Chapter 86

ELECTRONIC ANEMOMETRY - RECOMMENDED INSTRUMENTS & METHODS FOR ROUTINE MINE AIRFLOW MEASUREMENTS.

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ABSTRACT

Today there are numerous electronic rotating vane and thermal (hot-wire) anemometers, as well as vortex meters available to measure air velocity. Of these, a laboratory and field evaluation has found that certain instruments are better suited to routine airflow measurements in mine roadways and ventilation ducts. This paper concludes a study sponsored by the Atomic Energy Control Board of Canada, that was introduced at the 5th U.S. Symposium. The study investigated the suitability of currently available electronic anemometers as replacements for the traditional mechanical analog devices while maintaining standard methods such as the continuous traverse.

Six electronic instruments were subjected to extensive tests under controlled conditions both in a wind-tunnel and in the field at an underground mine. The evaluation concluded that ergonomics and design were major considerations in unit preference as most of the instruments had very similar performance characteristics. Specific findings were:

a) In the wind-tunnel the vane anemometers, especially the "micro" vanes, were more susceptible to misalignment or yaw effects but these were not noticeable in the field;
b) Both the vortex and hot-wire anemometers were suitable for continuous traverses of mine roadways;
c) Traversing ventilation ducts was more practical than a Pitot-tube multi-point assessments or discharge measurements;
d) Yaw is a major concern in duct measurements;
e) The continuous traversing method for roadways overestimates the average air velocity;
f) Hot-wire anemometers can require significant air density corrections; and
g) Hot-wire anemometers are better suited than rotating vanes to mine roadways of less than 1 m/s average air velocity.

Based on research detailed in this paper, the ventilation engineer should be able to match the mine's requirements with the presented instrument performance characteristics, thereby optimizing the purchase of a new anemometer and the efficiency with which air velocities are measured.

INTRODUCTION

CANMET has recently completed its evaluation of electronic instruments for routine airflow measurement in mines. This Atomic Energy Control Board (AECB), Canada, evaluation contract (Hardcastle, 1992) has been reported in-part previously:

1) Hardcastle et al (1991) reported at the 5th Symposium on the initial laboratory and mine roadway evaluation of rotating vane anemometers and a vortex-shedding air velocity meter.
2) Hardcastle et al (1992) additionally detailed the assessment of instruments for ventilation duct airflow measurements and also explored the use of hot-wire velocity meters for traversing.

This paper concludes the evaluation, it summarizes which electronic instruments were found most suitable and their optimum methodology for routine airflow in mines. The two primary types of airflow measurement are:

A) In mine roadways, as performed with a rotating vane anemometer and a vertical continuous traverse (Figure 1).
B) In auxiliary mine ventilation ducts which should be assessed with a Pitot-tube and manometer using a multi-point technique (Figure 2).

Historically, Airflow Developments' AM5000 and Davis's Biram Pattern rotating vane anemometers have been extensively used for mine roadway airflow measurement. Both are analog instruments with mechanical counters, as such they can be termed as "first" generation instruments. The AM5000 is no longer available and repair of existing units is limited. For duct flow measurement, Pitot-tubes are available from Dwyer and Airflow Developments, traditionally these have been combined with a Dwyer Magnehelic or other simple differential pressure device. Similar to the vane anemometers these are analog units.

Today micro-electronics and processor technology allows the production of what may be termed "third" generation instruments. The primary qualifier for this category is that the unit must have user-controlled measuring periods with time integration. Other attributes of today's units include memory functions, air density compensation and multi-sensor capacity. The following instruments qualify and may be used for traversing mine roadways or point analysis inside of ventilation ducts:

- Airdata ADM870, Shortridge Instruments U.S.A., a true density compensating electronic micromanometer/barometer.
- MPM500e, Solomat Instruments, U.K., a multi-functional rotating vane and thermal anemometer and differential pressure meter.
- Testo 4510/451/452, Testoterm, Germany, (Also marketed by Omega, U.S.A) a multi-functional meter as MPM500e.

