lä" International Mining Congress and Exhibition of Turkey-IMCET2003, P 2003, ISBN 975-395-605-3

Acoustic Anemometry Control Means Elaboration for Coal Mines

S.Z. Shkundin, O.A. Kremleva & V.A. Rumyantseva
Department oj Electro-engineering, Moscow State Mining University, Moscow, Russia

ABSTRACT: New class of airflow rates control devices has been developed in MSMU Electro-engineering dpt. Acoustic method of flow rates measurement is the most perspective and free of inherent to traditional methods defects. The main characteristics of the acoustical anemometer designed are: wide range (0.1 -20.0 m/s); high precision (measuring error 0.02+0.02V m/c); lag-free instrument (time of one measurement 0.01 s); possibility of interfacing with the computer; averaging during any time interval; reliability (absence of frail and moving parts). These features make acoustical anemometer an optimum for airflow velocities control, both in manual, and in the autonomous mode. A phase difference of two acoustical signals transmitted along and against the flow is being measured. Acoustic signals are being radiated and received by piezoelectric transducers mounted in the walls of anemometric channel. A phase difference is directly proportional to average velocity of airflow through the wave duct. Theoretical ard experimental researches have provided a basis of the method, construction parameters optimization, elimination of some inaccuracies (for example, caused by environment parameters changing).Anemometers operating in mines need the regular check, and checking installation has been designed in MSMU. Developed instruments already successfully work in number of mines. In the opinion of authors, acoustics method is the most perspective direction in mine anemometry.

1 ACTUALITY OF DEVELOPMENT

Mines atmosphere conditions have a great importance for mine safety and health. Ventilation is a main means of governing mines atmosphere composition. Ventilation provides both a dilution of toxic gas, and prevention of explosive concentrations of methane, evolved during process of coal mining. The main parameter of ventilation process is a quantity of air. The quantity is calculated as the product of working cross-sectional area and average velocity in the cross-section. Airstream velocity must be measured precisely, because insufficient ventilation (small velocities) may bring about unpermissible level of methane concentration. Opposite, excessively greater velocities may bring about significant condition of miners work worsening (airflow rise coal dust), besides, a greater amount of electric power is dispersed for it. Consequently, velocity of air must be not above and not below determined limits. Airflow velocity changes must be checked systematically by exact reliable instruments. Mine anemometer must have a velocity measurement range 0.1 -20.0 m/s with, reasonable accuracy not more than 10% all over range, high reliability in connection with particular conditions of usage.

At present time usually vane anemometers are used in mines. They have incurable defects of operation principle. On the one hand impeller must be as possible more light and must be inertia-free; on the other hand, it must be strong and firm.

Sometimes, for the measurement within the range of velocities below 1 m/s, thermo-anemometers are used, which have pinpoint accuracy, but also has essential defects. They contain frail heater, nonlinear characteristics and main, small dynamic range.

Therefore, the problem of free from proved above defects anemometer development is actual. And this anemometer must have another new method of airflow velocity measurement.

2 ACOUSTIC PHASE METHOD OF AIR VELOCITY MEASUREMENT DESCRIPTION

Acoustic anemometer was designed in the Moscow State Mining University (MSMU). An acoustic phase method for air flow rate velocities measurement is in the basis of it (Skundin et al., 1990).

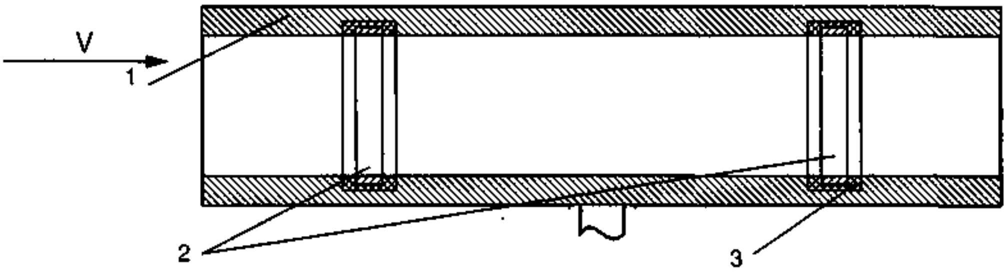

Figure 1 Acoustic anemometer sensor (anemometer channel). 1- Cylindrical waveguide-airduct. 2- Radiating and receiving transducers (piezoelectric rings). 3- Isolators

