Design of the Intelligent Heat Meter Based on MSP430FW425

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***Abstract*—This paper describes an optimized hardware and software design for the heat meter. It is equipped with the international popular low-power consumption single-chip microcontroller MSP430FW425, temperature sensor Pt1000, impeller flow meter and zero energy-consuming magnetic sensor. They improve the precision and sensitivity of heat measurement. It also concludes the RFID module which has realized the function of advance payment.*)**

***Keywords*—Heat meter, temperature measurement, flow measurement, MSP430FW425**

I. Introduction

The application of home heat meter is popular in developed country. They accept that heat meter is a gist between heat-supplying Company and the users, further more, it can save energy evidently. As far as our open country concerned, it is time that we pay for heat by measure rather than by the area. It is a mean of paying for consumed-heat by the measurement of heat meter. Actually, we want to pay in reason. It is a tread that reform heat-supply system by using of pre-paid heat meter [1]. And this paper introduces an economical and practical method of heat meter with the low consumption.

II. Working Principle and Formula for Heat Meters

A. Working Principle for Heat Meters

Install the temperature sensor pair at the flow and return of the heat-exchange circuit, and install the flow-meter which is connected to the zero energy-consuming magnetic sensor at either the flow or the return of the circuit. The temperature senor pair gives out the flow and return temperature signals, and the flow-meter connected to the zero energy-consuming magnetic sensor gives out the flow signals. After collecting the temperature and flow signals and calculating, the calculator can display the heat exhausted by the heat-conveying liquid from the flow to the return of the circuit.

B. Formulas for Heat Meters

There are two types of formula for heat transmission. One is

$$Q = \int_{t_0}^{t_1} q_m (h_f - h_r) d_t = \int_{t_0}^{t_1} q_m \Delta h d_t \quad . \tag{1}$$

Where Q is the quantity of heat given up, kJ; q_m is the mass flow rate of the heat-conveying liquid passing through the heat meter, kg/s; h_f and h_r are the specific enthalpies of the heat-conveying liquid at the flow and return temperatures of the heat-exchange circuit, kJ/kg; t is time, s; △h is the difference of the enthalpies, kJ/kg.

And the other is

$$Q = \int_{t_0}^{t_1} q_V K \Delta T d_t \quad . \tag{2}$$

Where Q is the quantity of heat given up, kJ; q_v is the volume of liquid passed, m^3/s; K called the heat coefficient, $KJ/m^3 \cdot$ ℃; △T is two consecutive measured time interval, s; t is time, s.

The two calculation methods are called enthalpies difference method and K heat coefficient method [2, 3].

According to China's national conditions, this heat meter adopts the enthalpies difference method and the flow meter is installed at the influent pipeline of the heat-exchange circuit. For the incorporate heat meter, this is meaning that the heat meter is installed at the influent pipeline of the heat-exchange circuit. And Fig. 1 shows the structure of heat measurement system.

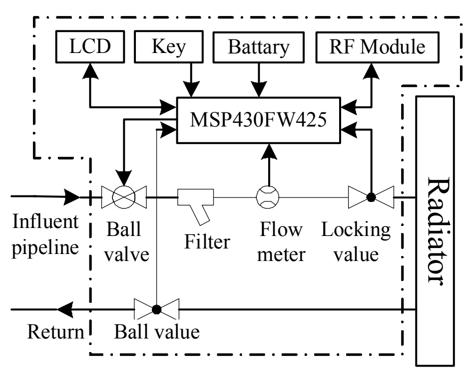

Figure 1. Structure of the measurement system

III. HARDWARE CIRCUIT

The dashed part in Fig. 1 shows the hardware structure of heat meter. This paper gives the control core and critical technologies.

A. *Control Core of the Heat Meter*

The control core of the heat meter is MSP430FW425 of the MSP430. The MSP430 incorporates a 16-bit RISC (Reduced Instruction Set Computer) CPU, peripherals, and a flexible clock system that interconnect using a von-Neumann common memory address bus (MAB) and memory data bus (MDB). Partnering a modern CPU with modular memory-mapped analog and digital peripherals, the MSP430 offers solutions for demanding mixed-signal applications [4]. Key features of the MSP430FW425 are as follows.

