The Design and Implementation of Low Power Electromagnetic Flowmeter with Trapezoidal Excitation Mode

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Abstract
Trapezoidal excitation mode with low voltage power supply is put forward based on the study of the various kinds of excitation ways. This method can effectively overcome the differential interference and in-phase interference, and improve the signal-to-noise ratio of the electromagnetic flow signal. A kind of electromagnetic flowmeter is designed based on low-power MSP430F4793 CPU. The trapezoidal excitation circuit is described in detail. The electromagnetic flowmeter is powered by two lithium batteries, can use more than five years. It will enlarge the application scope of electromagnetic flowmeter, and satisfy in many occasions such as no mains power supply or must be powered by battery.
Keywords: ELECTROMAGNETIC FLOWMETER, LOW POWER, BATTERY POWER, TRAPEZOIDAL EXCITATION

1. Introduction

The electromagnetic flowmeter is widely applied to the measurement of conductive fluid flow, especially for coal water slurry and pulp which contains a lot of impurities[1]. However, many practical flow detections, such as the measurement of flow field, oil fields, especially for the heat flow measurement in family application, all need batteries as the power supply[2~4].

The main part of energy consumption is the excitation circuit which generates a magnetic field electromagnetic flow with high voltage and large current[5~7]. In order to save this part of the current, permanent magnets are used to form the field excitation constant. Excitations are not part of the energy consumption, greatly reducing the total power consumption of the electromagnetic flowmeter, but there are some significant disadvantages. Electrochemical and other factors will generate a serious polarization phenomenon in constant magnetic field excitation electrode[8~10]. The random change of polarization voltage completely covers the induction electromotive force which reflects the velocity size. Therefore, permanent magnet excitation technology is always one of the main difficulties in the study of electromagnetic flowmeter[11]. In addition, the temperature of the medium affects the magnetic induction intensity of magnetic materials and the measurement accuracy is also affected. In order to improve the measurement precision, it has to compensate for the fluid medium temperature. Actually, electromagnetic flowmeter applied rarely used permanent magnet excitation. It is just suitable for measurement of liquid metal.

In order to meet the market for battery powered electromagnetic flow sensors, we design the excitation circuit of 3.6V lithium battery powered to generate trapezoidal excitation current. It reduces the noise interference and gets lower power consumption, greatly prolonging the battery replacement time.

2. Principle of Electromagnetic Flowmeter

Electromagnetic flowmeter is based on the law of electromagnetic induction. When the conductive fluid flows through the electromagnetic flow measurement tube, it cuts magnetic lines of the magnetic field sensor and generates the induced electromotive force. Velocity is proportional to the induced voltage. Nowadays, the mainstream electromagnetic flow sensor uses DC excitation. In sampling, the magnetic induction intensity electromagnetic flow sensor is usually constant. Constant current is used in the excitation coil to generate constant magnetic field. The expression of magnetomotive in electromagnetic field is as follows[12]:

$$Iw = \Phi \cdot R_c = \Phi \cdot \frac{L}{\mu A} = B \cdot \frac{L}{\mu}, \quad (1)$$

In the formula, Iw is magnetomotive force; I is exciter current; w is coils ampere - turn; Rc is reluctance; Φ is magnetic flow; L is the length of magnetic path, μ is magneto conductivity

Usually ,when the sensor design is completed, w, μ, L are fixed values. As long as the I is constant, it will generate a constant magnetic induction intensity. While maintaining the premise of the magnetic induction intensity, it can reduce the excitation current by increasing coil number. Ordinary electromagnetic flow sensor excitation current is about 250mA. Experiments show that electromagnetic flow sensor can work normally with the 40mA current. In order to reduce the excitation current further, it can increase the number of turns of the coil by 2 times. According to the theoretical calculation, the excitation current can be reduced to 20mA. Experiments showed that the device can work normally with the current 20mA. The sample excitation current is designed for 30mA to improve the measurement sensitivity.