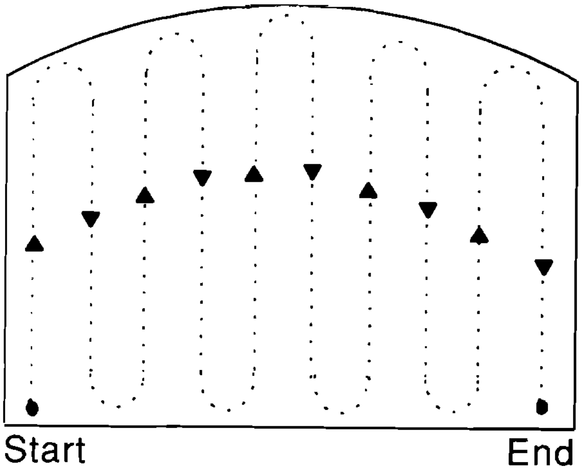

Figure 1. VERTICAL CONTINUOUS TRAVERSE

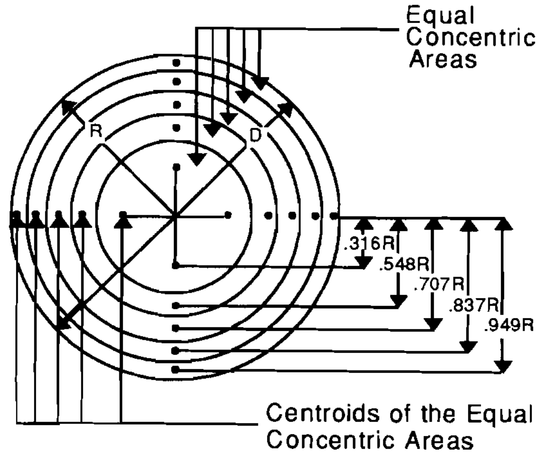

Figure 2. CIRCULAR DUCT POINT METHOD (AMCA, 1986)

- Climomaster 6511, Kanomax, Japan, a combined psychro/thermal anemometer.
- Tx5081, Trolex U.K., a single function vortex shedding air velocity meter.
- LCA6000VT(prototype), Airflow Developments, Canada, rotating vane anemometer.

Notably, the Testo units and the MPM500e employ "micro" vanes with a <25mm diameter impeller instead of the more traditional 100mm diameter.

LABORATORY INSTRUMENT ASSESSMENT

Initially some 46 different air velocity measuring devices were evaluated in a laboratory wind tunnel over a 0.3 to 30 m/s velocity range and assessed for misalignment tolerances. Instruments tested included: swing and rotating vane anemometers; hot-wire and vortex shedding air velocity meters; and Pitot and impact tubes with a variety of Magnehelics and electronic differential pressure cells. With the exception of swing vanes all the other instrument groups spanned "first" to "third" generation technology.

Linearity Calibration

The following points summarize the linearity calibration of the air velocity meters:

a) As a group of instruments, swing vane anemometers (Velometers, by Alnor) and their various probes, were the least consistent of the instrument types tested.
b) Electronic rotating vane anemometers with induction sensors provide a "truer" air velocity result than the mechanical linkage analog units: this was typified by near unity gradients and small constants in the electronic units' linear calibrations. It is also a function of manufacturers over-rating the gearing of the analog units to compensate for friction. One electronic exception to this was the MPM500e rotating vane.
c) Certain hot-wire anemometers have relatively low upper velocity limits, e.g. Alnor 8525 at 10m/s and MPM500e at 15m/s. These limits are a function of maintaining a temperature differential between the unit's hot and cold junctions, it is also suspected that these upper limits may reduce with a deteriorating battery.
d) Vortex shedding air velocity meters were not linear at <1.2m/s although responding from 0.3m/s.
e) Hot-wire anemometers were the most sensitive at low air velocities, however the Testo "micro" vanes and a good condition ball-bearing Davis rotating vane were suitable from 0.3m/s.
f) The accuracy and sensitivity of the Pitot/manometer combinations are primarily a function of the manometer sensitivity. Hand-held digital manometers with 0.1Pa resolution are readily available and facilitate air velocity measurement from 0.3m/s with a 7mm diameter Pitot tube.
g) Digital manometers are superior to Magnehelics as the sensitivity of the latter decreases as its range increases. Digital units can be multi-range and have up to a 5 character LCD display.
h) Of the classes of instruments tested, the results from the rotating and swing vane anemometers and the vortex shedding air velocity meter are independent of air density. Hot-wire anemometers and Pitot/manometer results require correction for ambient density conditions. Typically the hot-wire and the manometers quoting air velocities assume a standard air density in their internal calculations. The only exception found to this is the ADM870 which can derive the ambient air density with its barometric pressure and temperature sensors.