- Ultra-low power: It is able to work in the voltage of 1.8V~3.6V. It uses different operation modes (CPU and the different combinations of the external modules is activated) and five ultra-low power modes based on CMOS technology (CPU halts, external modules are still working)
- Strong Operational Capabilities: The 16-bit RISC architecture enables it have rich addressing modes for the source operand and four addressing modes for the destination operand that can address the complete address space with no exceptions. It has 16-bit interrupt source vectors and the interrupting nesting is enabled if the GIE bit is set inside an interrupt service routine. When interrupt nesting is enabled, any interrupt occurring during an interrupt service routine will interrupt the routine, regardless of the interrupt priorities. 8MHz high clock frequency enables the instruction circle to be up to 120ns.The CPU which incorporates hardware multiplier, large-capacity 16-bit registers, and 64KB flash and 2KB RAM guarantees the computational speed and data storage. These enables the single-chip microcontroller has a strong digital signal processing capability; therefore, we can use it to develop the highly efficient source.
- Variety of on-chip peripherals: The peripherals includes Watchdog Timer, Basic Timer 1, Timer A, Timer B, Commarator_A, USART Peripheral Interface (UART Mode and SPI Mode), LCD Controller and LCD_A Controller, digital I/O, 12-bit ADC and so on. Using the variety of on-chip peripherals the designer can easily build a complete system. Also, take full advantage of the multi-channel counter arbitrary waveform generator function and interrupt control function can ensure a number of complex sequential control tasks are completed.
- Facilitate the efficient development environment: MSP430FW425 is an erasable single-chip microcontroller. There is the JTAG (Joint Test Action Group) test interface which is an international standard testing agreement and it is mainly used to test the internal chip. Therefore we can download the program in the Flash, then using the software control the operation of the program, and at the same time the JTAG test interface read the information of the chip for designers to debug. This method doesn't simulator and programmer, so it is convenient for debugging.

B. *Measurement of Temperature*

The sense organ of temperature adopts platinum resistance P_t1000. This means when the temperature is 0℃, the value of the platinum resistance is 1000 Ω . The relation between platinum resistance value and temperature in the temperature range of 0℃ and 850℃:

$$R_t = R_0\,(1+At+Bt^2) \tag{3}$$

Where R_t is platinum resistance in t℃, Ω; R_0 is platinum resistance in 0℃, Ω; t is the temperature of the thermal resistance working, ℃; A, B are constant. For Pt1000, A is 3.90802×10^{-2}℃$^{-1}$, B is -5.80195×10^{-7}℃$^{-2}$.

According to the formula, R_t and t is not linear relationship. How much the non-linear error is? Will it affect the accuracy of the instrument? Tab.1 shows the temperature and the resistance relationship.

TABLE I. RESISTANCE AND TEMPERATURE TABLES

t(℃)	R_t (Ω)	R_t - R_{t-10} (Ω)
0	*1000.00*	
10	*1039.02*	*39.02*
20	*1077.93*	*38.91*
30	*1116.72*	*38.79*
40	*1155.39*	*38.67*
50	*1193.95*	*38.56*
60	*1232.39*	*38.44*
70	*1270.72*	*38.33*
80	*1308.93*	*38.21*
90	*1347.02*	*38.09*
100	*1385.00*	*37.98*

Non-linear error can be calculated:

$$E_f=(\triangle m/Y_{ES})\times 100\% \tag{4}$$

Where △m is the maximum deviation of the input-output characteristics and the fitting straight line, ℃; Y_{ES} is the full scale output value.

E_f=((1000+39.02×100－1385)/100%)=0.375%

The accuracy of the temperature measurement is important for heat meter, so the non-linear error is 0.375% and it is impermissible and the linear correction is necessary.

There are two ways of linear: one is using analog circuits. Pt1000 resistance-temperature characteristic curve is convex on the monotonous, and so as the temperature increases the rate of change of resistance is reduced gradually. Therefore designers can introduce positive feedback in the resistor voltage conversion circuit to constitute a constant deepening of positive feedback which is with the increase of R_t. And the other is using a look-up table method. The principle: Resistance-temperature table will be curing in the EPROM whose address is signed with the A/D converter output value. When the A/D converter output value is regarded as the address to visit the EPROM, the temperature in the EPROM will be received.

As long as the linearity of the original function better, or the distance between the two endpoints nearly enough, the linear interpolation can ensure the error of the various points is small. This heat meter adopts the software method to realize linearization and to achieve the meter's economic and rationality. When the sensor has the least temperature difference, the pair-error is less than 0.105℃.

And the design adopts 16-Bit A/D converts to realize the high precisely temperature measure. In order to compensate the impact of the wire resistant, this design uses three-line bridge circuit method. In order to restrain float of the time difference and the difference in temperature, there is only one difference amplifier circuit in the temperature sensor pair at the flow and return of the heat-exchange circuit.