3. Design for Trapezoidal Current Excitation Circuit

3.1. Trapezoidal Current Excitation Mode

The output signal of electromagnetic flow sensor electrode ends is represented by the following formula[13]:

$$E = BvD + \frac{dB}{dt} + \frac{d^2 B}{dt^2} + e_c + e_d + e_s, \quad (2)$$

BvD-flow signal; $\frac{dB}{dt}$ – differential interference signal; $\frac{d^2 B}{dt^2}$ – In-phase interference signal; ec-the common mode interference signal; ed-Series mode interference signal; es-DC polarization voltage

Differential interference is electromotive force which is produced by the excitation coil. The excitation coil generates a magnetic field which has detection signal inputs. Excitation lines are formed by two electrodes, fluid and wire loop. Put signal circuits into a plane as far as possible. We makes parallel lines to reduce the interference[14].

The interference is always there since the magnetic field distribution is not entirely parallel lines.

In order to reduce the signal interference and improve the signal to noise ratio, this paper adopts the trapezoidal waveform exciting current. If using the traditional value rectangular wave excitation shown in Figure 1, the excitation period is 160ms. When the excitation current occurs, differential magnetic induction intensity and quadratic differential system tend to infinity. Traffic signal to interference is large. In order to reduce the interference, this paper adopts the trapezoidal waveform exciting current. In figure 2, the differential interference is a constant and the in-phase interference is zero when trapezoidal current rise and fall.

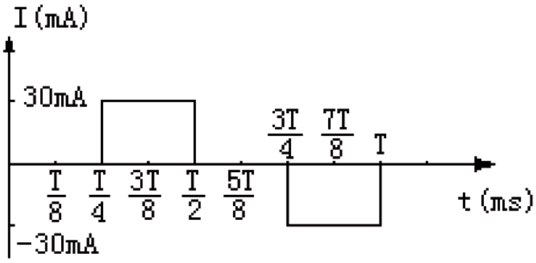

Figure 1. Excitation waveform

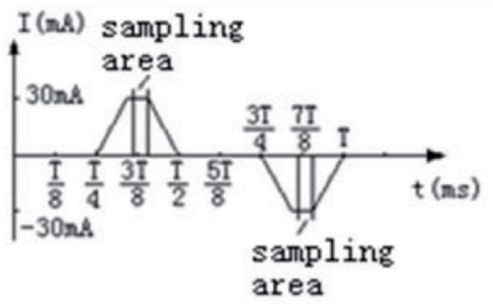

Figure 2. Trapezoidal waveform

Actually, ec, ed, es are secondary interference sources in electromagnetic flow. Common mode and differential mode interference are mainly caused by the outer electromagnetic field coupling into the transmission line. In order to reduce the interference, twisted pair winding ways is used in the amplifier. The grounding mode is used to remove string mode interference. Bipolar excitation is mainly used to eliminate DC polarization voltage of Es.

3.2. Trapezoidal Excitation Circuit

In order to generate trapezoidal current waveform in the excitation coil in figure 2, this paper designs a trapezoidal excitation circuit shown in figure 3. When the excitation current is constant, we must reduce the supply voltage of H Bridge to reduce power consumption of the whole excitation circuit. The main supply of voltage power is on the excitation coil.

