A Novel Digital Coriolis Mass Flowmeter

Zheng Dezhi,   Fan Shangchun

School of Instrument, Beihang University, Beijing 100083, China

010-82317859, mickeyzheng@163.com

Abstract: A novel digital Coriolis mass flowmeter (CMF) system is designed. The whole output signals of the flow sensor are acquired by the high performance and precision parallel A/D system and output signals are analyzed by the digital signal processor because of the powerful operation capability. The signals are filtered by finite impulse response (FIR) band pass filter. The new signal processing method is designed for calculating the frequency and the phase difference of the two signals. Moreover the temperature compensation model of the density and the mass flow are presented. The experimental results show that the precision and the offset of the system are improved, and the scheme of system realization is of actual significance.

Key words: Digital signal processor, Coriolis mass flowmeter, Finite impulse response band pass filter

1. INTRODUCTION

Coriolis mass flowmeters have wide applications in industry due to high accuracy, good repeatability, multi-parameter measure and the ability to measure mass flow directly. The U pipe type has shown excellent performance in both measuring mass flow and fluid density. The basic elements of the commercial flowmeter under test are two U type tubes with rigid supports at both ends (Fig. 1). It oscillates at its fundamental eigenfrequency (first mode) controlled by a digital closed loop, and is stimulated via a driver. In the ideal case, at zero mass flow, all parts of the measuring pipes will vibrate synchronously. When mass flow enters the pipe, the Coriolis forces are caused by two orthogonal velocities, one representing the fluid's velocity and the other the velocity of the pipe. These Coriolis forces acting on the pipe's wall are in opposite directions in the upstream and downstream side. In the resultant oscillation, the upstream side will lag, and the downstream side will lead with respect to the pipe's center. So, when flow enters the pipe, the oscillation will no longer be synchronous. In a formal way, the CMF can thus be viewed as an instrument that measures the two signals difference. The delay in time between the velocities of two given points along the length of the measuring pipe is due to this asymmetry. It is proportional to the mass flow rate. So the CMF accuracy is influenced by the instrument calculating precision of two signals time delay[1][2].

In traditional signal process, the two sine wave time delay is converted to voltage signal by analog line. The integral analog to digital converter is utilized to convert the voltage signal, and the mass flux is calculated by single chip processor. Because the analog line is less stability, the integral analog to digital converter conversion rate is slower, and so on, the problems such as: the offset of the system is greater, the response time is longer and the precision is less, exist in the system. Because of the problems mentioned above, the novel digital Coriolis mass flowmeter is introduced in the paper. The high performance and precision parallel A/D system is adopted to sample the signals, the digital signal processor (DSP) TMS320VC33 is the core of the system to process the two signals that are

exported by two sensitive components. The frequency and the two signals time delay are calculated accurately by classical signal process arithmetic, so that the mass flux and density of the liquid are calculated. And that artificial intelligence arithmetic is used to measure and fault diagnoses, so the precision and the reliability of the system are improved.
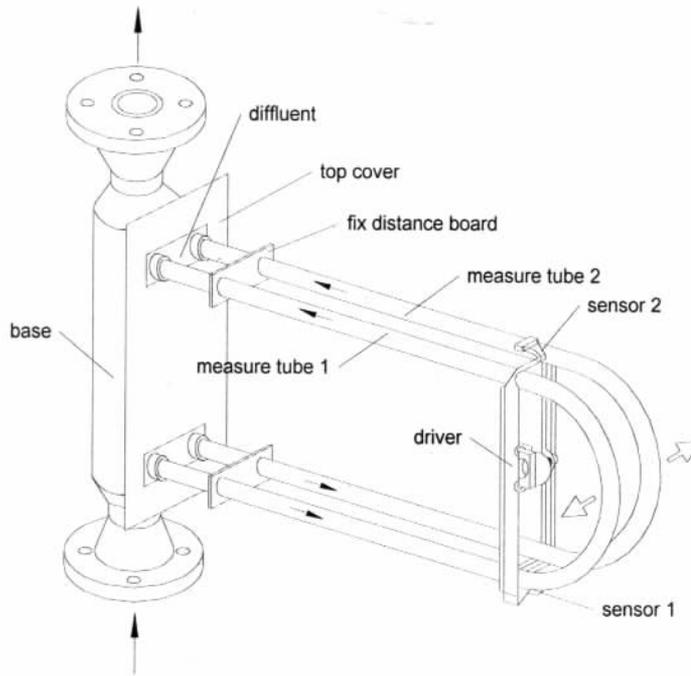