C. *Measurement of Flow*

The nonmagnetic impeller flow meter and the zero energy-consuming magnetic sensor are used in the measurement of flow. The principle of impeller flow meter is: One disk above the impeller is circumvolving with the impeller by the axis. And one half of the disk is alloy plating, the other is non-plating. There are three electrical inductances above the disk. During running, the plating and the non-plating pass by the inductances in turn. When the impeller and disk circumvolve they give out the inductive signals. The LC oscillating is damped as it pass by the plating part, which is called damping oscillation and is different to the continuous oscillation. When the electrical inductance is above the non-plating part, the LC oscillating is continuous oscillation. Fig. 2 shows Schematic diagram of flow-meter.

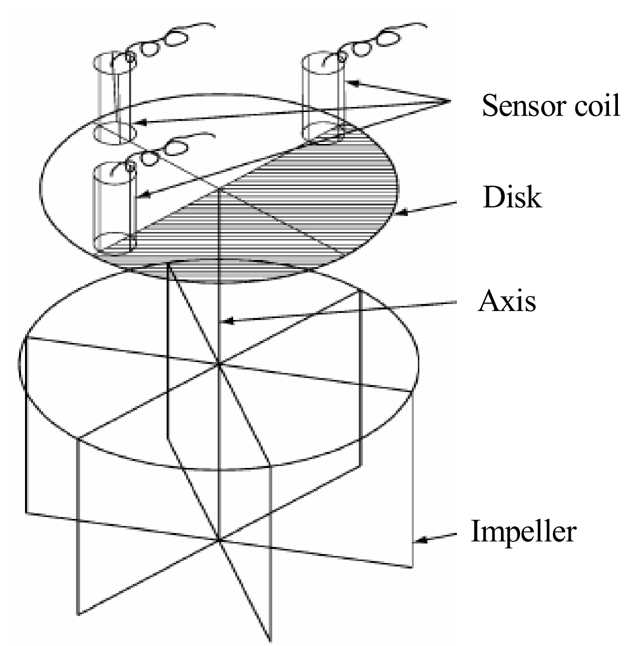

Figure 2. Schematic diagram of flow-meter

Those signals are sent to the MSP430FW425 microcontroller which is with the scan IF module [5]. The scan IF module is used to automatically measure linear or rotational motion with the lowest possible power consumption. It consists of three blocks: the analog front end (AFE), the processing state machine (PSM), and the timing state machine (TSM). The analog front end stimulates the sensors, senses the signal levels and converts them into their digital representation. The digital signals are passed into the processing state machine, which is used to analyze and count rotation or motion. The timing state machine controls the analog front end and the processing state machine, and controls the time and the frequent of the signal collection. Fig. 3 shows the theory diagram of flow measurement.

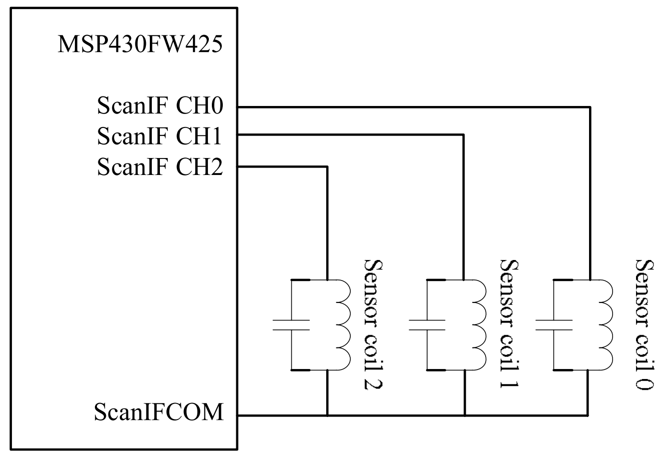

Figure 3. Flow measurement diagram

D. *RF Module*

The RF card module adopting the T5557 card achieves the prepayment and the control of the flow's on-off. It is produce by Atmel Company and based on the 125 frequency of the sensor chip, data storage space is 330 bit. It also has the set-up of password and the write protection and supports mechanisms for conflict prevention. A single coil, connected to the chip, serves as the IC's power supply and bi-directional communication interface. The antenna and chip together form a transponder or tag [6]. The on-chip 330-bit EEPROM (10 blocks, 33 bits each) can be read and written block-wise from a reader. Block 0 is reserved for setting the operation modes of the T5557 tag. Block 7 may contain a password to prevent unauthorized writing.