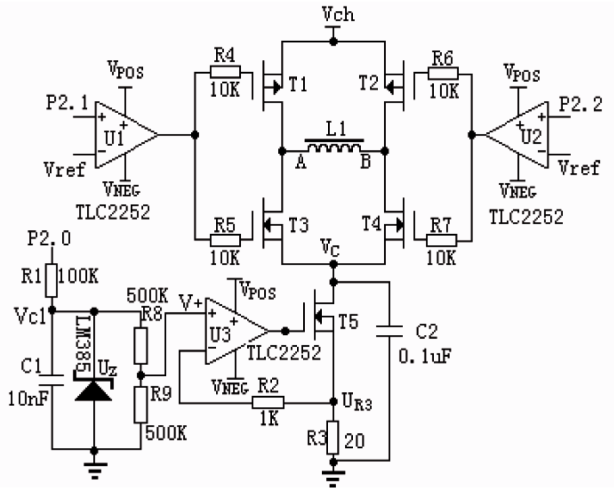

Figure 3. The excitation circuit

The excitation coil resistance of the electromagnetic flowmeter is about 40 ohms. When the constant current is 30mA, the voltage of excitation coil is 1.2V. In order to reduce the power consumption we use the low power voltage reference LM385 (1.2V). When the LM385 voltage is at 1.2V, the voltage of UR3 is 0.6V and the resistance of R3 is 20Ω. To ensure the constant current circuit is 30mA and the source drain voltage of T5 is 0.3V, the voltage of Vc is 0.9V. The power supply voltage of Vin is 2.1V. The working process for the H Bridge is complex. When T1 and T4 conducts, T2 and T3 are cutoff, add positive excitation current to the excitation coil. On the other side, T1 and T4 are cutoff and T2 and T3 conducts. To ensure that conduction or cutoff of the H tube field effect reliable bridge saturated, the gate voltage should be less than -4V when T1, T2 conducting. The gate voltages of T3, T4 conduction is greater than 4V. In order to generate the gate voltage, the low power rail is used to rail amplifier TLC2252 as the comparator. The power voltage is ± 5V. Under the control of MCU, the output to meet the requirements of the gate voltage is ± 5V.

Trapezoidal waveform generation process is also not easy. Excitation source Vch (2.1V) feeds H-bridge. A special field-effect tube is designed to reduce the pressure drop of H bridge device. The saturation of the turn-on voltage is lower than 0.05V. The excitation circuit power supply is controlled by MCU. When P2.3, P2.4 are in low level, the excitation circuit does not supply power and no energy loss. When P2.3, P2.4 are in high level, the excitation circuit starts to work. When P2.1 is in the low level and P2.2 in high level, the gate voltage of T1 is -5.0V, T1 conduction and T3 cutoff. The gate voltage of T2 is 5V, the T2 cutoff and T4 conduction. The P2.0 consists of a low level to high level, R1, C1 are series circuit. Voltage VC1 of C1 is rising according to exponential curve. Before LM385 achieve the regulator, the rise is linear. V+ is 0.5 times VC1 and Is is V+/20. We add the current from a Vch power to the excitation coil current. Along the T1, L1, A, B, T4, Vc, T5, R3 direction, ladder rising edge. When VC1 is greater than Uz, LM385 start voltage 1.2V, Vc1 is 1.2V,V+ and VR3 are 0.6V. The constant current source electric current keeps constant and its size is V+/R3=30mA. We start sampling after a period of time. P2.0 becomes from high level to low level after sampling. This discharge will occur through R1, which is caused by the charge stored in capacitor C1. Vc1 will decrease linearly. The excitation current decreases according to the linear, falling edge of a ladder. When P2.1 is high level and P2.2 is low, T1 gate voltage is 5.0V. While the T1 cutoff, T3 conduction. While T2 gate voltage is -5V, T2 conducts T4 cutoff. The current source goes through the T2, B, A, T3, VC, T5, R3, excitation current into negative. Put P2.0 into a high level status. The output is a negative trapezoidal excitation current.

