Chapter 60

ELECTRONIC VANE ANEMOMETRY
FINDING A SUITABLE REPLACEMENT OF MECHANICAL ANALOG DEVICES FOR MINE AIRFLOW ASSESSMENT

by

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Abstract. The most common method of determining airflow employed by mine ventilation engineers is the product of i) the average air velocity as measured by a vane anemometer and stopwatch through a continuous traversing technique, with ii) the cross-sectional area of the roadway. This method requires the vane anemometer to accumulate the total flow over the duration of the traverse. Historically, this has been facilitated by a mechanical analog instrument that has either a counter or set of dials that display the flow. Common instruments of this type are Airflow Development's AM5000, Davis's, or Taylor's Biram type anemometer. The AM5000 is widely used in the Canadian mining industry but is no longer available. Therefore, regulatory authorities have seen fit to evaluate presently available commercial instruments to replace the AM5000. This paper describes an instrument evaluation contracted by the Atomic Energy Control Board of Canada which regulates the uranium industry.

Over the last two decades there have been numerous advances in the development of electronic air velocity meters. Currently available units have the following features: a) battery operation; b) are compact and can be hand-held; c) employ LCD's, and microelectronic circuitry; and d) provide a time integration for the duration of a traverse. These features make such instruments a possible replacement to the analog units and stopwatch determinations.

This paper details five of the new generation of vane anemometers plus a vortex air meter, and it explores their limitations in comparison to analog units. Specific consideration is given to linear response, the effects of yaw, traversing speeds and ergonomics relating to both handling and use. The paper concludes with some features that are attractive and should be considered when purchasing a new anemometer.

INTRODUCTION

The accurate measurement of air volumes is essential to environmental control in the mining industry. The air volume alone defines the degree of dilution and final concentration of a pollutant. One of the most common methods employed by mine ventilation engineers to determine airflow is through the product of the average air velocity and the cross-sectional area of the air passage.

Typically, the mine ventilation engineer has obtained the average air velocity with a time integrating vane anemometer and a stopwatch. These are employed over a continuous traverse of the airway using one of the many recommended methods (Figure 1). The traverse methods include a continuous sweep either horizontally or vertically, partial sweeps of each half of an airway, or numerous partial sweeps of a further subdivided airway (i.e. 3 x 3 or greater). The research detailed in this paper used the vertical traverse technique.

The most common method of determining the cross-sectional area of the air passage is through horizontal and vertical taped linear measurements. These may be reduced into average dimensions or parameters of regular shapes to produce an area. Alternatively the dimensions could be used to draw a plan of the section and the area determined through planimetry, weighing, or surveying computer software. In this evaluation of anemometers, the cross-sectional area is obtained through two methods both using horizontal and vertical taped measurements; plotting the profile on graph paper and weighing both it and a standard area of the same paper, using a surface plotting computer program to calculate the area.

Historically, the type of vane anemometer employed would be an analog device with either a counter, or set of dials to give accumulated meterage or footage for an independently measured timespan. Common trade names of such instruments that have been used for decades are: the AM5000 by Airflow Developments, U.K. (Figure 2); and, the Biram's pattern type meter by Davis (Figure 3) or Taylor, U.S.A.

In the Canadian mining industry, the AM5000 could be defined as the standard. Unfortunately, it will become obsolete in the very near future as it can no longer be purchased or repaired. As a result of this, Canadian regulatory authorities are seeking a new standard instrument for the mining industry they oversee. It is one such body, the Atomic Energy Control Board (AECB) of Canada, which

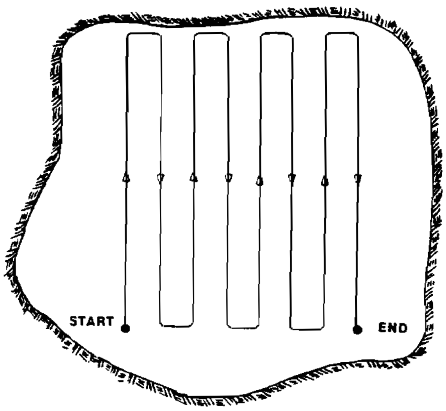

Figure 1a. Full vertical traverse.

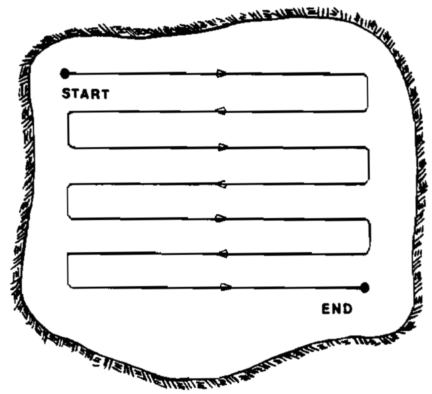

Figure 1b. Full horizontal traverse.