Misalignment Characteristics

Figures 3&4 summarize the misalignment or "yaw" tolerances of the various types of air velocity meter with the exception of velometers. Figure 3 details the yaw characteristics of the more traditional instruments, namely a Pitot-tube and mechanical analog rotating vane anemometers. The only non-symmetrical profile is that of the AM5000 which is affected by the off-centre location of the counter behind the impeller. Figure 4 describes the yaw characteristics of two "micro" rotating vanes, the vortex shedding meter and a hot-wire anemometer. Both the "micro" vanes show severe and non-symmetrical yaw affects, the Tx5081 vortex unit displayed a greater tolerance to yaw within ±25° and symmetry, but the hot-wire anemometers were most tolerant to yaw. The Climomaster 6511 was the most tolerant hot-wire anemometer as evidenced by its near horizontal response, for others such as the Alnor 8525 the horizontal zone only extended to ±30°; the width of this zone is a function of the shrouding around the flow sensor. Several electronic rotating vane anemometers with more conventional size sensing heads, i.e.

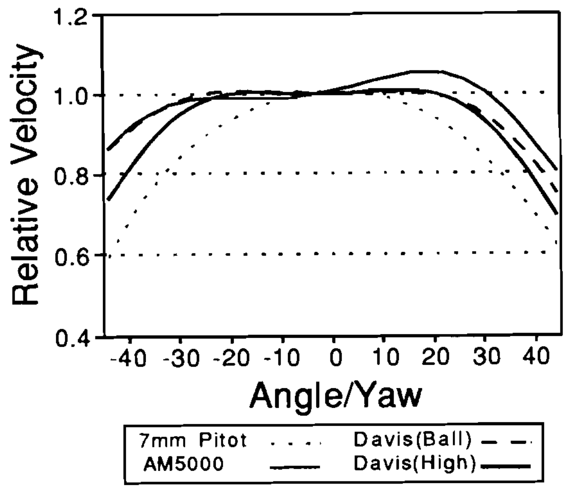

Figure 3. YAW OF TRADITIONAL AIR VELOCITY MEASURING DEVICES

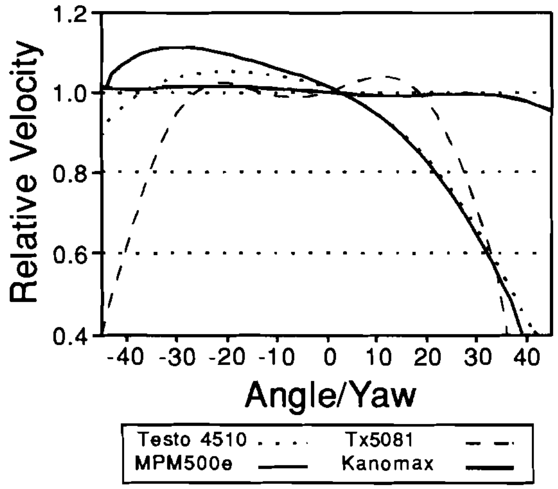

Figure 4. YAW OF "THIRD" GENERATION ELECTRONIC AIR VELOCITY MEASURING DEVICES.