4. The Excitation Power Circuit

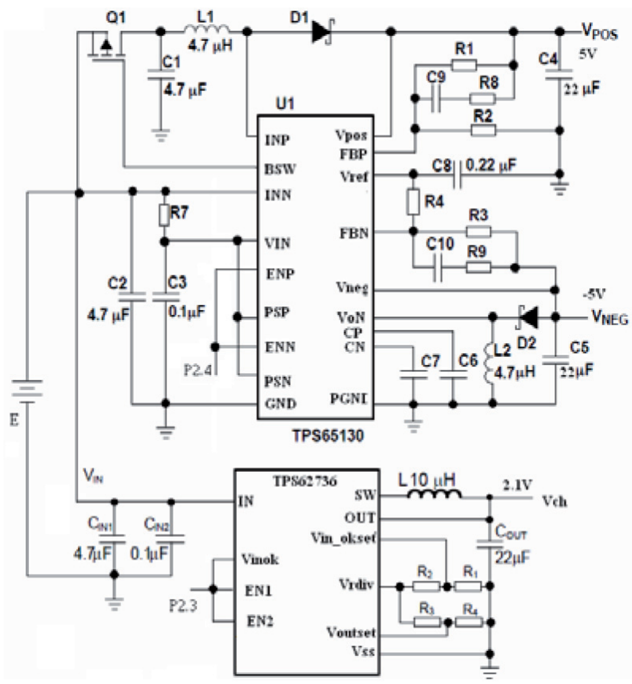

Figure 4. The power supply circuit

In order to meet power excitation circuit needs, we design the efficient DC/DC chip drawing power supply circuit as shown on the Fig.5. TPS65130 generates ± 5V power. Because power load current main supply low power amplifier TLC2252, each amplifier power supply current is about 40uA, 2 pieces of supply current 160uA. Considering the resistance load, current polarity power supply load is about 200uA. So, using Power-Save Mode, PSP PSN connected to the VIN terminal, positive and negative power output enable is controlled by P2.4. From the provided efficient data shown in Figure 5, the conversion efficiency is about 43%. Power excitation coil is realized by TSP62736. The output voltage is Vch (2.1V) and excitation current is 30mA. Supplied from the chip manufacturers, the efficiency of data is shown in Figure 6. And the efficiency is 93%.