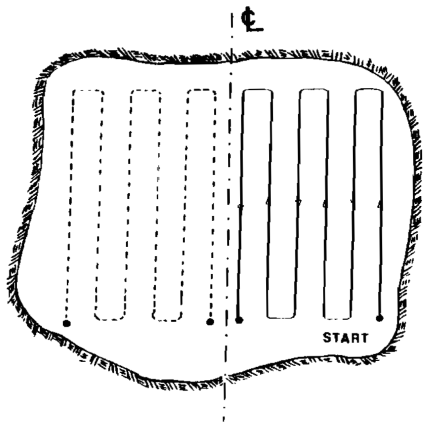

Figure 1c. Half-airway vertical traverse.

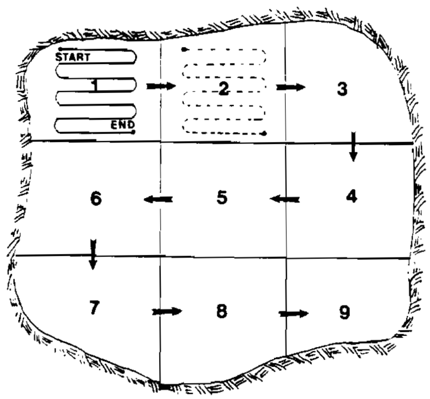

Figure 1d. Full-airway partial traverse.

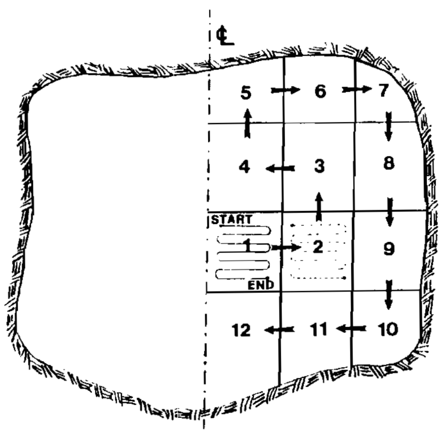

Figure 1e. Half-airway partial traverse.

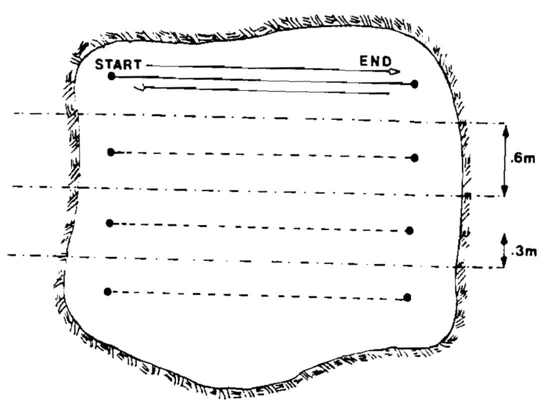

Figure 1f. Horizontal element traverse.

Figure 1. Recommended continuous traversing modes.

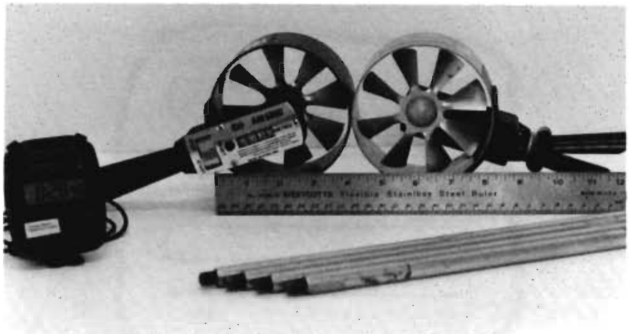

Figure 2. Airflow developments AM5000 analog anemometer.

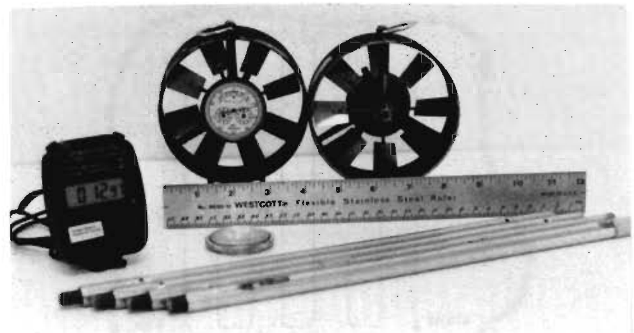

Figure 3. Davis Biram type analog anemometer.

regulates the uranium mining industry, that has contracted the research to find an alternative instrument which is documented in this paper.

It is not the objective of this paper to specify whether, the continuous traverse technique is the most accurate method of determining the airflow. Rather, this method has been assumed as the most common in one form or another. It can be performed quickly, easily and will probably prevail as long as time integrating units are available. Therefore, all instrumentation have been evaluated by this technique. However, attention has been given to the historical concerns of traversing speed and alignment of the instruments in the airstream.

Other aspects included in the evaluation of the instruments are the linearity of response, range of measurement, ergonomics, data reduction, associated functions and cost.

The following section describes the basic vane anemometer and its development to the present day. As far as possible the authors have evaluated the most common versions of each manufacturer's product line.

DEVELOPMENT OF THE VANE ANEMOMETER

The vane anemometer is a direct method of measuring air velocity, it utilizes the kinetic energy of an airstream to drive its windmill like impeller. The rotation of the impeller blade is proportional to the air velocity and translation of the impeller rotation speed will give a measure of the air velocity. During the last two decades there have been various stages of development each introducing the latest technology of the time up to the present day with with the inclusion of micro-electronics and processors.

