Optical Bubble Detection System for Chemical Industry Pipelines

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This work describes the development of an optical system to detect bubbles on chemical industries pipelines. The experimental apparatus was assembled and tested at the Process Control and Automation Laboratory at FEQ/UNICAMP. The developed optical system used laser pointers as light sources and phototransistors, as receivers. Two optical sensors were developed. The first one was assembled using one emitter and one receiver. The second one, called multpoint sensor, was developed using four emitters and four receivers. Electronic interfaces were successfully developed to connect the optical sensor to a Fieldbus network. For the one-emitter-sensor, the interface uses the latch feature so that the transmitter output did not change until a new bubble event happened. The interface worked as an asynchronous counter at the multipoint sensor: for every bubble event, the counter was increased by one. The use of Fieldbus technology is growing nowadays in chemical industries and for this reason it was chosen to transmit the signal from the optical sensor to the control room. A supervisory system was developed in Visual Basic to get the information from the field devices using OPC (OLE for Process Control). In order to measure the bubble speed, one more multipoint sensor was connected to the pipeline, separated by a known distance from the first multipoint sensor. The developed bubble sensors are non-intrusive, cheap and easy to implement.

1. Introduction

Detecting and monitoring bubble events are important for efficiency and safety reasons. Cavitation is a classical example of how bubble presence could endanger liquid pumping systems. For high-pressure liquid storage tanks, bubble presence may indicate that the internal pressure is decreasing, caused by a possible leak or even some problem on the pressurization system. The bubble detection is crucial to avoid major leaks and even explosions. Also, if a pipeline is connected to a heat exchanger system, the heat transfer efficiency may decrease by a surge of bubbles.

In an equipment known as air lift, bubbles are necessary to promote a suitable mixing inside the equipment and to enhance mass transfer between gas and liquid. By measuring and manipulating bubbles frequency, the good control of the mass transfer rates is allowed.

In this context, the present work is concerned with the development of optical sensors for bubble detection in chemical processes pipelines, using Fieldbus network as data communication system.

This system is based on the light emission and reception principle, a non-intrusive method which uses an optical barrier. The classical intrusive sensors may be a contaminant and require regular cleanings.

The optical technique was also employed by Musazzi (2001) and Guelt (2003). These authors use a system based on light emission and reception. The difference between these systems and the system developed in the present work is the type of sensor and the purpose of application. Guelt (2003) determined the speed and the individual bubbles size in pipes using four probes of optic fiber. Meanwhile, Musazzi (2001) uses the variation of the received light to detect solid particles.

Among the data communication technologies found in industrial plants, the Fieldbus Network was chosen to be used in this work. The use of this technology is growing in chemical industries due to the flexibility to change the control strategies, easy installation and maintenance, and distributed intelligence in the field. The Fieldbus system is equipped with the OPC technology (OLE for Process Control) which uses the communication based on Ethernet. Thus, the field variables may be controlled or monitored through independent developed software, and specific commercial softwares are not necessary.

2. The Developed System

Two optical sensors were developed. The first one was assembled using one emitter and one receiver devices. The second one, called multipoint sensor, was developed using four emitters and four receivers.

The optical barriers were fitted to a vertical glass tube, 3 cm internal diameter, filled with water (Figure 1). A low power compressor injects air bubbles at the bottom of the tube. A needle valve performs the inlet airflow adjustment.

The laser was chosen to be the emitter source because of being a narrow beam of concentrated light. Since the acquisition cost of a laser diode is relatively high and also the diode requires collimator lens for the light bunch, commercial laser pointers were used instead. Low cost and easy acquisition are additional features that make the laser pointer very attractive.

Phototransistors were used as receptors, and worked as ON/OFF digital switches: when bubbles passed through the optical barrier, the laser beam is diverted, turning the phototransistor off. Electronic interfaces were mainly built to convert voltage signal from the phototransistors into electrical current signal (4-20mA). These interfaces were connected to the Fieldbus network through the IF302 converter. Three input channels were available (CH1, CH2, CH3).