Acoustic flowmeters for liquid are well known. Attempts to build acoustic instrument for gas velocity measurement also have been made, however such instrument creation is difficult because of low gas density in comparison with liquid. The acoustic-waveguide prevents the dissipation of the acoustic energy, so the signal amplitude is big enough.

Sensor of acoustic anemometer (anemometer channel) is a cylindrical waveguide-airduct with the piezoelectric transducers mounted in the wall (Figure 1).

Acoustic signal propagates along waveguide axis. Aneinometer channel is put into the airflow along its direction. Each transducer is radiator and receiver of acoustical signal by turns. A phase difference between two acoustical signals transmitted along and against the flow is being measured. A phase difference is directly proportional to average airflow velocity in the cross-section of the airduct. Figure 2 illustrates the simplified model of the anemometer operation.

The source of acoustical waves radiates a plain wave, propagating along z-axis. Uniform airflow of velocity V has positive direction (Figure 2a).

The signal comes to receivers, located at the distance / from the source along and against the flow. Input notation;

$$p_+(z,t) = P_0 \sin\left(\omega t - \frac{\omega}{c+V} z\right) \quad (1)$$

$$p_-(z,t) = P_0 \sin\left(\omega t + \frac{\omega}{c-V} z\right) \quad (2)$$

These are expressions for acoustic pressure waves, propagating in positive and negative direction respectively.

Receiver's acoustic pressure dependency on a time is shown on the figure 2b.

c - sound speed in the air; ω - an angular acoustic radiation frequency; $(c + V)$ phase velocity of waves, propagating in positive direction of z-axis; $(c - V)$ phase velocity of waves, propagating in negative direction of z-axis.

Therefore phase difference of these signals is;

$$\Delta\varphi = \omega l\left(\frac{1}{c-V} - \frac{1}{c+V}\right) = \omega l \frac{2V}{c^2 - V^2} \approx \omega l \frac{2V}{c^2} \quad (3)$$

We can see that the phase difference is directly proportional to How velocity, when flow velocity is SITU,I in comparison with sound speed $(V \ll c)$. Sound speed in the air at normal conditions is about 345 m/s, and airflow velocity usually is not higher then 20 m/s, therefore this condition is satisfied.

However the factors such as gas temperature, gas content depend on proportion factor in Formula 3. American researchers of similar design (David et al., 1980) noted absence of repeatability in experiments and special basic research for this phenomena needs explanation.

We also have got to the conclusion that it is necessary to take into account wave propagation particularity for designing such instrument. Basic research results are in publications (Skundin et al., 1998; Skundin et al., 2001)

Characteristics of acoustic wave propagating in the acoustic anemometer channel, i.e. in cylindrical waveguide is more complicated. Acoustic pressure on receiving transducer is a number of harmonic elements - normal modes; each of them has its own amplitude and propagation velocity:

$$p_+ = \sum_n A_n \sin\left(\omega t - \frac{\omega}{V_n} z\right) \quad (4)$$

where A_n - an amplitude of n -th mode, V_n - a phase velocity of n -th mode.

Fundamental investigation has been made to create air-acoustic interaction in the anemometer channel mathematical model. It has been shown that phase difference of signals, which are the sum of modes, is directly proportional to tlow velocity also just as for the plain wave propagation in opened space. So phase characteristic of acoustic anemometer is linear.