First Generation Vane Anemometers

The AM5000 and Biram type meters are representative of the first generation of vane anemometers. In these the impeller rotation is translated through a direct mechanical linkage to a gearing mechanism which drives a cumulative counter or series of needle dial gauges. The most common head diameter of this device is 100 mm (4"), as can be seen in Figures 2 and 3, they can be used with extension poles and require a stopwatch to time the counting period of the meter. This direct linkage type of device has clutch and reset mechanisms for starting, stopping and resetting the meter.

Certain precautions are necessary with the use of direct linkage meters, friction in bearings and the gearing linkage should be considered at low velocities. Although friction can be reduced with the likes of jewelled bearings, these may deteriorate with long term exposure to dust and gases or operating the meter beyond its upper limit so causing frictional heat damage. In order to compensate for friction some manufacturer overrate the gearing mechanism.

Second Generation Vane Anemometers

The second generation of vane meter employs a capacitance or inductive sensor to detect the rotation of the impeller. This type has no direct coupling and should be less prone to friction both on start-up and during running. The sensor transmits an electronic signal and the frequency of these signals is proportional to the air velocity. Simple circuitry can convert the signal frequency directly into a velocity on an analog calibrated voltmeter scale. Such an instrument, shown connected to a datalogger, in Figure 4, is the Edra5, by Airflow Developments, U.K.

This type of meter is not suitable for performing traverses as it has no time integrating capacity (with the exception of using an external datalogger with a high sampling rate).

A further advancement of this generation of instrument was the replacement of the voltmeter with a digital LCD display. Figure 5 displays the DA4000, (also marketed as the HH30 by Omega, U.S.A.), that will average only over a 2 or 16 second timespan. Other similar instruments are Airflow Development's LCA6000 and DVA30, which are lower grade units of those in Figures 6 and 7.

Although the LCA6000 was designed to replace the AM5000, similar to the calibrated voltmeter, it and other early digital vane anemometers are not suited to performing continuous traverses.

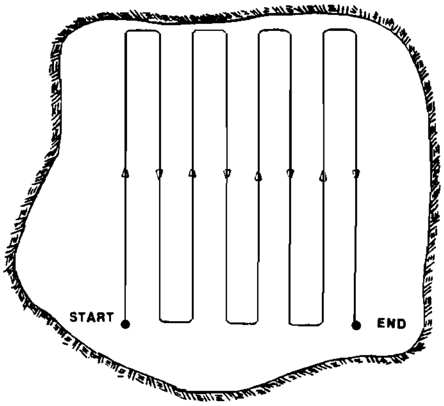

Figure 1a. Full vertical traverse.

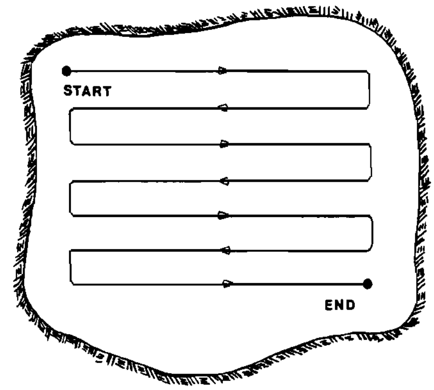

Figure 1b. Full horizontal traverse.

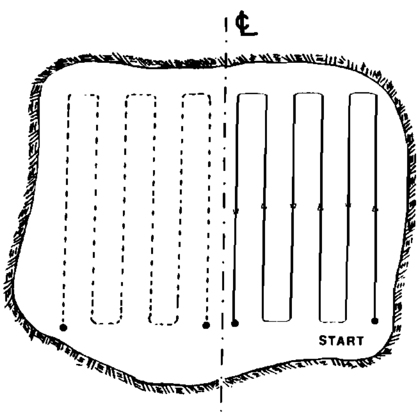

Figure 1c. Half-airway vertical traverse.

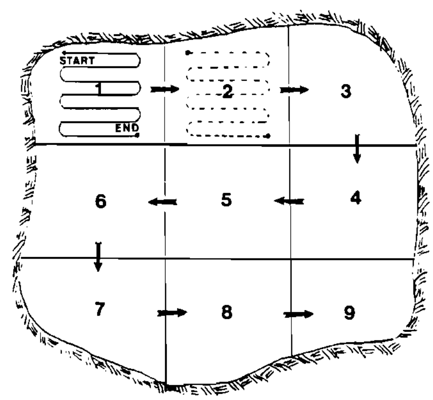

Figure 1d. Full-airway partial traverse.

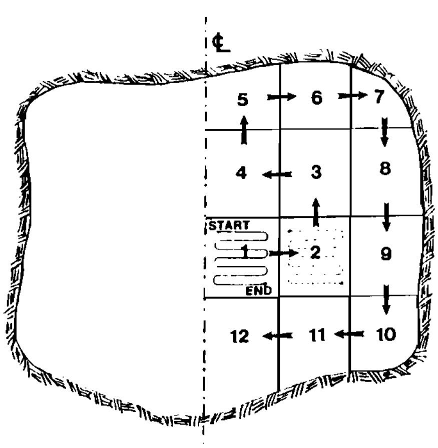

Figure 1e. Half-airway partial traverse.