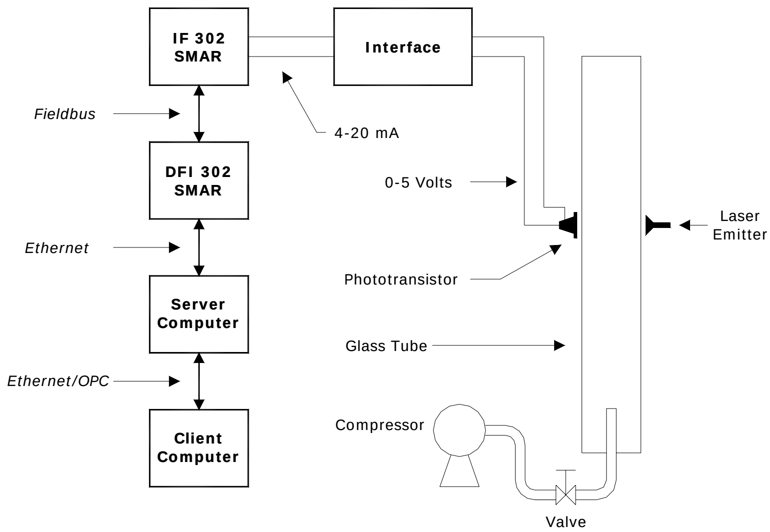

Figure 1. Experimental apparatus.

The distributed Fieldbus interface (DFI302) installed in the laboratory accepts digital, analogical and also Fieldbus signals from the process. The server computer (Figure 1) allowed the Fieldbus network configuration. It also supplied the client computer with the field data through the Ethernet network based on the OPC communication protocol.

2.1 One-Emitter Sensor

The one-emitter sensor was developed using one laser emitter and one receptor (phototransistor) devices.

Besides converting the phototransistor output signal, the electronic interface developed for this sensor also presented a characteristic called latch. This was obtained using an eletronic device called Flip Flop, which worked on toggle mode. As a consequence, the phototransistor output signal was inverted (0 Volts $\rightarrow$ 5 Volts or 5 Volts $\rightarrow$ 0 Volts) every bubble event was detected. Using latch component was required because the sampling frequency of IF302 was not high enough to manage and detect the bubble event using a linear interface (without latch).

In order to eliminate noise and to guarantee suitable signal amplitude to the Flip Flop, a Schmitt-Trigger circuit was also implemented in the interface.

2.2 Multipoint Sensor

This sensor is composed of four laser emitters and four phototransistors evenly distributed around the pipe (Figure 2). The detection area was then increased, turning the multipoint sensor more sensitive compared to the one-emitter sensor.

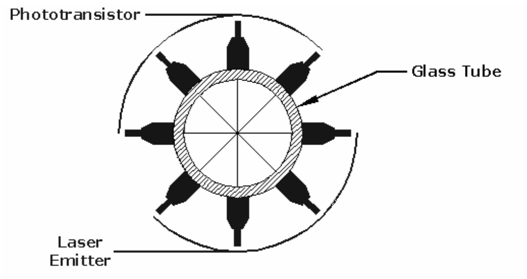

Figure 2. The multipoint sensor scheme.

As the multipoint sensor had four phototransistors, a logical system was developed to produce only one output signal. The digital logic AND gate was used. The AND gate output presented high level (1) only if all inputs were in the high level. Using this logic gate, the low level (bubble event) is obtained since any of the four phototransistors was interrupted.

Aiming at minimizing the low sampling frequency of the IF302 transmitter, three available channels of the IF302 were used. A 3-bits asynchronous counter circuit was added to the interface to get different codes every time that a bubble event occurred.

This new electronic interface worked as follows: performing an acquisition at (t0=0 ms), the interface produced a code that was a combination of three numbers. When the IF302 performed a new acquisition at (t0+225ms), a new code was acquired if bubble event happened. The supervisory system compared the new acquisition with the previous one. If the codes were equal, no bubble event happened. If the codes were different, the supervisory system checked how many bubble events happened. Table 1 shows all the codes that the interface may produce.