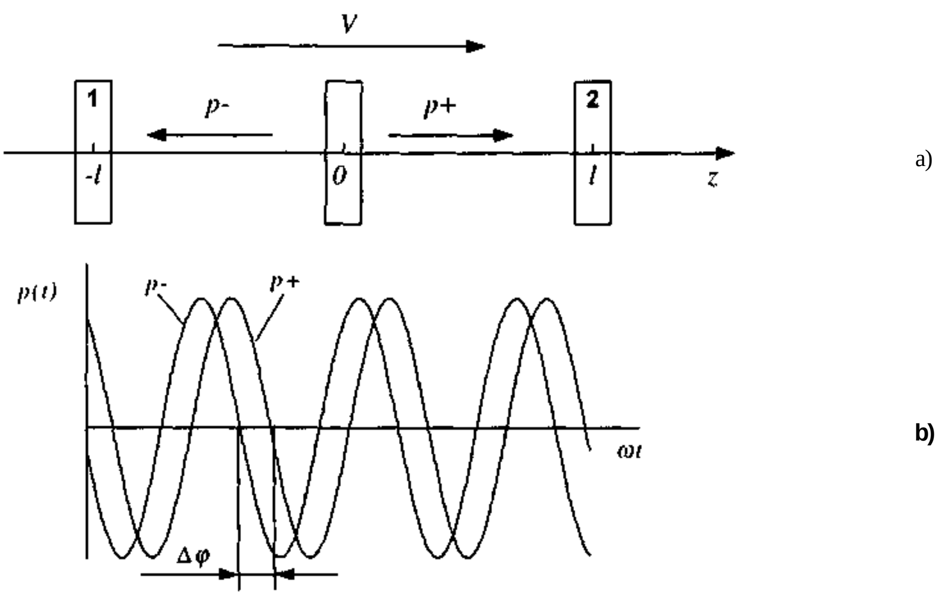

Figure 2. The schematic form of acoustical method of airflow speed measurement

3 CHARACTERISTICS OF ACOUSTIC ANEMOMETER

The acoustic anemometer designed in MSMU has the following characteristics:

- it can define the direction of flow being measured;
- it is not critical to the gas contents of the controlled tlow;
- an aerodynamic resistance - not more than I0 Pa:
- measurement dynamic range - to 1.500;
- It is practically inertia-free (not more than 3 ms);
- airflow velocity measurement range 0.1 - 30 m/s;
- inaccuracy (0.02+0.02V) m/s;
- working temperature 0 - 40 °C;
- combinable with PC:
- supply voltage- 5 V:
- consumed power - 400 mWatt;
- work resource 10,000 hours;
- sizes of anemometer channel - a length of 120 mms, external diameter - 38 mms (internal - 28 mms):
- dimensions of electronic block -200x50x45 mm:
- weight - 400 g.

Structural anemometer scheme is shown in Figure 3. Generator works out pulses with the frequency of 80 MHz. The lime between receipts of same phases of signals propagating along and against the tlow is filled by these pulses. Counter controlled by a controlling system counts these pulses. Therefore, phase difference is proportional to a number of filling pulses.

Controlling system forms a packet of pulses by the frequency 30 kHz and gives it through the commutator to the radiating ring. This system also controls a switching of rings connecting them by turns as a radiator or as a receiver. Signal from the commutator through the amplifier is transmitted to analog entrance of the controlling system, where a comparator is built-in. Data is coining to the computer port through the interface device.

4 INDEPENDENCE ON ENVIRONMENT

Phase difference of acoustic signals, propagating along and against the flow can be calculated according the Formula 3. We can see that the phase difference depends on sound speed. Sound speed is a function of air parameters, such as temperature, pressure, gas content. Excluding the dependence on the out come inductions upon the sound velocity we eliminate the influence of the named above parameters upon the velocity measurement. This algorithm is designed and realized in the anemometer functioning at one of the normal modes (Skundin et al., 2000).

