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Proper Selection of Ultrasound Level Meter for the Flow Rate Measurement in Open Canals

There are a great number of ultrasound sensors for the level measuring, as well as ultrasound devices for the flow rate measuring in the market. "The best" sensor for level measuring doesn't exist, nor exist "the best" flowmeter in open channels. There is only sensor or flowmeter which corresponds in the best manner to a certain project task. The idea of this paper is to give directives how to choose ultrasound level sensor and ultrasound flowmeter which should in a best way relate to a project requirements.

1. Introduction

Prior to ultrasound level meter purchasing it is necessary to design measuring object which would with satisfactory accuracy provide measuring of predicted measuring range. It is also necessary to be aware of all limitations and possibilities of ultrasound level meters. The selection of ultrasound level meters is based on dimensions and characteristics of measuring object.

One must have in mind following before purchasing ultrasound level meter for measuring in open channels, as well as "ready" ultrasound flow meters in open channels:

- Connection between sensor and control unit for data analyses;
- Measuring range;
- Angle of conical beam of ultrasound signals;
- Air temperature compensation;
- Power supply and output signal of sensor, as well as performances of control unit.

2. Connection between sensor and control unit for data analyses

There are two types of ultrasound level meters in the market:

- Compact version – sensor and control unit are united in one housing;
- Separated version – where sensor and control unit are separated.

Ultrasound flowmeters for flow rate measuring in open channels are produced only as separated version.

But the price of this version of devices is considerably higher than the total price of ultrasound level meter and control unit. When choosing ultrasound level meter, one must carefully choose ultrasound sensor and its adequate control unit.

Compact version is more suitable for the purposes of level metering in tanks which are placed in closed space with controlled microclimate. They are produced in protection IP65 which doesn’t allowed submerging, which could happen during level metering in open channels because of the bad judgement of water quantity during designing (abundand falls).

If compact version is built in certain measuring object, previously mentioned incident could produce permanent damage of device because of submerging.

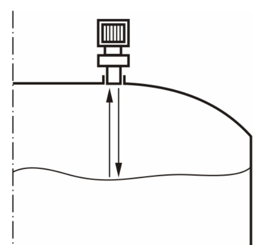

Figure1. Application of compact ultrasound level meter for measuring in tanks

In the case of separated version it is possible to distinct control unit from the zone of water, and because of that this version is mainly produced in protection IP20. It is not justifiable to burdain the price of this device with protection higher than IP20, which should enable building in this device in open area. Cheaper variant is to put control unit in steel box with door which provides manipulation and maintenance of control unit. This should be sufficient to protect the device from moisture and operator from electric shock.

3. Selection of measuring range of ultrasound level meter

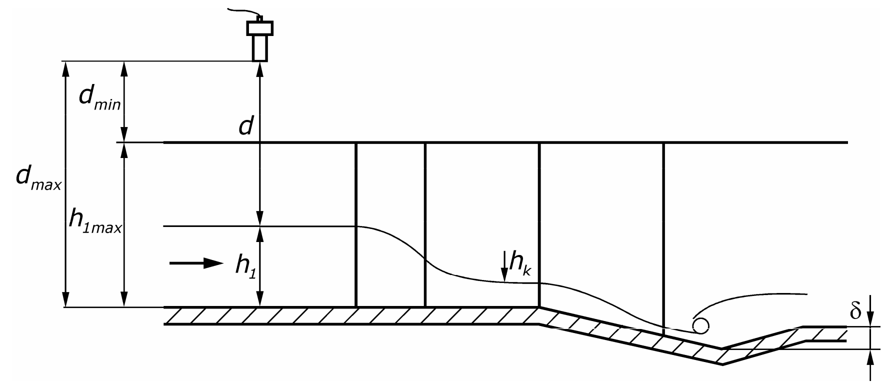

Figure 2. Significant values in level metering

In **Figure 2** are shown values significant for selection of ultrasound level meter, where are:
d - distance between measuring sensor and instantaneous liquid level in measuring object $[\text{m}]$;

d_{min} - minimal distance from measuring sensor to measuring object $[\text{m}]$;

d_{max} - value of full scale (maximal distance) $[\text{m}]$;

h_1 - instantaneous liquid level in measuring object $[\text{m}]$;

h_{1max} - maximal level (height of measuring object) $[\text{m}]$;

Producers of ultrasound level meters provide acuracy related to maximal value of full scale d_{max}. For example,

- accuracy of ultrasound level meter is $\pm 0.25 d_{max}$ %;
- measuring range $0.3 \div 10$ m, i.e. $1:33$.

This leads to value of full scale $d_{max} = 10$ m, i.e. accuracy of ultrasound level meter is 2.5 %, i.e. 2.5 cm.

Production of ultrasound level meters with different values of measuring ranges $d_{min} \div d_{max}$, i.e. full scales d_{max}, enables application of these devices with satisfactory accuracy for the measuring in objects of different dimensions, channels and rivers. Ultrasound level sensors are produced with different measuring scales $d_{max} = 1.8 \div 10$ m and accuracies $\pm(0.15 \div 0.25) d_{max}$.