Fig.1 The structure of double U type CMF

2.Statement of the system hardware

The system is composed of the hardware portion and the software portion. The hardware portion (see Fig.2) are made up of the closed loop circuit, the signal preprocess circuit, A/D converter circuit, signal process circuit, control and display circuit.
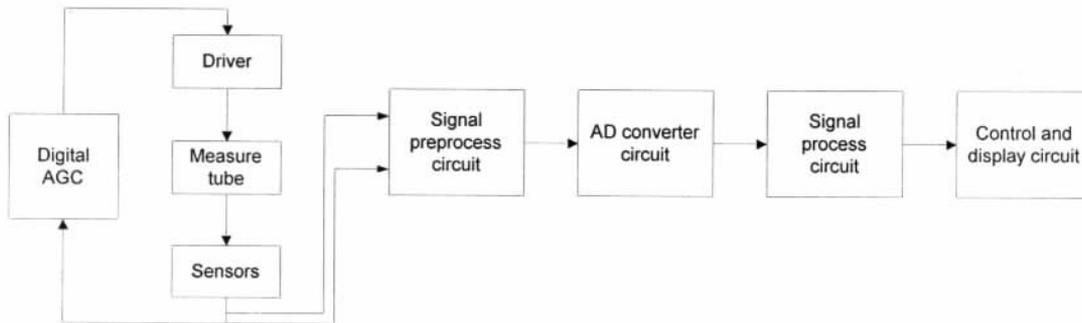

Fig2.System hardware fig

Closed loop circuit is based on resonance measurement, most of all resonance sensors work at closed loop self-oscillation. The Coriolis mass flowmeter is alike. The feedback signals must be according with the magnitude and phase condition:

Magnitude condition:

$$A_2 \geq A_1 \qquad (1)$$

$$\phi_T = 2n\pi \qquad n=0, \pm 1, \pm 2, \cdots \qquad (2)$$

where, $A_1 > 0$ is impulse voltage magnitude, $A_2 > 0$ is output voltage magnitude, ϕ_T is the

impulse frequency.

The traditional closed loop system adjust the power supply of the fan-out operation amplifier by analog auto gain control circuit (AGC). To make up of the high precision AGC, the control system is more complex, and because the temperature and time excursion of the analog circuit is more difficult to avoid, the closed loop system output magnitude changes. Whereas the problems, on the base of analyzing the AGC, the new closed loop system is designed in Coriolis mass flowmeter.

The new closed loop system is composed of the single chip processor (C8051F020), AD and DA of C8051F020 and high precision operation amplifier. The system utilize the digital signal process method to filter the signal and auto-track the fundamental eigenfrequency of the massflower. Because the signal process is on base of the digital signal process, it is effective that the system overcome the influences of the different resonance frequency on the various condition and the temperature and time excursion. Furthermore, the digital closed loop circuit is more simple, the components are less and the system reliability is enhanced.

The main function of the signal preprocess circuit is the faint signals amplified and filtered. The low noise amplifier OPA604 is the core of the preprocess circuit. The amplifier and the essential high precision resistances and capacitances make up of the signal amplifier and low pass filter circuit.

The A/D converter circuit is the key of the system. It is directly influencing to the system precision. The accuracy and the conversion rate of the AD are the important parameter. Via analyzing the signal character and Matlab software emulate, the system adopt AD676 to realize analog to digital convert. The AD676 is

3. Statement of the system software[4]

There are many kinds of the software in the Coriolis mass flowmeter, including digital filter

a multipurpose 16-bit parallel output analog to digital converter which utilizes a switched-capacitor/charge redistribution architecture to achieve a 100 kSPS conversion rate (10 ms total conversion time). Overall performance is optimized by digitally correcting internal nonlinearities through on-chip autocalibration. Because the output of the Coriolis mass flowmeter are two sine wave, two chip AD676 is utilized to sample the signals. The sample clock is generated by the oscillation. When a sample period is over, the AD676 generates a interrupt to inform the DSP reading the data.

