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Improvement of signal processing in Coriolis mass flowmeters for gas-liquid two-phase flow

Key words: Coriolis mass flowmeter; Digital signal processing method; Two-phase flow condition; Quadrature demodulation; Sliding discrete time Fourier transform (SDTFT); Hilbert transform

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Motivation

1. The signal processing technology is a key to the Coriolis mass flowmeter and plays a decisive role in improving the accuracy and stability of Coriolis mass flowmeter measurement under different conditions.
2. With the rapid development of digital signal processing technology, many scholars have applied digital signal processing technology to the signal processing of Coriolis mass flowmeter.
3. The signal processing problem of Coriolis flowmeter in the two-phase flow condition is still not solved.

Main idea

1. Three digital signal processing methods are analyzed for their applications in processing sensor signals and providing measurement results under the gas-liquid two-phase flow condition.
2. The phase difference tracking performances of these three methods are evaluated in the simulation.
3. Based on the digital signal processor, a converter program is implemented on its evaluation board.
4. The converter program is tested under single- and two-phase flow conditions.

Method

1. The traditional discrete Fourier transform (DFT) algorithm is improved in our study. Calculation and redundancy of DFT are greatly reduced using the actual frequency from phase-locked loop (PLL).
2. Dropout and finite impulse response (FIR) are implemented in the Hilbert transform, which eliminates the effects of the endpoint and improves its accuracy.
3. The all-digital Coriolis flowmeter converter is designed based on a digital signal processor (DSP), and the improved methods are implemented on the converter.

Major results

Phase difference results

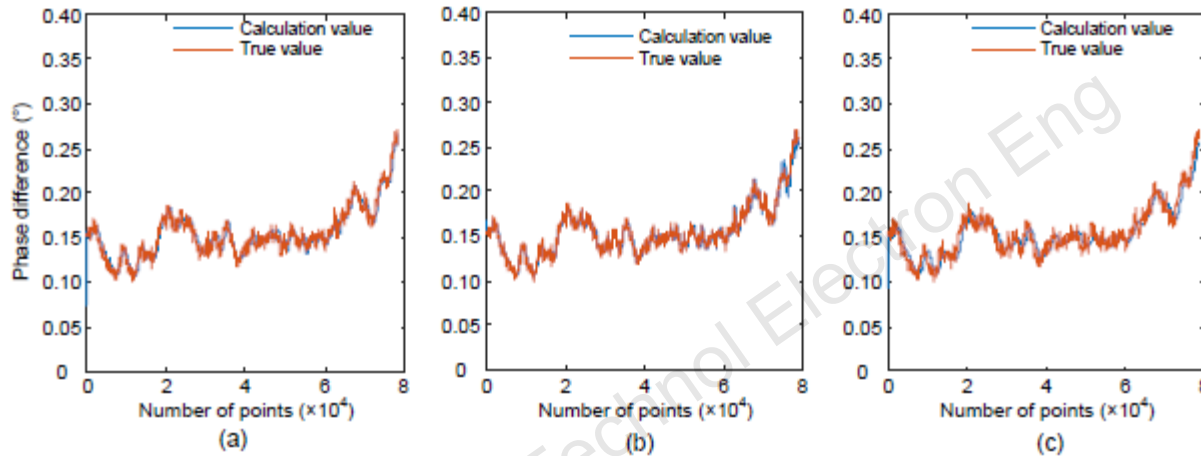


Fig. 4 Phase difference results obtained using the QD (a), SDTFT (b), and Hilbert (c) algorithms under the single-phase flow condition (References to color refer to the online version of this figure)

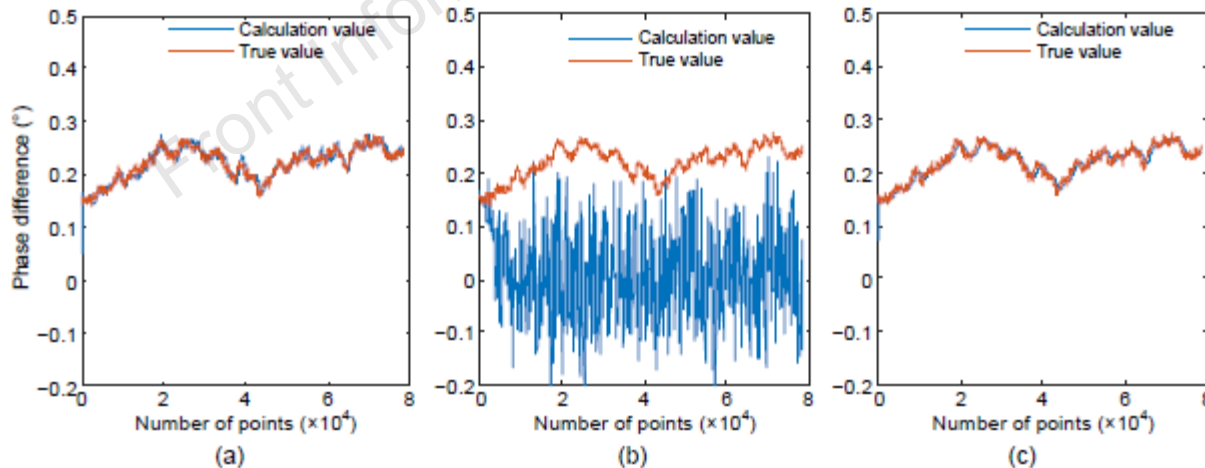


Fig. 5 Phase difference results obtained using the QD (a), SDTFT (b), and Hilbert (c) algorithms under the two-phase flow condition (References to color refer to the online version of this figure)