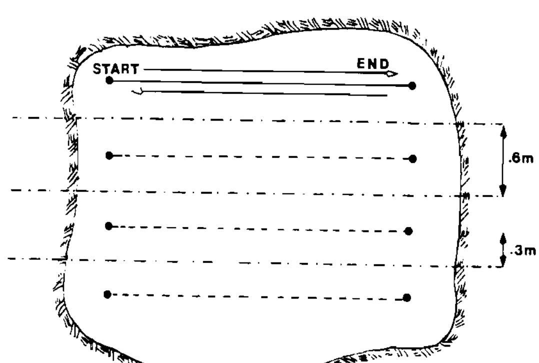

Figure 1f. Horizontal element traverse.

Figure 1. Recommended continuous traversing modes.

Figure 4. Airflow's Edra5 anemometer and data-logging station.

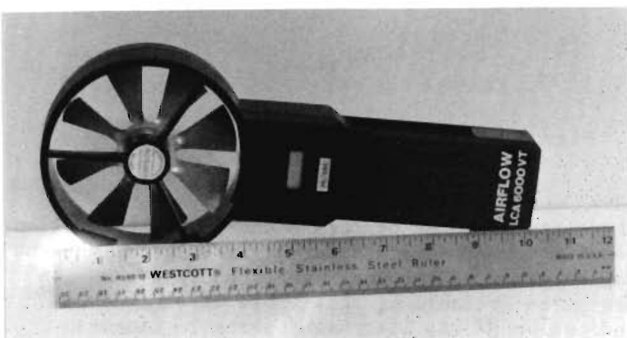

Figure 6. Airflow's LCA6000VT hand-held digital anemometer.

Third Generation Vane Anemometers

It is probably over the last five years that a third generation of vane anemometers have become available. These units have user controlled variable time bases and microprocessor circuitry to calculate the time weighted average over a traverse. Similar to the second generation they use capacitance or inductive sensors.

Some of the third generation meters maintain the traditional large diameter head (100 mm, 4"), but other developments have introduced "micro" heads that range from 24 down to 12 mm (1 to 0.5"). Although such units look appealing, little information is available on their performance characteristics beyond the manufacturer supplied operating range and linearity. Prior to their general acceptance they should be evaluated alongside the first generation instruments which are still widely used in industry. Specific concern is given to their operational range, linear range, effects of misalignment, and influence of traversing speed.

The third generation of vane anemometers selected for evaluation include the following:

1) LCA6000VT, Airflow Developments, Figure 6;
2) DVA30VT, Airflow Developments, Figure 7;
3) MPM500e, Solomat, U.S.A. & U.K., Figure 8;
4) 4510, Testoterm, Germany, Figure 9, this unit is also marketed as HHF451, Omega, U.S.A.

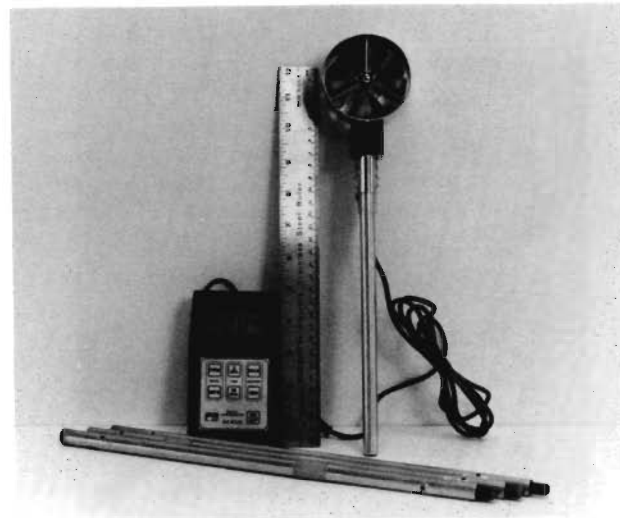

Figure 5. The DA4000 digital anemometer.

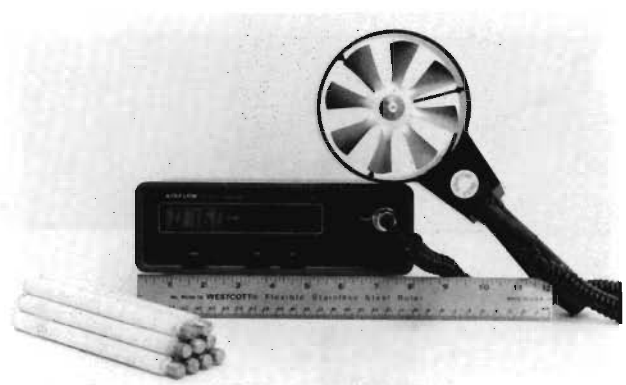

Figure 7. Airflow's DVA30VT digital anemometer (100 mm head).