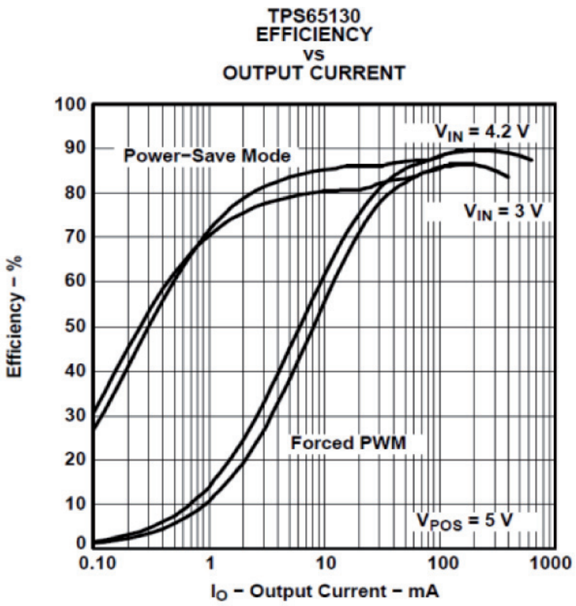

Figure 5. The TPS65130 conversion efficiency curve

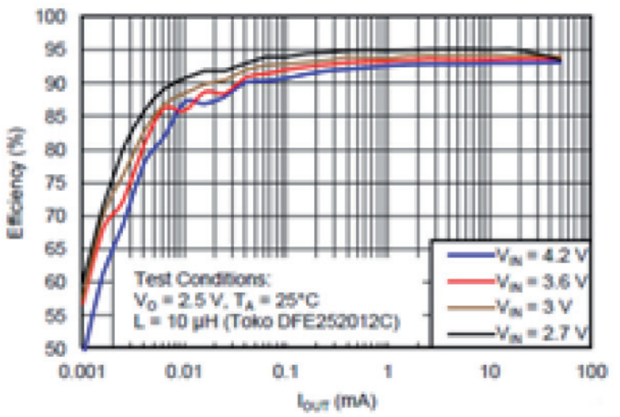

Figure 6. The TSP62736 conversion efficiency curve

5. The Power Consumption of the Circuit Analysis

Electromagnetic flowmeter system block diagram is shown in figure 7, and the supply of power circuit is divided into two parts: The excitation circuit and single-chip microcomputer system, and it is supplied respectively by two sections 3.6 V lithium battery E1 and E2, the power adopts the original Israel lithium battery TL - 5930 whose capacity is 19 ah. Excitation circuit includes excitation circuit and signal processing part, seeing in figure 4. It is supplied the power after the E1 circuit transformation. Single chip microcomputer system consists of MCU, LCD display, keyboard, communication part, directly supplied by the battery power E2, it empolys ultralow power -- MSP430F4793 which was produced by TI company. The MCU is a kind of activity patterns and five kinds of low power consumption mode, in the activity model, maximum current is only 560 ua; in low power mode, minimum current can reach 0.1 microampere. System adopts the scheme of intermittent measurement, and intermittent time can be set. If the flow is stable, the interval can be larger, such as 20 s or more, in general, it can be set for 3 s. Microcontroller will go into a activity pattern to measure the flow every 3s, the single chip microcomputer will be in the low power sleep mode if it doesn't measure the flow.

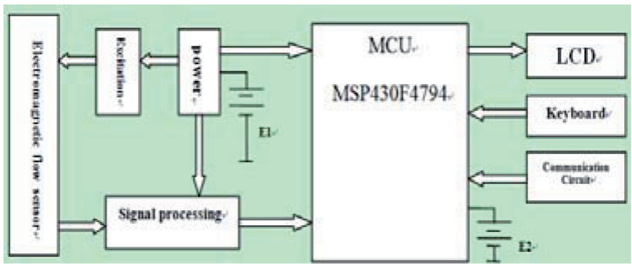

Figure 7. Block diagram of electromagnetic flowmeter system.

Part of Single-chip microcomputer system's power consumption is small, considering most of time of MCU stays in the dormant, the current is about 400 ua when the data is collected and processed. If it adds the display and keyboard communication circuit, the current will be about 500 ua, its average currents can be less than 200 ua. But the system have to be active when the keyboard is frequently used active , so system power consumption is concerned with how often it is used, If it is estimated according to the average current 300 ua , the battery life will be: 19000 / (0.3 * * 24 * 365) = 7.23 years. In excitation circuit, sampling when open the power, other time off. We make every 3 seconds sampling, excitation frequency is 6.25 Hz, eight points for power frequency and its cycle is 160 ms, open source during the whole 160 ms, its positive and negative power supply is 200 ua for both, convert to the battery terminal. (plus or minus DCDC conversion efficiency is calculated for 43%): 5 * 0.4 / (0.43 * 3.6) = 1.29 mA. in the excitation source Vch power consumption, there is no current for 80 ms in the 160 ms. Two trapezoidal field current time is 80 m. According to a calculation, supposing the time of rising and falling is 15 ms, constant current 30 mA for 10 ms, the average output current during the trapezoidal current is: (15 + 10 * 30 * 30) / / 40 = 18.75 mA. The average current occupys its half: 9.38 mA in 160 ms, equivalent to the battery current to calculate (conversion efficiency is 90%) : 9.38 * 2.1 / (3.6 * 0.9) = 6.08 mA. In a sampling period excitation circuit integral part, the average current is: (6.08 * 160 * 160) / 160 + 1.29 = 0.393 mA. The time for using the battery of Exciting part is : 19000 / (0.393 * 24 * 365) = 5.5 years.

6. Conclusion

In this paper, based on the traditional electromagnetic calorimeter research, a low voltage, low power excitation circuit is designed and realized. Under control of MCU, trapezoidal excitation waveform is automatically generated. We effectively reduce the differential interference and in-phase interference, increase the SNR of electromagnetic flow. Using the low power MSP430F4793 as the treatment of CPU, the power consumption of the whole circuit greatly reduces. Two cell lithium battery can work for more than 5 years and it well promotes the scope of application of electromagnetic flowmeter.

Acknowledgments

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