In order to achieve satisfactory accuracy, ultrasound level sensor must be provided to comply with measuring range of measuring object

$$h_{1max} \approx d_{max} - d_{min} . \quad (1)$$

Producers should provide in their prospects necessary information about value of measuring range (full scale value), while information on accuracy alone does not give any sense. Measuring range harmonization of measuring object and measuring device is of a great importance.

Minimal distance from measuring sensor to measuring object d_{min} is recomended by producer. If measuring range of measuring device is a little bit greater than measuring range of measuring object (the most common case), measuring sensor is placed to height greater than d_{min}, what is also recommended by producer.

4. The Angle of conical beam o ultrasound signals

After selecting ultrasound level meter according to measuring range $d_{min} \div d_{max}$, follows selection according to angle of conical beam φ of ultrasound signals. Ultrasound level meter emits conical beam of ultrasound signals, **Figure 3**.

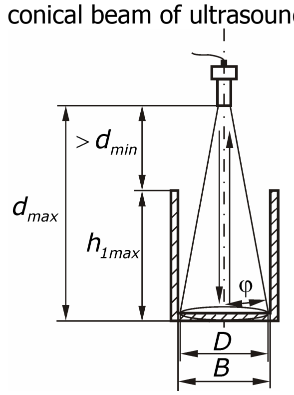

Figure 3. Proper selection of measuring device according to conical beam angle of ultrasound signals

Ultrasound level meters are produced with different angle of conical beam, for $\varphi = 4 \div 11\ °$. In order to operate properly and with satisfactory accuracy, device emits beam in shape of cone which base diameter at the bottom of open channel must be less than width of open stream *B*.

If this requirement is not fulfilled, ultrasound signal is going to deflect from the channel walls, travel lesser distances from measuring distance and go back to receiver in shorter interval of time compared to other rays, and this will influence measuring acuracy, **Figure 3.**

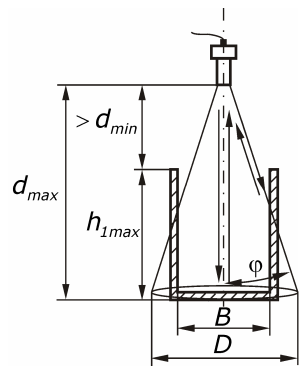

Figure 4. Improper choice of measuring device according to conical beam angle of ultrasound signals

In **Figure 5** is shown cross-section of conical beam. By applying well-known trigonometric relation to shaded part of cross-section,

$$tg\varphi = \frac{D/2}{d_{max}}, \qquad (2)$$

it could be determined diameter of conical beam at the bottom of flume

$$D = 2 \cdot d_{max} tg\varphi . \qquad (3)$$

If the width of flume is bigger than base diameter of conical beam at the bottom of flume $B > D$, ultrasound level meter is adequate according conical beam angle of ultrasound signals.

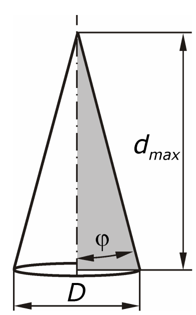

Figure 5. Cross-section of conical beam

Producers of ultrasound level meters make set of meters with variable angle of conical beam in order to satisfy different magnitude of flume. It must be emphasized that ultrasound level meters with big angle of conical beam $\varphi = 10 \div 11\,^{\circ}$ are commonly used for level measuring in huge channels and rivers. Producers usually make control units, which eliminate deflected ultrasound signals. Elimination of deflected ultrasound signals is happening with accompanying effect of signal filtration. Producer's prospects have to content information about angle of conical beam of ultrasound signals.

5. Air temperature compensation

There are two types of ultrasound level meters from temperature compensation point of view:

- with automatic air temperature compensation;
- with manual air temperature compensation.

It is vary important to choose ultrasound level meter with automatic air temperature compensation. Ultrasound level meter with manual air temperature compensation has temperature sensor, but it is not automatic one, so user must manually adjust air temperature data according to outside air temperature.

Ultrasound level meter measures distance d, by measuring time t in which ultrasound crosses distance d with sound velocity c

$$d = ct$$

Temperature changes cause changes in sound velocity

$$c = \sqrt{\kappa RT}\ , \tag{4}$$

where sound velocity changes $0{,}59\ \mathrm{m/s}$ due to temperature change of $1\ ^{\circ}\mathrm{C}$.

In case of manual air temperature compensation user adjusts air temperature, and simultaniously sound velocity which corresponds to adjusted temperature (for example $t = 0\ ^{\circ}\mathrm{C}$ and $c = 331{,}4\ \mathrm{m/s}$). In this case, selected adjustment will be considered as referent point, and temperature changes and accuracy will be considered for referent point. Due to outside air temperature changes user must adjust new air temperature, otherwise measured results will be displayed for referent and not for real data.