100mm diameter, were also assessed; they displayed symmetrical yaw characteristics similar to the Davis units (Figure 3).

FIELD TESTING OF INSTRUMENTS

A total of 15 instruments were carried forward into the underground uranium mine tests. These included traditional analog instruments (e.g. Davis & AM5000 rotating vanes) and the third generation instruments listed earlier. The field testing of the instruments comprised both mine roadway and auxiliary ventilation duct airflow measurements.

Mine Roadway Airflows

Four mine roadways with average velocities ranging from 0.32m/s to 8.2m/s were used to assess the instruments. For reference a multi-point analysis was used to derive the true flow at each section and the consistency of the flow monitored with a continuously recording anemometer. Figure 5 depicts the roadway profile and velocity contours at such a survey station. Note, a regular spaced measurement point array and using computer mapping software was found to be more expedient than using the British/European standard prescribed log Tchebycheff distribution (BSI, 1980). Computer mapping software can provide the area of the roadway, the average flow and detail the velocity profile along the continuous traverse route as shown in Figure 6.

Overall, the tests at the four locations indicated that all the instruments gave comparable results when using a vertical continuous traverse providing that their operational limits were observed. Specific points to note are:

1) The Climomaster 6511 hot-wire anemometer and the TX5081 vortex meter were proven to be suitable for traversing mine roadways. No significant differences were observed with these instruments at lateral traversing velocities of 0.2,0.4 & 0.6 m/s.
2) The yaw intolerance of the "micro" rotating vanes established in the laboratory did not appear to be significant in their field usage.
3) It should be emphasized that the lower operational limit has to be significantly below the average air velocity of the roadway to ensure a representative result. This limits the use of certain instruments, for example only hot-wire units such as the Climomaster 6511 should be considered for roadways with air velocities <1m/s.
4) During the four tests, the correction for non-standard air density conditions were significant for the hot-wire units with 0.93 to 0.98 correction factors having to be applied to observed velocities. In comparison, 0.96 and 0.99 factors respectively, only applied to the calibration correction for rotating vane anemometers.

As a method, the vertical continuous traverse with any of the instruments was shown to inexplicably but linearly overestimate compared to the average flow obtained from the contour profile. Theoretically the traverse route was shown as representative of the profile by the computer simulated traverse. Also the validity of the profile method was confirmed by tracer gas techniques where they could be applied.

Various other traversing methods were investigated as well as operator positioning, such as traversing each half of the roadway independently or centre-line traverses of horizontal elements. Similar to the instrument comparison, there was little to distinguish between the results of the different traversing methods tested. With respect to instrument operator location, comparisons were made between the operator being >2m down or upstream of the instrument with being immediately downstream of the measurement plane but laterally >2m away from the instrument. Generally, trying to remove the operator up or downstream was impractical:

A) using a rigid elbow to orientate the instrument on the end of extension rods increasingly introduced yaw as the instrument is traversed to the walls, floor or roof.
B) use of a flexible elbow suspending the instrument off the end of extension rods allows the airstream itself to yaw the instrument.

In certain mines a single centre-point measurement and application of a correction factor has been observed to determine the average velocity. This evaluation has shown that method to overestimate even in excess of the continuous traverse.

The influence of instrument traversing speed was also assessed with respect to the continuous traverse. Three speeds were tested 0.2, 0.4 and 0.6 m/s without any distinct trend