Signal process circuit is the center of processing the signals. Because the signal process is very complex, high speed performance is necessary. Traditional single chip processor is not competent for the operation speed. Thus the high-performance floating-point digital Signal Processor TMS320VC33 is chosen in this system. 34K × 32-Bit (1.1-Mbit) On-Chip Words of Dual-Access Static Random-Access Memory is used to store the signal data. The 32-bit data port is very ease to connect the AD676. When DSP receives the interrupt from AD, it read data port from exact address. Two signal data are filtered in interrupt service subroutine of DSP. The digital filter arithmetic will be introduce in the next portion of this paper[3]. The results are displayed and the parameters of the flowmeter are input by display and control circuit. For the most control and the data transmission are completed in this portion, and then the results are displayed on LCD in time, the processor must have the enough ports and high performance speed. In addition, FPGA is utilized to complete the data transmission from DSP to single chip processor.

arithmetic and calculating frequency and time delay arithmetic on DSP and control program on the single chip processor. The digital filter

arithmetic and calculating frequency and phase difference arithmetic on DSP will be described in this paper.

Digital filter arithmetic is more important in software, it is influencing to the precision of the system. Before designing the filter arithmetic, it is necessary to analyze the original data of the sensor output. According to the experiences of the Coriolis mass flowmeter, the output of the sensor are the two sine wave: the frequency is from 60 Hz to 110 Hz, the phase difference is from 0.09° to 1.8°. Fig. 3 is the frequency spectrum of the origin data of the some type of the Coriolis mass flow meter.
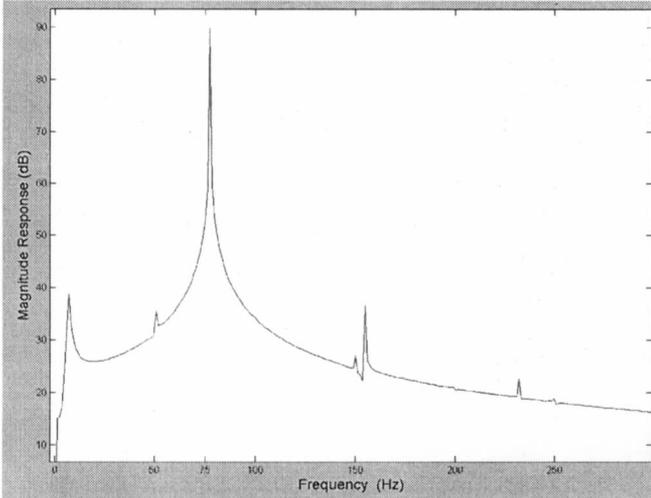

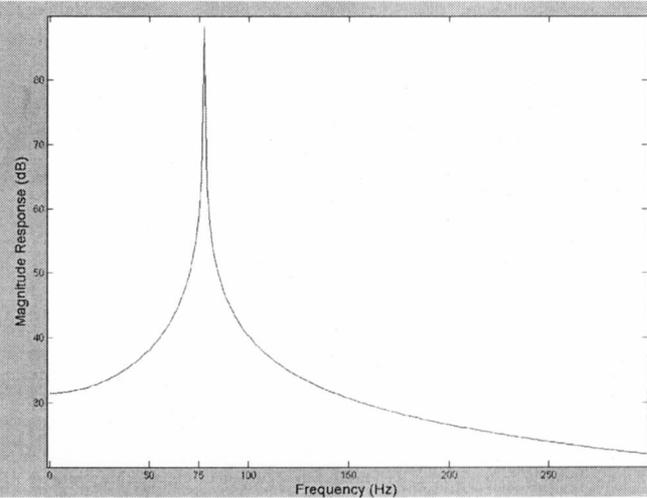Fig.3 Frequency spectrum of the origin data

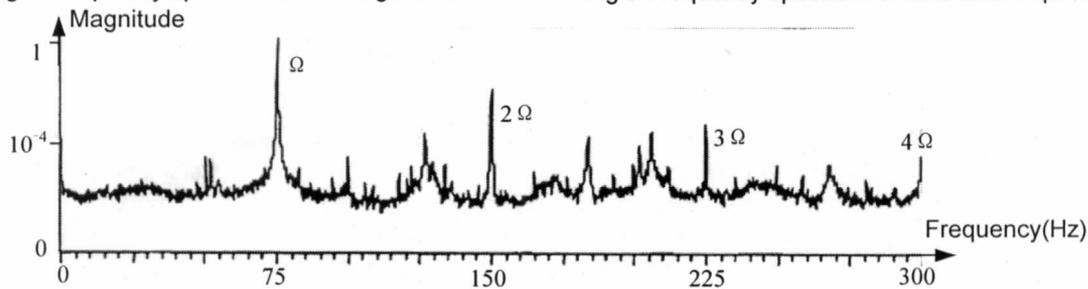Fig.5 Frequency spectrum of data after improve FIR filter

