system is also important from the point of view of the safe and the profitable system management.

This requires equipping a measuring device at the consumer and the integration of this device into a information system. This can offer a straightforward solution to the problem.

*Preliminaries*

Previously those devices were used in district and central heating systems, which allowed the so-called charge distribution/division. These devices usually were attached to the heater and worked on principles of chemical reactions. Several external effects influenced the measuring result, therefore these had relatively low accuracy. On the other hand, the devices provided only visual reading. The device provided no information about the system operation and the state of the devices. Due to the evolution of the digital techniques, several micro-controller based heat meter devices have come to existence recently. These usually use turbine flow meter that has the disadvantage of requiring regular maintenance of moving parts and having lower accuracy Currently, the majority of these devices work usually independently and allow not more than reading of the measured value through some kind of interface.

The authors have developed a heat-meter device and an information system which eliminates the mentioned insufficiencies.

## II. MEASURING SYSTEM

Fig. 1. shows the proposed measuring setup. The so-called forward-going warm water flows to the consumer through the pipeline system. At the consumer the water flows through a heat transmitter surface (heater, heat transmitter, floor heating), loses heat, cools down and comes back to the service in the returning pipeline. The primary task of a heat meter device is to calculate the heat consumption from the heating warm water volume, and the temperature of the flow of the forward-going and the returning water. The first law of the thermodynamic describes the behavior of systems in thermal equilibrium. Thermal calorific energy and mechanical work could influence the state of this system. In case of liquids, which supposed to be incompressible (e.g. water), the mechanical work can be neglected. The specific energy changing is equal to the changing of specific enthalpy [1].

$$\Delta E=\Delta H \qquad (1)$$

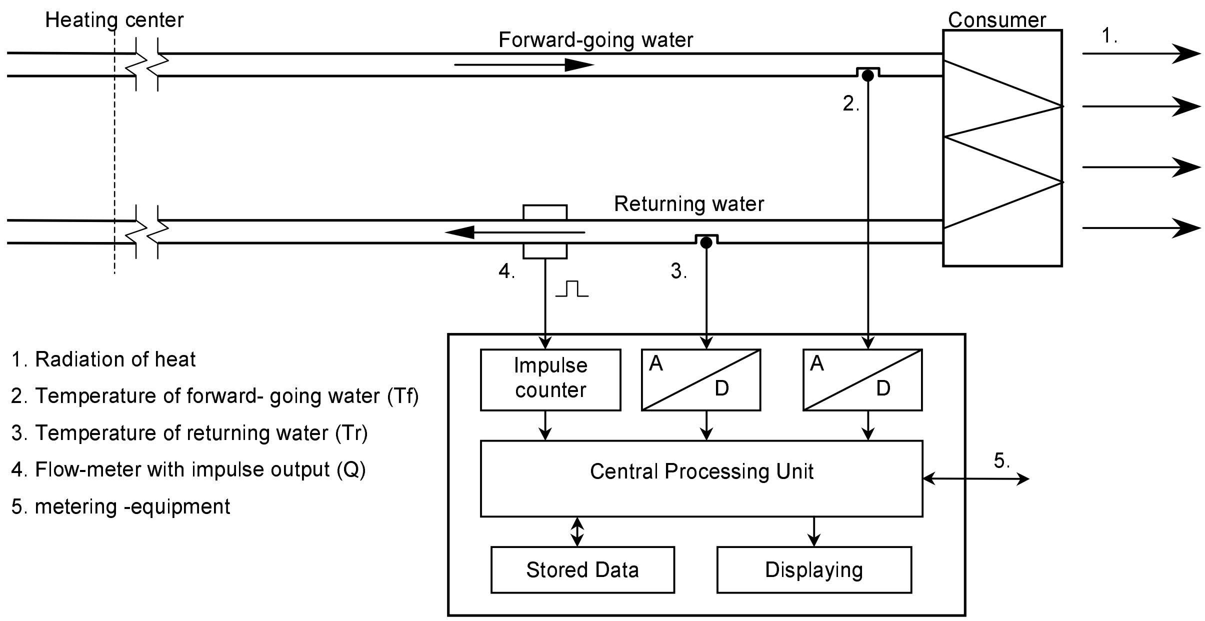


Fig.1. Measuring system

The energy, which was taken to the system *($E_{in}$ [J])* by the heat carrier during $\tau$ time, is the function of specific enthalpy and mass flow velocity *($q_m$ [kg/s])*