Of these four units, the DVA30VT has two interchangeable heads 100 and 35 mm (4 & 1.4") diameter, and the 4510 has three interchangeable heads 25, 16 and 12 mm (1, 0.6 and 0.5") diameter. Of these, only the 100 and 25 mm heads were available for the full set of evaluation tests and the 35 mm head for laboratory testing.

These units are compared against two AM5000s and two Davis vane anemometers.

Other Technologies for Air Velocity Measurement

The most common other type of air velocity meters are generally termed "thermal" anemometers, however these are also only suited to spot measurements and not continuous traverses. Therefore, they are not considered in this evaluation.

Another technology meter quoted as suitable for velocity traverses is the TX5081 vortex shedding meter, Trolex, U.K., Figure 10. This unit is very similar to the J-Tec VP100 velocity meter, but

Figure 8. Solomat's MPM500e digital "micro" vane anemometer.

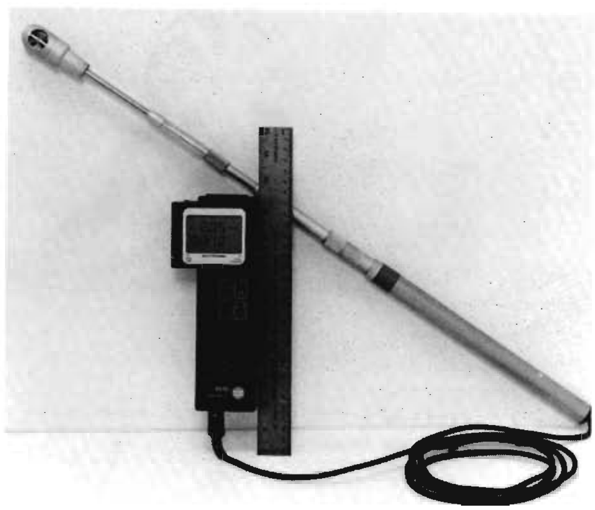

Figure 9. Testoterm's 4510 digital "micro" vane anemometer.

Figure 10. Trolex's TX5081 vortex shedding velocity meter.

includes a time weighted averaging function whereas the VP100 was only a spot reading unit. The principle of both of these units is the same. A strut facing the airstream generates vortices that pass through an ultrasonic detector. The detector measures the frequency of the vortices which is proportional to the air velocity and converts it into a linear output signal.

The TX5081 is also included in the subsequent anemometer evaluation.

LABORATORY ANEMOMETER EVALUATION

The laboratory evaluations of seven different anemometers were performed in a wind tunnel. This facility permitted two velocity range calibrations in different sections of the tunnel, and two misalignment (yaw) analyses in each section. All the tests could be performed under well controlled conditions. The manufacturer's specifications and capabilities of the instruments under evaluation are given in Table 1, this table also gives an indication of the instrument price in Canadian funds.

Velocity Calibration

Where possible, each unit underwent two twelve point velocity calibrations, these were a low range, 0.3 - 3.7 m/s (60 - 700 fpm) and a medium range, 1.5 - 18 m/s (220 - 3500 fpm). In each instance the true air velocity was calculated with either a standard Pitot tube or static tube and a digital micromanometer (0.01 Pa resolution). The static tube was employed at the low air velocities <1 m/s (200 fpm).

The results of the calibrations are shown in Table 2, these include the calibration density, linear calibration parameters for each velocity range, the observed operational range and the units linear range. Table 2 shows each unit to give a very linear response for most of the tested range, this is demonstrated by the regression's standard errors and correlation data. Also, most instruments showed reasonable agreement between the two linear calibrations, the only exceptions were the MPM500e and the TX5081. In most cases the instruments met the manufacturer's specifications.

The TX5081 has the lowest regression correlation coefficient (R^2) at 0.996, and some of the largest standard errors. This unit also appeared not to operate linearly to manufacturer's low velocity specifications. Although it operated from 0.3 m/s (60 fpm), a linear response was not obtained until 1.2 - 1.5 m/s (230 - 290 fpm).

In all the other units, the linear range corresponded to the measured range. Other units that failed to reach manufacturer's lowest velocity

Table 1. Manufacturer's specifications and capabilities of instruments selected for evaluation.

Anemometer	Range m/s,(fpm)	Resolution m/s,(fpm)	Accuracy	Head Size mm,(")	Body Size	D/A	PH	PS	MEM	AVG	TH	TS	MEM	AVG	Weight kg,(lb)	Price $(Can)
AM5000	0.2-30 (50-6,000)	1.0 (1.0)	±2% fsd	110 (4.3)	N/A	A	X	X			X	X				N/A
Davis Low Speed	0.2-25 (30-5,000)	0.01 (1.0)	±1%	76 & 100 (3.0 & 4.0)	N/A	A	X	·X			X	X			0.9 (2.0)	700
LCA6000VT	0.2-30 (50-6,000)	0.1 (1.0)	±2% fsd	110 (4.3)	110x40x265 (4.3x1.6x10.4)	D	X			X	X			X	0.3 (0.6)	1050
DVA30VT	0.2-30 (50-6,000)	0.01 (1.0)	<1% fsd	35 & 100 (1.4 & 4.0)	245x130x190 (9.6x5.1x7.5)	D	X	X		X	X	X		X	2.0 (4.5)	1800 (inc. 2 heads)
MPM500e	1.0-40 (200-7,800)	0.01 (1.0)	0.05% fsd	16 (0.6)	95x50x255 (3.7x2x10)	D	X	X	X	X	X	X	X	X	0.6 (1.2)	1800 to 2000
4510	0.4-41 (80-8,000)	0.01 (1.0)	1% ±1 digit	12, 16 & 25 (1.0,0.6,0.5)	85x45x200 (3.3x1.8x7.9)	D	X	X	X	X	X	X	X	X	0.3 (0.7)	1000 +650/hd
TX5081	0.3-30 (60-6,000)	0.01 (1.0)	±1% fsd	40 (1.6)	110x45x205 (4.3x1.8x8.1)	D	X	X	X	X	X	X	X	X	0.9 (2.0)	2400