Table 1. Eletronic interface code sequence.

Code n°	**Ch 3 (mA) - Most Significant Bit**	**Ch 2 (mA)**	**Ch 1 (mA) - Less Significant Bit**
1	4	4	4
2	4	4	20
3	4	20	4
4	4	20	20
5	20	4	4
6	20	4	20
7	20	20	4
8	20	20	20

With the goal of monitoring the bubble velocity (V), another multipoint sensor was installed on the glass tube. Another IF302 transmitter was implemented as well. From now on, two signals was sent to the software allowing bubble speed calculation. These two sensors were placed at a well-known distance (L). The time interval between the activation of the multipoint sensor 1 (t_1) and the activation multipoint sensor 2 (t_2) due to passage of a given bubble was measured. The bubble ascension velocity was calculated through Equation 1.

$$V= L/(t_2-t_1) \quad (1)$$

2.3. Computational Program

Due to the flexibility that the OPC presents, a supervisory software was developed (Visual Basic language) which ran in the client computer. The computational program performs the following tasks:

- OPC Communication Network: the program allows connection with the OPC network to get the tags (name of the field variables) from the Fieldbus network;
- Data File: creates a data file, in the text file format (TXT), recording the current values of each IF302 channel installed in the process;
- IF302_01 and IF302_02: using OPC tags, the program selects and checks the IF302 inputs;
- Bubble Counter: the program displays the number of bubbles that passes through the optical barriers;
- Bubble Velocity: the program calculates the bubble speed through Equation 1.

3. Experimental Results

The main aim of the experimental tests was to determine the performance of both sensors in detecting bubble events. The bubble frequency was maintained and the counting procedures were performed during 5 minutes. Visual counting was taken as the correct bubble event measurement.

The results using one-emitter sensor are shown in Table 2. This sensor presented a good performance to detect large bubbles (size similar to the pipe diameter) and slugs (bubbles that fill completely the pipe diameter). The counting error increased for small bubbles as the upward movement along the pipe is random and the bubble might not found the optical barrier.

Tables 3 shows the results obtained with the multipoint sensor for large bubbles and slugs and for small bubbles counting. For this sensor, pipe diameter was evenly divided into eight parts, constituting an optical barrier similar to a “spider web” and thus increasing the scanned area. The sensitivity was improved and also the accuracy in detecting bubble events.

The computational program calculated the time phase lag between both sensors as well. Several tests were performed and the average phase lag calculated is 1.1 s. As the distance between both multpoint sensors is known (17 cm), using the average speed formula (Equation. 1), a bubble speed of 15 to 21 cm/s approximately was determined, which are within values reported in the literature.

Table 2. One-emitter sensor performance – large bubbles and slugs.

Acquisition	Visual Counting	Automatic Counting	Error (%)
1	50	47	6.0
2	53	49	7.5
3	44	41	6.8
4	48	45	6.3

Table 3. Multipoint sensor performance – large bubbles and slugs / small bubbles.

Acquisition	Visual Counting	Automatic Counting	Error (%)
9/ 13	27/ 45	26/ 43	3.7/ 4.5
10/ 14	32/ 47	30/ 44	6.3/ 6.4
11/ 15	25/ 50	24/ 48	4.0/ 4.0
12/ 16	29/ 43	27/ 41	6.9/ 4.7

4. Conclusions

Laser pointer and phototransistor devices were the basic components employed in the development of the optical bubble detection systems presented in this work.

Electronic interface were built in order to execute properly the signal conditioning. Fieldbus transmitters were used and their A/D converters showed to be very slow. For this reason, an asynchronous counter was implemented in the interface and it results a code related to the number of bubble events detected.

To manage the optical system, a supervisory software was developed. Average bubble speed was also computed on-line.

For the multipoint sensor, suitable counting results were obtained to bubble frequency up to 0.25Hz due to the time delay from the Fieldbus transmitter plus the communication network delay. As advantages, the developed bubble sensors are non-intrusive, cheap and easy to implement.

5. Acknowledgements

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6. References

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