Fig.4 Representative frequency spectrum of CMF

From the fig.3, the conclusions can be found: there are many frequencies including second frequency and other frequencies in the signal expect the fundamental eigenfrequency. This result is the same as the conclusion that R. Cheesewright found in 1999 (see Fig.4) [?]. The second frequency and other frequencies will influence the precision of the system directly. Thus the filter arithmetic must eliminate them furthest. Considering the two signal character, the filter can not influence the phase difference of the signal. So the finite impulse response band pass filter is chosen to realize the signal filter. The band pass The decompose and compose methods are used in the improved FIR band pass filter. The frequency is set from 55 Hz to 120 Hz, the signal sample rate is set 19200 kHz. But for the frequency of the interferential signal is very close to the fundamental eigenfrequency, it is necessary that the transition of the band pass filter must be steep enough. By computer emulate, the 3,000 orders of the band pass filter can fulfil the task. However, the 3,000 orders filter is very difficult to realize by modern single chip processor and digital signal processor in project. Therefore the improved FIR band pass filter is put forward in this paper.

origin data are decomposed to fifty subsequence, and each subsequence is same

as the origin data sampled by 384 Hz (19200 divide 50). Because the data is sampled one by one, every time there is one subsequence data to filter. Thus the 60 orders filter achieves the request of the subsequence. Finally, the filtered subsequence is composed together.

The linearity phase difference merit of the traditional FIR band pass filter is reserved in the improved FIR band pass filter and the operand is less than traditional filter. The improved FIR filter needs 61 multiple operands and 60 addition operands, however the traditional FIR filter needs 3001 multiple operands and 3000 addition operands in order to achieve the same filter effect.

The fig.5 is the frequency spectrum of the filtered data by the improved FIR band pass filter. By contrast with the fig.3, the filter effect is very distinctness.

For the data is filtered by the improved FIR filter, the frequency and phase difference arithmetic can be more simple. The Chebyshev curve fitting arithmetic is adopted to fit the curve that pass the zero. So the zero result can be calculated by traditional method. Consequently the frequency and the phase difference are calculated.

Because the density of liquid is variety with the temperature, so the compensation arithmetic is designed to compensate the influence of the temperature.

The density coefficient:

$$K_C = \frac{\rho_f}{[1-\alpha_t \cdot (t-20)]\frac{f_0^2}{f_v^2} - 1} \qquad (3)$$

where ρ_f is the density of liquid when temperature is 20 ℃, α_t is the meter coefficient, f_0 is the empty tube oscillation frequency when temperature is 20℃, f_v is the current oscillation frequency, t is current temperature.

The flux coefficient:

$$f_y = f_x \cdot [1-\alpha_t(t-20)] \qquad (4)$$

where f_x is standard flux coefficient when temperature is 20 ℃, α_t is the meter coefficient, t is current temperature.

4. Experimental results

In order to validate the precision of the novel mass flowmeter, the sensor which diameter is Φ25 is utilized to demarcate. The sensor maximum flux is 3000 kilogram per hour. f_x is 84.4083, circumstance temperature is 20.3 ℃, the experimental liquid is water. The results are shown in table 1.

Table 1.Actual measurement result and relative error

Mass flux(Kg/h)	Measure mass (Kg)	Actual mass(Kg)	Relative error%
160	6.029	6.04	-0.182
293	7.675	7.69	-0.195
620	9.987	10	-0.130
987	10.077	10.09	-0.128
600	10.158	10.17	-0.118
300	7.519	7.53	-0.146
155	6.837	6.85	-0.190

5. Conclusions

Modern signal process technology is adopted in the novel Coriolis mass flowmeter. It utilized enough the powerful operation capability of DSP and realized the signal band pass filter. The actual experimental results shows that the

relative precision is achieved to $\pm$0.1%. Now the instrument is experimenting ulteriorly.

6.Reference

[1] R.Cheesewright, C.Clark. The effect of flow pulsations on Coriolis mass flow meters. Journal of Fluids and structures, 1998, 12:1025-1039

[2] Manus Henry. Self-validating digital Coriolis mass flow meter. Computing & control engineering journal, 219 ~ 227, October 2000

[3] TMS320C3X User's Guide. Texas Instruments, 1996

[4] Damir Ilic and Josip Butorac. Use of Precise Digital Voltmeters for Phase Measurements. IEEE Transactions on Instrumentation and Measurements, Vol.50, No.2, 449~452, April 2001