Major results(Cont'd)

Converter design

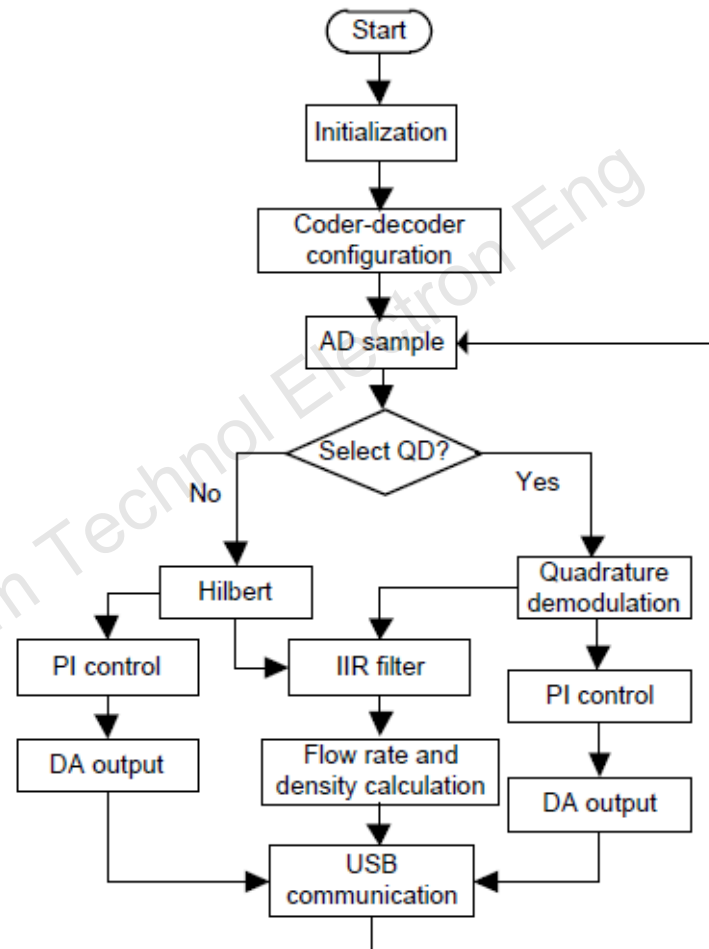


Fig. 6 Software system of the Coriolis mass flowmeter converter

AD: analog-to-digital; QD: quadrature demodulation;
DA: digital-to-analog; IIR: infinite impulse response;
PI: proportion integration; USB: universal serial bus

Major results (Cont'd)

1. Test results of quadrature demodulation (QD) and Hilbert algorithms under the single-phase flow condition

Table 11 Experimental calibration results under the single-phase flow condition

Flow point (kg/h)	Indication error (%)		Repeatability (%)	
	QD	Hilbert	QD	Hilbert
160	0.111	0.302	0.049	0.130
250	−0.031	−0.138	0.139	0.180
420	−0.015	−0.085	0.066	0.085
600	−0.065	−0.080	0.038	0.023

Major results (Cont'd)

2. Test results of QD and Hilbert algorithms under the two-phase flow condition

Table 12 Experimental calibration results under the two-phase flow condition

Flow point (kg/h)	GVF (%)	Indication error (%)		Repeatability (%)	
		QD	Hilbert	QD	Hilbert
160	22.5	-6.228	-6.418	0.110	1.436
250	14.4	-3.917	-5.046	0.523	0.723
420	8.6	-2.102	-2.128	0.230	1.355
600	6.0	-1.820	-0.827	0.840	0.549

GVF: gas volume fraction

Conclusions

1. The flow test results showed that the improved Hilbert algorithm can reduce the measurement error and improve repeatability.
2. Under the two-phase flow condition, the indication error of the QD algorithm was slightly smaller than that of the Hilbert algorithm at low flow rates, but the indication error of the Hilbert algorithm was smaller than that of the QD algorithm at the highest flow rate.
3. The improved Hilbert algorithm reduced the influence of the endpoint effect of the algorithm, and the performances (accuracy and repeatability) were greatly improved compared with the unimproved algorithm.



Prof. Lijun SUN received his PhD degree from School of Electrical and Information Engineering, Tianjin University, China. From 2005 to 2007, he was a post-doctor of Tsinghua University. From 2014 to 2016, he was a visiting scholar of the University of Kent. His research interests focus on flow measurement, intelligent flow devices, and optimal design of flow sensors.

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