$$E_{in} = \int_0^{\tau} q_m h_{T_f} dt \qquad (2)$$

The $h$ specific enthalpy on $T_f$ temperature *[°C]*

$$h_{T_f} = \int_0^{T_f} c_p(T)dT \quad [J/kg] \qquad (3)$$

where $c_p$ is the coefficient of specific heat capacity on a permanent pressure, which is function of the temperature *[J/kg °C]*. The energy of heat carrier, which leaves the system during this $\tau$ time is:

$$E_{out} = \int_0^{\tau} q_m h_{T_r} dt \qquad (4)$$

The heat consumption of the system *(H [J])* is determined by the difference between the input and the output energy

$$H = \int_0^{\tau} q_m (h_{T_f} - h_{T_r}) dt \qquad (5)$$

The amount of the heat carrier (water ) passed through is measured by volume-flow meters. For this the $v$ volume velocity is introduced instead of the $q_m$ mass velocity.

$$q_m = \rho v \qquad (6)$$

where the $\rho$ *is* the density of medium *[kg/m³]*.

The amount of heat ( water ) carrier passed through is measured by flow meter. The impulses, which are on the output of the flow meter are in directly proportional to volume of the water passed through *(Q [m³])*.

$$Q = n\, Q_v \qquad (7)$$

where $n$ is the number of the impulses, $Q_v$ is the proportion of the volume/impulse of the flow meter *[$m^3/N_n$]*. Therefore $H$ is calculated:

$$H = nQ_v\rho(h_{T_f} - h_{T_r}) \qquad (8)$$

This last formula gives the functional algorithm of the heat-meter device.

If $\rho$ and $cp$ are regarded as constants then $H$ could be written as:

$$H = nQk(T_f - T_r) \qquad (9)$$

where $k$ is the constant from the product of coefficient of specific heat capacity and density. The traditional heat meters, which are cheap or do not include processors, use the (9) formula for metering. The dependency of the specific heat capacity and of the density on the temperature causes a significant error, which is shown in Fig.2 [2]. To allow a higher accuracy, we propose to calculate the heat consumption from the input and output specific enthalpies and from the mass flow, rather than from the temperature difference, as it is applied in other systems.

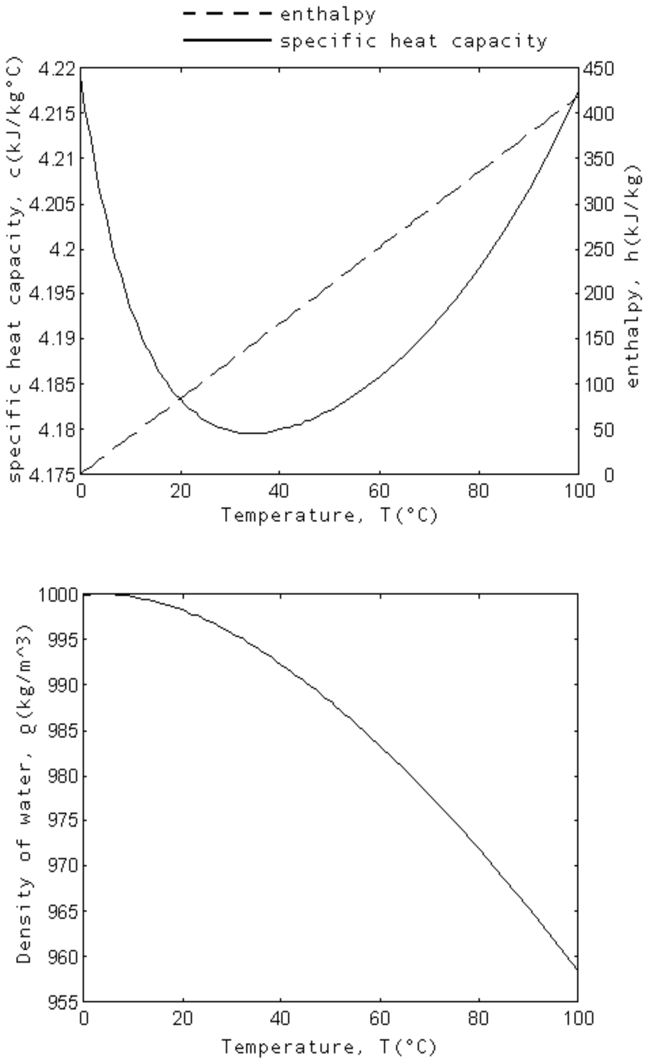


Fig. 2. Temperature dependence

The temperature dependency of enthalpies and of the mass flow are taken into consideration by a special polynomial approximation. The density of the medium:

$$\rho = x1 + x2T + x3\,p + x4\,T2 + x5\,T3 \qquad (11)$$

where p it the service pressure [bar], which is constant in the system, and $T$ is the temperature [°C] For the accuracy the specific enthalpy was approached using two ranges.

$$h=h_{x1}+h_{x2}T+h_{x3}p+h_{x4}T^2+h_{x5}T^3 \qquad (12)$$

from 25°C to 70°C the (12) and from 70°C to 125°C the (13)

$$h = h_{hx1}+h_{hx2}T+ h_{hx3}p+h_{hx4}T^2+h_{hx5}T^3 \qquad (13)$$

where $h$ is the enthalpy [J/kg], p is the pressure [bar], $T$ is the temperature [°C]. The approach gives the right value with less than 0.05% error in the range from 20°C to 125°C with the values of $x_1$, $x_2$, $x_3$, $x_4$ $x_5$ together with $h_{x1}$ ,$h_{x2}$, $h_{x3}$, $h_{x4}$, $h_{x5}$ and $h_{hx1}$, $h_{hx2}$, $h_{hx3}$ , $h_{hx4}$, $h_{hx5}$, calculated coefficients, which were calculated by us[3], [4].

## III. THE DEVICE

*Hardware*

The thrift was the supreme in the development of the heat-meter near the covering of accuracy and number of the functions. For this we endeavored to use simple, effective and small hardware. The set-up of the system is shown Fig.3. The TSS400S3 micro-controller was developed specifically for simple measure devices. It has high currency, low power consumption. It is easy to program and it requires only a few additional components. Its advantage attributes are the 12 bits A/D converter, the programmable current source, the direct LCD driver, the Inter IC bus ( $I^2C$ ), the support of M-Bus and the extremely low power consumption. At the same time it can handle more real time like signals only with strong limitations. Hence it is completed by a low-cost PIC micro-controller. The two micro-controllers communicate via $I^2C$ bus.
The tasks were shared between the TSS and the PIC. Look below.

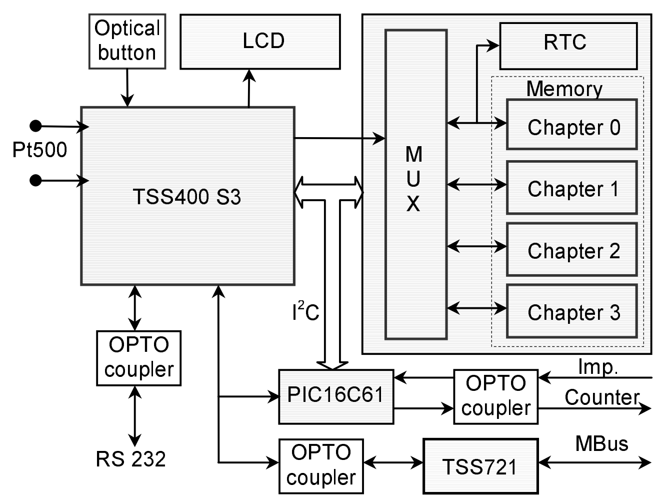


Fig.3. Hardware block diagram

*The tasks of TSS400S3:*

- Measuring of forward and backward temperature with Pt500 resistor thermometer
- Calculating values, storage of the counted values
- Handling of real time clock and calendar
- The visualization of data on LCD

- M-Bus communication (via TSS721 M-Bus adapter)
- Serial communication with the PC

*The tasks of PIC16C61:*

- Counting the flow-meter impulse like signals (max. 2 pieces )
- Receiving data from the M-Bus Master
- Observing the end of the M-Bus transactions, which were started by TSS
- Two digital, potentially isolated output for driving of external units.