Usage and Functions:

D/A - Digital or analog display
PS - Suitable for stick mounted point measurement
TS - Suitable for stick mounted continuous traverse
AVG - Calculates average
PH - Suitable for hand-held point measurement
TH - Suitable for hand-held continuous traverse
MEM - Stores measurements

Table 2. Laboratory velocity calibrations and operational range assessment.

Instrument	Velocity Range	Gradient	Linear Regression Parameters SE ±	Constant	SE ±	R^2	Calib. Density kg/m^3	Operat. Range m/s	Linear Range m/s	Design Range m/s
AM5000 #1	L	0.949	0.003	0.115	0.009	0.9999	1.137	0.6-18	0.6-15	0.2-30
	M	0.933	0.003	0.130	0.043	0.9999	1.123			
AM5000 #2	L	0.942	0.006	0.122	0.017	0.9997	1.129	0.9-18	0.9-18	0.2-30
	M	0.931	0.003	0.144	0.036	0.9999	1.129			
Davis #1	L	0.930	0.003	0.064	0.010	0.9999	1.129	0.3-18	0.3-18	0.2-25
	M	0.936	0.003	0.019	0.044	0.9999	1.121			
Davis #2	L	0.866	0.003	0.090	0.011	0.9999	1.130	0.3-18	0.3-18	0.2-25
	M	0.885	0.002	0.078	0.026	0.9999	1.119			
LCA6000VT	L	0.834	0.002	-0.024	0.007	0.9999	1.360	0.6-4	0.6-4	0.2-30
DVA30VT (100 mm)	L	0.961	0.002	-0.002	0.008	0.9999	1.149	0.6-18	0.6-18	0.2-30
DVA30VT (35 mm)	L	0.960 ·	0.002	0.058	0.009	0.9999	1.145	0.3-4	0.3-4	0.4-20
	M	0.974	0.001	0.049	0.014	0.9999	1.131			
MPM500e	L	0.817	0.008	0.368	0.026	0.9993	1.142	0.9-15	0.9-18	1-40
	M	0.917	0.008	0.280	0.117	0.9994	1.128			
4510	L	1.006	0.008	-0.062	0.022	0.9995	1.148	0.6-18	0.6-18	0.4-41
	M	1.043	0.001	-0.114	0.022	0.9999	1.320			
TX5081	L	0.858	0.011	0.123	0.022	0.9991	1.124	0.3-18	1.5-18	0.3-30
	M	1.040	0.021	-0.716	0.235	0.9966	1.420			

specifications were both the AM5000s, the LCA6000VT and the DVA30VT with the 100 mm head. Of these, one AM5000 was an old unit that had been extensively used, it needed velocities in excess of 0.6 - 0.9 m/s (120 - 180 fpm) to operate. The newer AM5000, and the other two units required velocities greater than 0.3 - 0.6 m/s (60 - 120 fpm) in order to operate.

In general, all these units could be used to measure velocities greater than 1 m/s (200 fpm), but only the Davis, and the DVA30VT with the 35 mm head could measure accurately down to 0.3 m/s (60 fpm) the lowest velocity tested. At this time the units have not been tested to the upper limit of their specifications.

Misalignment (Yaw) Analyses

Maintaining the correct alignment of the vane anemometer in the airstream is very important. To determine a unit's tolerances to misalignment, each unit was tested at four velocities 0.9, twice at 3.7 and at 7.4 m/s (180, 720 1440 fpm). At each speed the meter was rotated in ten steps to a maximum of 50 degrees with respect to the airstream. Each individual instrument showed consistent performance profiles at all evaluation speeds. Therefore, the results have been reduced to an average format. Also both pairs of Davis and AM5000 units demonstrated similar results and have been combined. The LCA6000VT and DVA30VT with 100 mm heads are effectively the same instrument and have also been combined. The profiles of velocity ratio against angle of yaw are depicted in Figures 11, 12 and 13. The velocity ratio is defined in equation 1,

$$\text{Velocity Ratio} = \frac{\text{Reading at yaw angle}}{\text{Reading at zero yaw angle}} \quad (1)$$

Common to each of these diagrams is the yaw profile of a standard Pitot tube, this was included to show that the airflow was near normal to the instruments at zero degrees. As the pitot profile is not completely symmetrical about zero, it indicates that the flow in the calibration tunnel has a lateral velocity component, this is also apparent in the TX5081 and Davis profiles.