Data is transmitted from the IDIC using load modulation. This is achieved by damping the RF field with a resistive load between terminals Coil 1 and Coil 2. The IC receives and decodes 100% amplitude (OOK) pulse interval encoded bit streams from the base station or reader. The chip also integrates analog front end, data-rate generator, write decoder, HV generator and so on.

The reader's main operation processes on the card include CardReady(), CardAnticollision(), CardSelect(), CardAuthertication() and Halt(). And the management's processes on the card are ReadCard(), WriteCard(), FormatPurse(), Increase(), Decrease() and so on.

This module combining the PC sales management system which is developed based on the Microsoft Visual Basic can also be extended to the water electricity gas and caloric meter one-card-through system. Fig. 4 indicates the hardware circuit of the RF module.

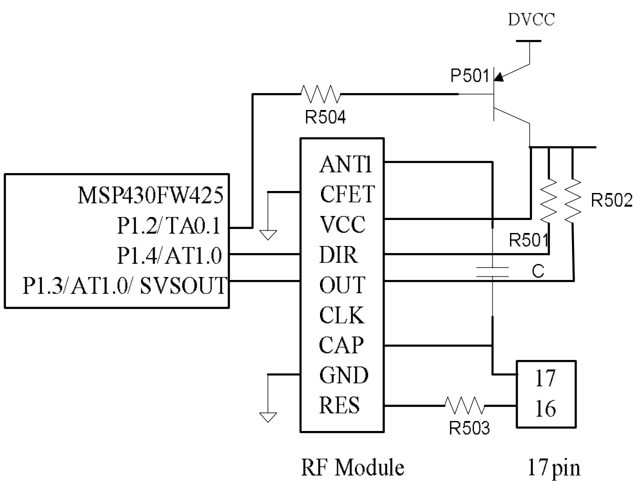

Figure 4. The schematic diagram of RF module

IV. THE SOFTWARE DESIGN

The software of the heat meter uses C language of the principal. It supports structured programming, and its modular structure to the programming has great convenience. The heat meter application is made up of the main program and interrupts, and the main program is composed of a number of subroutines. The subroutines are system initialization subroutine, configuration parameters subroutine and LCD display subroutine; Interrupt handling procedures include: Flow Detection subroutine, temperature measurement subroutine, A / D conversion subroutine, keystroke subroutine, storing configuration data subroutine, such as radio frequency card processing subroutine.

The first time at power Calorimeter system initialization, the pre-heat storage shows that if the pre-calorie value is less than a value the system alarm to remind users to the relevant departments to buy calories. After a certain period of time after LCD display is closed, and the heat meter enters a low - Power Mode 3. When the interruptions listed above appears the CPU will be wakening from the LPM3 to perform the interrupt handling procedures.

If a pulse flow, a flow accumulation, and giving the power to temperature measurement circuit, starting A / D converter, and measuring the input and back temperature at the same time, then calculates the calorie consumption of this period for the users (twice interrupted pulse interval). And then the last pre-heat value minus the value of this time is the new pre-heat value of the users. If the new value is less than a certain value, the heat meter alarms and cut down heat providing. After a certain time, the heat meter enters a low - Power Mode 3 once again.

If a RF card enters the area of the card reader, the pre-heat stored in the card which is recognized as the legal card will be read into and added to the remained. The valve is opened and heat meter begin to provide heat to the users. Then the heat meter enters a low - Power Mode 3 once again.

If the key is pressed, the remained value, the accumulated heat, temperature of the input and output will be displayed. After a certain time, the heat meter enters a low - Power Mode 3 once again.

If the power is not enough to drive the heat meter, the users will be reminded to change the battery and if the pre-heat is less than the advanced, the users are also reminded to buy the pre-heat.

V. CONCLUSION

The innovation of this heat meter is using the non-magnetic flow sensor technology instead of the magnetic coupling technology, which resolves the rust, adsorbed impurities problems, so that the signal acquisition of stability, accuracy is improved. Integral instrument adopting the latest generation of low-power microprocessors and advanced software technology, the calculation error is greatly reduced; Large-capacity memory can be long-term permanent storage of all the important data, and the perfect self-checking function greatly improves the maintainability. The PT1000 matching precision temperature sensor improves the measurement accuracy of the temperature and transmits anti-jamming capability. The heat meter is suitable for the status quo of heating pipe network. In a small flow of water, more rust impurities, the network such as a long period of poor working environment does not affect the long-term use of measurement accuracy.

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