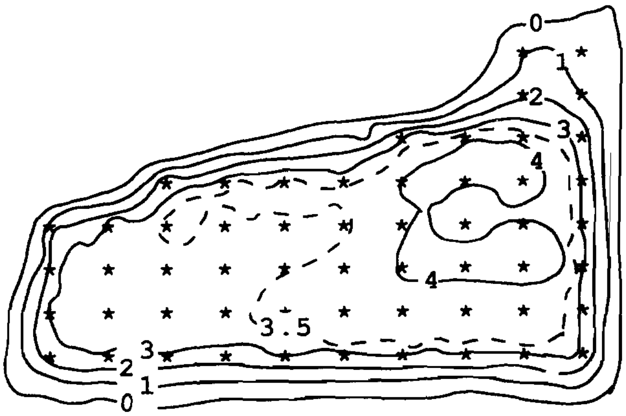

Figure 5. A TEST AIRWAY PROFILE AND ITS VELOCITY CONTOURS

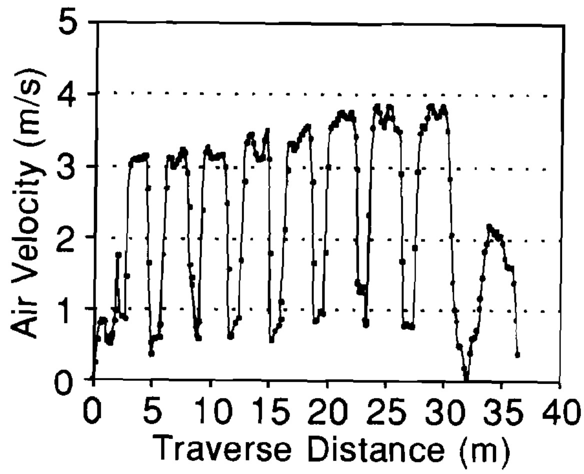

Figure 6. VELOCITY PROFILE ALONG THE CONTINUOUS TRAVERSE PATH OF THE EXAMPLE AIRWAY

occurring. The differences between observed velocities at these traversing speeds were rarely greater than 5% which is the acceptance limit of individual results taken under repeated conditions. Therefore selecting a traverse speed is more a matter of operator comfort and during these evaluations the 0.4m/s speed was found to be the optimum.

At this time it is suggested that underground mines continue to use the vertical continuous traverse for routine measurements despite its overestimation as a multi-point profile method is too time consuming. The continuous traverse samples the whole roadway cross-section and can be performed relatively quickly. The method shows good repeatability and linear relationship with more detailed methods.

Auxiliary Ventilation Ducts

A primary concern for the determination of mine duct airflows, is the measurement location. Ideally one would like to know the volume at or close to the duct's discharge. However, at such a location the measurements values can become uncertain because of:

a) an exhaust restriction of the duct to pressurize the final section and minimize flapping of the duct,
b) the flapping itself, and
c) holes in the duct that create irregular velocity profiles.

It is recommended that the measurement location be in a "good" section of duct that is stable and free of bends and holes. In certain situations this will require the operator to retreat from the discharge duct section.

A suitable measurement location was found in each of two 0.9m diameter auxiliary ventilation ducts to evaluate "third" generation instruments. The average air velocity at these locations were ≈12 & 15 m/s. The reference flow at each location was established using the self compensating Airdata ADM870 and a 7mm diameter Pitot-tube and a 10 point traverse of two diameters, similar to Figure 2. The evaluation showed that whether the points were defined by an equal area or log linear rule was insignificant and whether the results were combined through an arithmetic average or Radius.Velocity analysis (Schmitz and Drummond, 1982) was also negligible.

Both the Testo 4510/451/452 units with their 25mm diameter rotating vane and the Climomaster 6511 were deemed as possible alternatives to a Pitot-tube because they could be inserted through a small hole in the duct. Tests subsequently showed that both instruments were suitable replacements of the Pitot/manometer combination. Neither the rotating vane or thermal probe belonging to the MPM500e had sufficiently long telescopic extensions to span the tested ducts. Traditional size vane anemometers and the Tx5081 were discounted because of the size of hole required to be made in the duct for their insertion and the space they occupy in the duct's cross section.

The main disadvantage of the multi-point analysis across the diameter of the ducts is that it is time consuming. Therefore the study also investigated the validity of a centre-point with correction factor and evaluated taking a continuous traverse of the duct for 1 minute, at a 0.15m/s traversing speed, across the same diameters. The centre-point analysis indicated that the correction factor varied between 0.84 and 0.9. The duct continuous traverse typically agreed within 5% of the multi-point analysis.