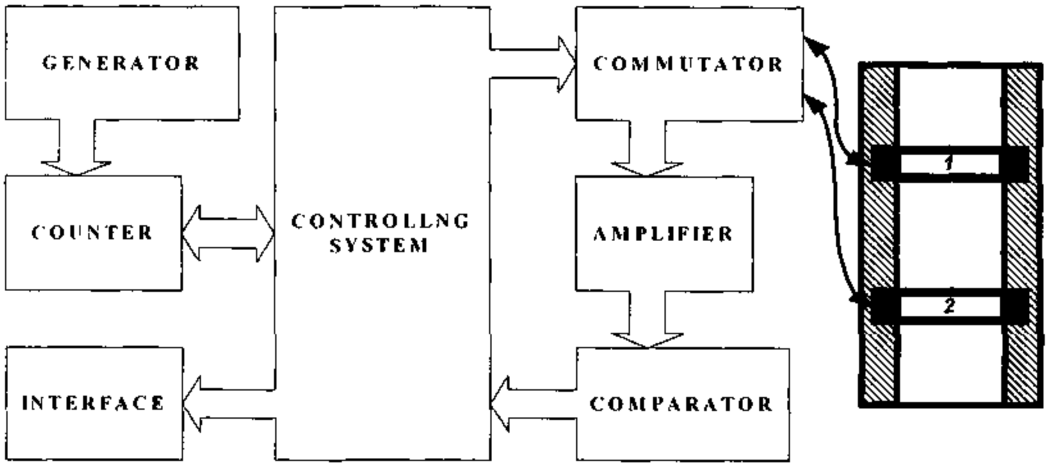

Figure 3. The structure of the acoustical anemometer

5 ACCURACY OF PHASE ACOUSTIC METHOD

Minimum inaccuracy of acoustic anemometer is defined by the time interval between nearby pulses i.e. frequency of filling pulses /„. Minimum inaccuracy is calculated by the formula.

$$\delta V = \frac{c^2}{2lf_0} \quad (5)$$

We can see that inaccuracy is inversely to length of base (distance between radiating and receiving transducers). However, sizes of portable instrument must be small enough. Besides the longer the tube, the bigger it's aerodynamic resistance. But stationaiy installation based on described above principle of operation can have pinpoint accuracy.

In MSMU the aerometrie installation for the checking of anemometers was designed. It is a wind tunnel with the electroacoustic transducers system which is similar to the one described above. Airstream is created in the pipe. Stability and linearity of characteristics, pinpoint accuracy gives possibility of using an acoustic sensor as the referring one.

6 CONCLUSION

The authors consider that acoustic methods are the most perspective direction for mine anemometry development. The portable acoustic anemometer and aerometrie installation for the checking of anemometers were designed. In the present time our laboratory is developing a stationary air velocity sensor, which could become part of mine safety monitoring system.

REFERENCES

David I. Plaut & John & G Wehster. 1980 Design and Constiuction of an Ultrasonic Pneumotachometer. IEEE

Shkundin S.Z.& Lashin V.B 1990 Oa-jOBbiH enocoô aKycTH'iecKoH aHeMOMeTpun Moscow. *Mempoiocmi* JVÜ7 p.39-43.

Shkundin S Z. & Kremleva O.A. 1998. A method for calculating Acoustic Fields in finite Cylindrical Channel with air flow. *AuustUul Pimm,* vol.44, USA

Shkundin S Z. & Buyanov S.I. & Rumyantseva V A 2000. OuenKa B.iiiflHi!« coerasa KOHTpojiHpyeMoro nOTOKa Ha norpeuiHOCTb aKycTtnecKoro aHeMorneTpa// *ropHbifi tw(/)opMaımeHO-ananumwwcKWî ômtJiemeHb.* -Moscow MSMU. JVüO. p. 181-182.

Shkundin S Z. & Kremleva O.A & Rumyantseva V.A. 2001. *TeopitH cikyamnecKoii aneMOMempuii.* Moscow H3H-BO «AKaaeMini ropm>i\ nayK»