The resistive temperature sensors are loaded by the programmable current source. The current source and the A/D converter are ratio metric. The proportional measuring solves the resistance measuring. The resistance of the cable and the data of calibration are stored in EEPROM memory under the calibration but before the installation. During the measurement we made self-tests with the stored reference values. The properly designed double precision arithmetical operations provide the accuracy of the signal processing. An important aspect was the application of a low-cost and effective liquid crystal display (LCD) in the system. The devices have to have asynchronous serial and M-Bus connections. Another important aspect was to provide low-power consumption, because in case of power failures five years of battery-powered stand-by had to be provided. The complete heat-meter device realizes the next functions:

- the accuracy of the measurement and processing at least 1%, (0.2% without error of flow-meter)
- measuring of momentary (inside one measuring cycle) and summed heat consumption
- measuring of momentary and summed amount of flowed heating warm water
- measuring of forward and backward water temperature
- measuring of power failure
- visualization of measured and counted values, which are listed above
- storage of summed data
- storage of consumption data for a given duration (last 24 hours and 30 days)
- daily determining the maximum and the minimum values
- Serial (RS232) communication
- Meter-Bus (M-Bus) control (two wire cable, max. 128 units, as slaves can connect, one master does the data acquisition and data transfer to the center).
- Error log (logging of different fault events occurring and ending)
- Driving of electronic mechanical counter optional impulse output
- Storing of summed and logged data in EEPROM memory

We developed a new version where the Texas MPS 430 16bits micro-controller is used. (Fig. 4.) Here is not necessary any additional micro-controller.

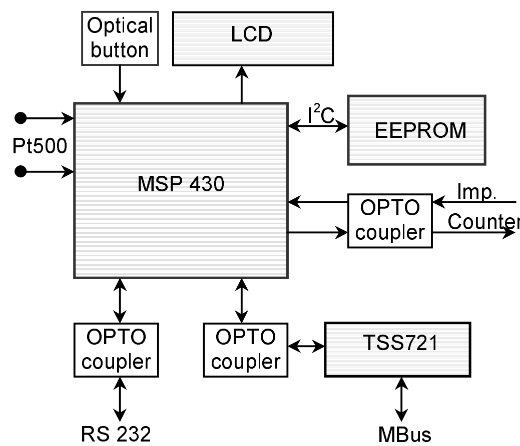


Fig.4. MSP430 hardware

*Software*

The main tasks of the program, which run on the TSS, are the continuous measuring and the counting of derived values from measured values. One part of these are necessary variables for the following calculations, other part of the values are summed and momentary amounts, which are results of the calculations. Accordingly the program consists the following parts. These are the main measuring and processing loop, the initialization phase, which prepares the function of the main loop, the subroutines and program parts, which realize the functional parts of the main loop independently to each other. Also an important part of the program is the connection with the supervisor and external devices. Calculations and measurements of the wanted amounts take long time and there is no option for the micro-controller to make interrupts so the main loop is interrupted several places to run tasks, which are necessary for communication. The TSS controller is able to handle only 2 Kbytes external memory all at once, therefore we had to use paging with 4 chapters (Fig. 3.). This made necessary the developing of new methods.

It was necessary to write high precision arithmetical subroutines, which are double registers versions of eight digits arithmetical operations and other complex arithmetical operations to reach the high measuring and counting accuracy. With this, the error became less than it could be from the limited world length. The large amount of data ( logged and summed amounts ) made necessary the initiating of the paging technique.

The device gets the electric power from the power supply. During the power failure a battery supplies the electric power. During power failure the device does not make measurements and calculations (the flow-meter device does not work) but it is waiting for the returning of the power supply in stand by mode. As soon as the power returns, the device continues the interrupted processing after a warm restart. The measured consumed amounts, which were measured by the device, are the base of the accounts, that is why „time keeping" is necessary while the device did not measure the desired amounts, in other words the summa time of the power failures. Other methods are necessary for counting of the used heat consumption during this period (e.g. average counting). The device logs the start and the end time of the last 30 power failures (month, day, hour, minute) and the summed power failure periods. The device makes self-test continuously and in case of error it sends signal and makes a log.