Where a well established velocity profile can be assumed the study has confirmed that a centre-point measurement with correction is valid for ventilation ducts. However, when the condition of the velocity profile is in doubt a continuous traverse of two diameters of the duct is suggested as it more likely to include any profile anomalies and is hence more representative of the flow in that section. The Testo "micro" vanes and the Climomaster 6511 are just as suitable for traversing ducts as they were for roadways, however each has a disadvantage:

1) Yaw is difficult to control for the "micro" vanes as the instrument head is hidden inside the duct.
2) The Climomaster 6511 again required a significant air density correction factor, 0.93, applied to the observed velocity.

The study also evaluated measuring the velocity with a single centre-point at the duct discharge, and either a centre-point or continuous traverse of only one diameter in the last section of ducting through an existing hole in the duct. At this time the study also included the traditional 100mm diameter rotating vane anemometers. Neither of these locations and methods, nor the large rotating vane anemometers provided acceptable results. For example in one duct evaluation:

A) At the constricted exhaust of the duct the maximum expected centre-point velocity was 16m/s, however the instruments tested displayed velocities ranging from 13.7m/s to 21.8m/s.
B) In last section of the duct the maximum expected centre-point velocity was 13m/s yet the instrumentation measured velocities ranging from 13m/s up to 15.6m/s.
C) The maximum expected traverse velocity for the last section of the duct was 11.8m/s but the instrumentation showed air velocities from 11.6m/s through to 14.2m/s.

This demonstrates that selection of a suitable measurement location is paramount to obtain results with high degrees of confidence. In this instance it was necessary to measure the airflow ≈75m back from the duct discharge because of leaks, bends and duct movement beyond that point. At this location the standard errors in the air velocity were ±4%, as compared to ±8% in the last section of the duct and ±18% at the discharge.

For ventilation duct airflow assessment, the operator has the option of continuing with the traditional multi-point Pitot/manometer analysis. However, to reduce the number of instruments he is required to carry, the hot-wire and "micro" vane anemometers used for roadways have been shown as equivalent instruments. To reduce the time necessary to perform a duct measurement the operator may want to consider a continuous traverse rather than the multi-point methodology.

INSTRUMENT ERGONOMICS

Through the laboratory and field evaluations it became apparent that instrument ergonomics are a major factor in instrument selection. The relative advantages and disadvantages of the six "third" generation instruments listed at the outset are discussed individually.

Airdata ADM870 Micromanometer

This is a primary accuracy instrument traceable to national standards. It proved to be the optimum electronic manometer if one wishes to perform the traditional Pitot-tube assessment of mine ventilation ducts. Combined within the instrument are temperature and barometric pressure sensors which permit self compensation for ambient air density. In this study correction factors ranging from 0.97 to 1.06 had been automatically applied. The ADM870 is self-zeroing and has averaging capabilities; this latter option removes any operator bias but it requires several keystrokes to initiate. The self-zeroing ability is far superior to an external manual zero of other electronic manometers tested.

The main disadvantage for the ADM870 is not a function of the instrument but rather time consuming measurement methodologies. However, unless some of its other features are desired at $5000(Can) it is expensive compared to other instrument options.

Solomat MPM500e

All three of this instrument's options for airflow measurement, "micro" vane, hot-wire and electronic manometer, were tested during this investigation. The manometer was only tested in the laboratory as it was found that the external zero adjustment could easily be moved accidentally to an unknown degree invalidating the pressure cells laboratory calibration. The hot-wire was also only tested in the laboratory as it was unavailable for the mine roadway tests and its extendible sensing head was too short for the duct tests plus the duct air velocities were close to the upper limit of the probe. The "micro" vane was used in the field and the following disadvantages were noted:

1) Limiting yaw for this unit's 14mm diameter vane was more difficult than for the Testo 25mm vane.
2) The instrument body is ill-suited for one-hand operation, it is ill-balanced, relatively heavy and has a poorly located recessed tactile keyboard.
3) The instrument also employs stiff cabling between the body and sensor which proved to be awkward.