In these figures the Pitot tube shows a near symmetrical profile dropping off rapidly with misalignment whereas some of the vane anemometers are less susceptible.

The only yaw profiles displaying some symmetry apart from the Pitot tube are the LCA6000VT/DVA30VT (100 mm) and the Davis, these anemometers have no major obstructions in their heads. The AM5000 shows a positive bias at positive angles, this may be the result of the counter stem being off-centre behind the blades (see Figure 2).

The remaining anemometers, the MPM500e, the 4510 and the DVA30VT (35 mm) all show a positive bias at negative angles and a negative bias at positive angles. The unit most affected is the MPM500e, then the 4510 and lastly the DVA30VT (35 mm). There seems to be no apparent reason for these abnormal

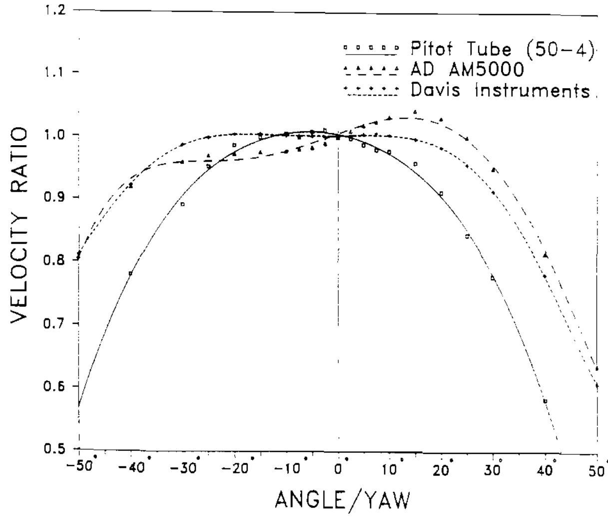

Figure 11. Yaw analyses of analog vane anemometers.

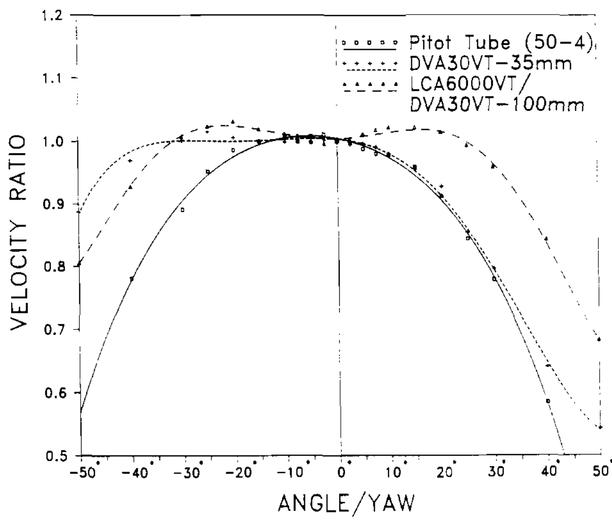

Figure 12. Yaw analyses of 35 and 100 mm head digital anemometers.

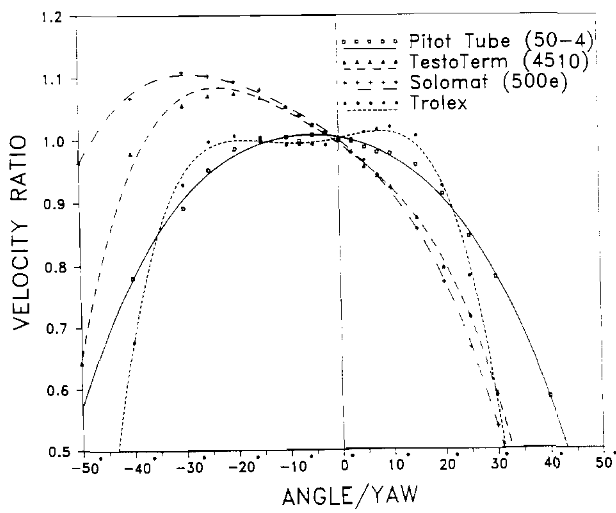

Figure 13. Yaw analyses of "micro" head digital anemometers and vortex air meter.

yaw profiles. Apart from head size, the only other difference between the other anemometers is the number of blades; four in the small units as opposed to eight in the large.

Generalized results of the yaw analyses are given in Table 3, which lists the average permissible yaw angle for each instrument for ± 2.5 and 5% tolerances. With the exception of the MPM500e, the 4510, and the AM5000e ± 2.5% can be achieved within ± 20 degrees, whereas, ± 5% can only be achieved at within ± 9 degrees for the "micro" head instruments.

Table 3. Summary of laboratory yaw evaluations.

Instrument	Average Yaw Tolerance on Velocity (°) ±2.5%	±5.0%
Pitot Tube	14.9	19.3
AM5000	8.9	33.2
Davis	25.3	30.6
DVA30 VT(35 mm)	21.0	26.5
LCA6000VT and DVA30VT (100 mm)	32.0	34.8
TX 5081	21.8	24.1
MPM500e	3.7	8.6
4510	4.2	8.6

FIELD ANEMOMETER EVALUATION

Field evaluation of the seven types of anemometer consisted of two parts; firstly, a standard traverse of all instruments at 0.4 m/s (80 fpm), and secondly, a comparison of selected instruments at traversing speeds of 0.2, 0.4 and 0.6 m/s (40, 80, 120 fpm).