As an example, ultrasound level meter which measures distance of $d = 0{,}5\ \mathrm{m}$ and which is adjusted to referent point will be considered.

For air temperature of $t_1 = 0\ ^{\circ}\mathrm{C}$, ultrasound signal crosses distance of $d = 0{,}5\ \mathrm{m}$ with velocity of $c_1 = 331{,}4\ \mathrm{m/s}$ in time

$$t_1 = \frac{d}{c_1} = \frac{0{,}5}{331{,}4} = 1{,}508\ \mathrm{ms}\ .$$

The same distance, for air temperature of $t_2 = 30\ ^{\circ}\mathrm{C}$, ultrasound signal crosses with velocity of $c_2 = 349{,}1\ \mathrm{m/s}$ in time

$$t_2 = \frac{d}{c_2} = \frac{0{,}5}{349{,}1} = 1{,}43\ \mathrm{m/s}\ .$$

In case when automatic compensation doesn't exist, relative temperature difference in measuring time, in which signal crosses distance of $d = 0{,}5\ \mathrm{m}$, for temperature change of $\Delta t = 30\ ^{\circ}\mathrm{C}$ is

$$\frac{\Delta t}{t_1}\times 100\ \% = \left(\frac{t_1 - t_2}{t_1}\right)\cdot 100\ \% = \frac{1{,}508 - 1{,}43}{1{,}508}\cdot 100\ \% » 5{,}17\ \%.$$

During accounting are used referent conditions, not real ones, so signals cross in two different times two different distances

$$d_1 = c_1 t_1 = 331{,}4\cdot 1{,}508\cdot 10^{-3} = 0{,}5\ \text{m},$$

$$d_2 = c_1 t_2 = 331{,}4\cdot 1{,}43\cdot 10^{-3} = 0{,}474\ \text{m}.$$

Relative accuracy of distance measuring is

$$\frac{|\Delta d|}{d}\times 100\ \% = \frac{|d_2 - d_1|}{\mathrm{d}_2}\cdot 100\ \% = \frac{|0{,}474 - 0{,}5|}{0{,}5} = 5{,}07\ \%.$$

For temperature change of $\Delta t = 30\ °\mathrm{C}$ and for different values of distance d, relative accuracy is always constant $5{,}07\ \%$.

In **Figure 6** is shown relative accuracy of distance against temperature change compared to referent (adjusted) temperature $t = 0\ °\mathrm{C}$.

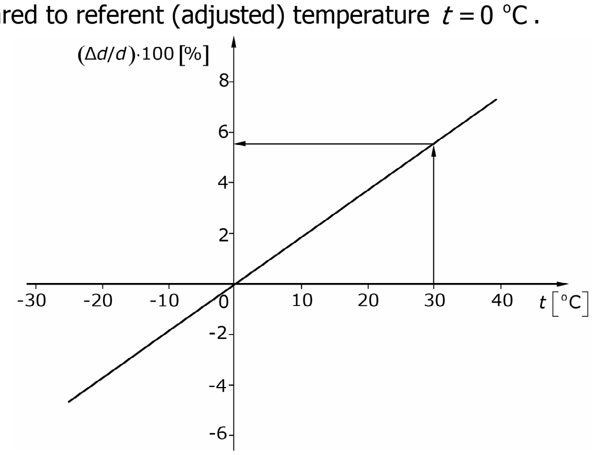

Figure 6. Relative accuracy of distance against temperature change

It could be seen in **Figure 6**, that relative accurancy of ultrasound meter with manual air temperature compensation can be decresed by manual adjustment of air temperature data according to outside air temperature. In this way, relative accurancy is decresed, but it requires more work, and could not be long-term solution.

Ultrasound level meter with manual temperature compensation could be only used for waste water measuring in open area without significant changes of temperature. It could be applied for waste water instantaneous measuring in open area too, in systems with forced flow (for example, pumping waste water from basen to open channel). In this case measuring is vary short (a couple of hours) and periodical, so for each measuring the air temperature should be manually adjusted according to outside one. Ultrasound level meter with manual temperature compensation is applied in level measuring in tanks, which are placed in closed space (with constant microclimate), as well as in laboratory conditions.

6. Power suply, output signal and control unit performance

The choice of adequate control unit depends on power supply and signal output of ultrasound sensor. Power supply could be internal and external, while current output signal $4 \div 20$ mA is most common one. The control unit is selected by investor, regarding the way of data displaying, storing and eventual sending of data to remote distance.

7. Conclusions

Mentioned analysis has proved the fact that „the best" ultrasound sensor for level measuring and „the best" ultrasound meter for flow rate measuring in open channel do not exist. There are only the sensors or the meters which correspond to a certain project tasks in the best manner.

It is obvious that selection of adequate ultrasound sensor and flow meter is vary serious task. Inadequate ultrasound sensor or flow rate meter could not only decrease measurement accuracy, but make whole measuring system nonfunctional.

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