Testoterm 4510

The Testo 4510 and the Climomaster 6511 were the most easiest to use. The Testo 4510 has subsequently been replaced by the Testo 451 & 452 upgrades. The Testo instrument body is well designed: it is light, fits in the user's palm and has good tactile key location for one-hand operation. An attractive feature of this unit is the stop-watch display of the averaging mode. As with the MPM500e yaw with the "micro" vanes may be a concern but this can be averted by using the optional 100mm diameter vane of the Testo 451 & 452 for roadway air velocity measurements. In ducts the unit's hot-wire probes may be an option. This investigation was limited to testing only the 25mm "micro" vane.

Kanomax Climomaster 6511

This hot-wire air velocity meter was very easy to use. For in-hand comfort it is second to the Testo units but is still well designed with respect to weight, balance and key placement. Compared to the Testo units and the MPM500e, it also has a slightly inferior averaging function requiring complex keystroking. It also has a smaller stop-watch counter display than the Tx5081 and Testo units.

Trolex Tx5081

One notable advantage of this unit over the other electronic instruments is its intrinsic safety certification. The unit also has a large stop-watch display. However the Tx5081 was noted to have the following drawbacks:

a) The rigid membrane keyboard resulted in the operator lacking confidence that keys had been depressed.
b) The instrument body was also slightly wider than other instruments hampering one-hand operation.
c) The most serious problem of the unit was the weight of the unit's sensing head when attached to long extension poles which created problems when traversing roadways of large cross section.

Airflow Development's LCA6000VT (prototype)

This instrument splits the conventional LCA6000VT into two parts through using a detachable 100mm diameter rotating vane that can be mounted on extension poles. This instrument proved to be very easy to use in mine roadways and with minor modifications to the processing logic could be the most economic choice.

CONCLUSIONS

The overall investigation of mine airflow measurement has shown that:

a) A continuous traverse is still the most expedient method to assess the flow in mine roadways despite overestimating.
b) Rotating vane, hot-wire, and vortex shedding principle instruments can all be used for traversing provided they have user-controlled time integration.
c) The average velocity in an airway must be significantly greater than an instrument's low velocity linearity limit. This limits the number of instruments suitable for airways with average velocity <1m/s.
d) For mine ventilation ducts, it has been shown that "micro" rotating vanes and hot-wire units may replace the traditional Pitot/manometer combination.
e) Also for ducts, a continuous traverse of two diameters has been shown to be as accurate as multi-point techniques but more importantly much quicker.
f) Centre-point measurements either in roadways or at duct discharges should be discouraged.

With respect to instrument selection, providing the operational limits of each was observed there was little difference in the results to justify the selection of one unit over another. However points to consider for those commercially available are:

1) For ergonomics the Testo units and the Climomaster 6511 were the easiest and most convenient to operate.
2) Hot-wire anemometers are better suited to low average air velocity airways i.e below 1m/s.
3) Hot-wire anemometers can require significant air density correction to their observed value.
4) Electronic rotating vane anemometers provide a "truer" observed result than the traditional mechanical linkage instruments.
5) "Micro" vanes were shown in the laboratory to be more sensitive to yaw induced effects, however in the field with care they did not materialize.

ACKNOWLEDGEMENTS

The authors would like to thank the AECB, Canada for supporting this evaluation. Appreciation is also extended to Denison Mines Ltd. and Rio Algom Ltd. of Elliot Lake for supplying underground tests sites and to the numerous mining companies, equipment manufacturers, government agencies and universities that loaned CANMET their instruments.

DISCLAIMER

The views expressed and conclusions drawn in this paper are the sole responsibility of the authors they do not necessarily reflect the opinions of the AECB for whom this work was conducted.

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