## IV. SYSTEM INTEGRATION

Basic functions of the device, over the measuring and counting functions, are displaying data, operation parameters and possible errors and forwarding them to the supervisor and to the accounts center. On one hand the LCD is used for this purpose, which is on the front panel of the device. The LCD shows the momentary measured/counted and the summed values. An optically sensing press button is used for stepping between the displayed data. In addition the device consists an asynchronous serial port, which is for the connection with a PC, or a service device. We can communicate with the heat-meter by a program, which runs on the PC. The service link helps in calibration, verification and maintenance.

The third communication possibility is the Meter-Bus. Of course all important data and settings could be requested via this interface. The system settings and consumer data could be set via this interface.

The Meter-Bus (M-bus), which is developed by Texas Instruments, allows connecting of one Master and 256 Slaves through a twisted cable in one system [8]. Special signaling transfer is used on the bus, which means noise indifferent voltage (from the Master) and current modulated signaling (from the slave). It allows that the system can operate while one or more slave devices are out of operation. The Master starts the request, then the Slaves (heat-meters) send 20 bytes useful data in order their own base addresses. The 20 bytes are not enough for all useful data, therefore the data is requested in three cycles (frames). Of course the Master has to select the current frame because of the two-way synchronization before the request. The Master→Slave data transfer is implemented by 300 baud asynchronous voltage modulated signal, which is interpreted by the PIC micro-controller. The PIC transfers the received message to the TSS via $I^2C$ bus.

We also had to build a Master device for the system (Fig. 5. ). This is a processor card (separated card for the analogue and digital M-bus functions), which is designed for a PROCONT type data acquisition and control device [5]. The function of the master analogue card is to generate the physical signal level with the necessary drive-power. The digital part of the Master is also a PIC16F84 micro-controller. The PIC process the serial bit stream from the slaves and checks errors. Eight-bit, two-way handshaking communication is realized between the PIC16F84 and the PROCONT. The PROCONT stores data, which are received by the master card, in a table where records are sorted by the M-bus address of the stations.

The supervisor computer is connected to the PROCONT via a GSM modem. This connection uses the well-tried X-bus protocol, which is the standard protocol for this PLC and data acquisition family [6],[7]. This master card forwards the operation information, and it requests and shows the above-mentioned elements of the data table. The whole data requesting takes about 1,5-2 minutes. The supervisor computer can collect a lots of useful information, thus the safety of operation and the efficiency could be increased.

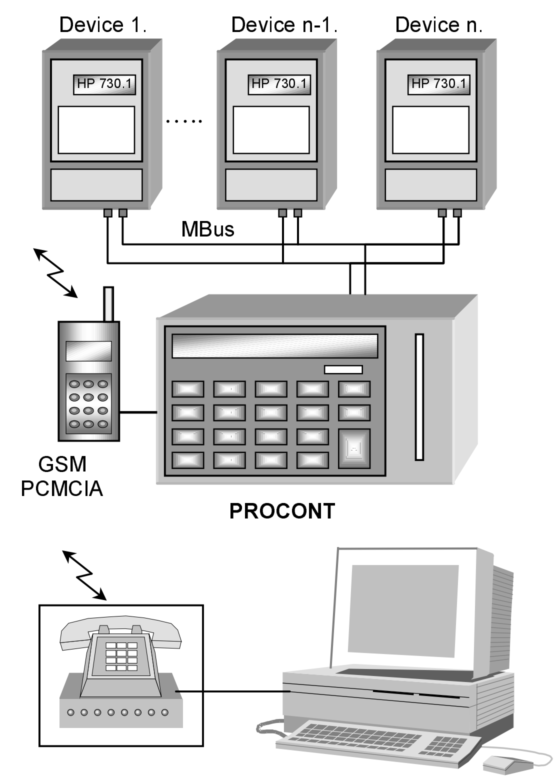


Fig.5. System architecture

## V. NOVELTIES

We summarized the viewpoints of development of the heat-meter (devices, local data acquisition device, central supervisor computer) in a distributed hierarchical system. We introduced the principles of the low-cost correctional measuring. The authenticated results prove that the measuring and counting algorithms, based on the accomplished error analysis, are correct. The devices and the hierarchical information and supervisor system worked well under our tests. The shared data acquisition and processing intelligence increase the reliability of the system. The next step of the development is to make the system accessible via the Internet.

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