These field evaluations were performed underground in a uranium mine. This mine typically had large dimension airways with average air velocities ranging from 0.3 to 3 m/s (60 - 580 fpm). Three straight sections of airway, free of obstructions or changes in cross-section were selected to test the anemometers.

In association with the anemometer evaluations, various precautionary measures were employed to monitor air velocity, psychrometric properties of the air, and airflow for the duration of each evaluation.

The temporal consistency of the air velocity during each test was monitored with a continuous anemometer and datalogger at 1 second intervals. This system as well as a combined temperature/ humidity probe are shown in Figure 4. The barometric pressure was recorded at the beginning and end of each individual instrument test with a Negretti-Zambra precision barometer.

The air quantity was measured during each evaluation test series with an SF_6 tracer gas injection, the gas concentration was analyzed every 5 minutes on a portable gas chromatograph and its output converted to yield air flow velocity.

The spatial quality of the air velocity at each evaluation section was determined with spot velocity readings on a regular grid by a digital thermal anemometer. These velocities and their coordinates were entered into a topographical survey plotting program along with boundary (wall) locations. This program, through interpolation, was then able to derive the velocity contours at each test section and provide the average velocity for the whole cross-section.

The cross-sectional area at each survey location was determined from vertical and horizontal measurements taken at regular intervals across the floor and up the walls. These were taken with an electronic tape measure. The distances were plotted on graph paper and when the roadway outline was defined, the area was cut out and weighed in comparison to a standard area. The wall locations were also entered in the survey plotting program to provide the cross-sectional area of the roadway. The combination of average velocity and cross-sectional area obtained from this program also produced an average air quantity for the measurement station.

In order to maintain consistency in the operation of each anemometer and its traverse across the roadway, the following protocols were adopted. The roadway floor width was divided into ten, with the floor marked at the centre of each section. The length of a traverse vertically along each centre line and the width of roadway were summed to provide the total traverse length. Then, for each desired traversing speed, the times were calculated at which the anemometer should complete each vertical sweep. These times were monitored by one member of the survey team and transmitted to the anemometer operator to gauge the traverse speed.

The airway cross-sections and their velocity contours for the three test locations are shown in Figures 14, 15 and 16. Profiles of velocity, temperature, humidity and airflow derived from a continuous SF_6 injection as well as their relationship with vehicle movements are presented in Figure 17. The influence of vehicles is notable on both temperature and humidity, therefore, the corresponding airflow and air velocity readings were rejected from the average analysis.

Test Series #1

The results from the instrument evaluations using a 0.4 m/s traverse speed are listed in Table 4. No data is present in the table for the MPM500e as operational problems persisted throughout the field study due to low air velocity. At location #1 the DVA30VT was not available, and due to low air velocity only the Davis instrument would operate. At location #2 all the units performed, whereas at location #3 one of the AM5000's and the TX5081 failed to operate.

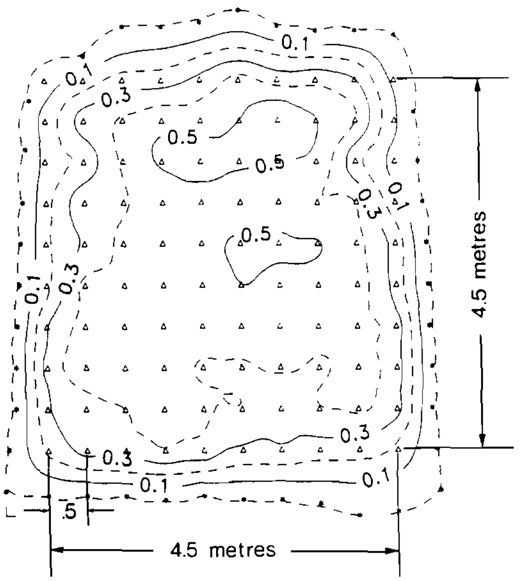

Figure 14. Roadway profile and velocity contours at location #1.

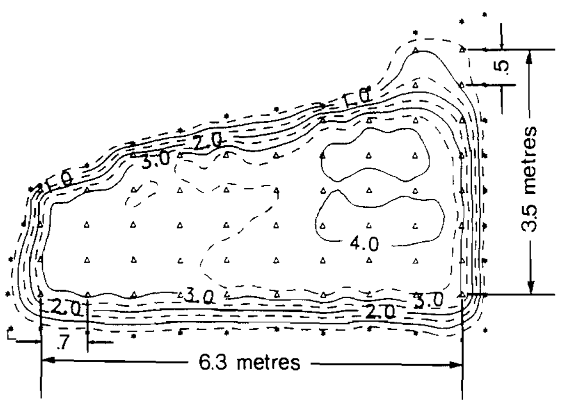

Figure 15. Roadway profile and velocity contours at location #2.

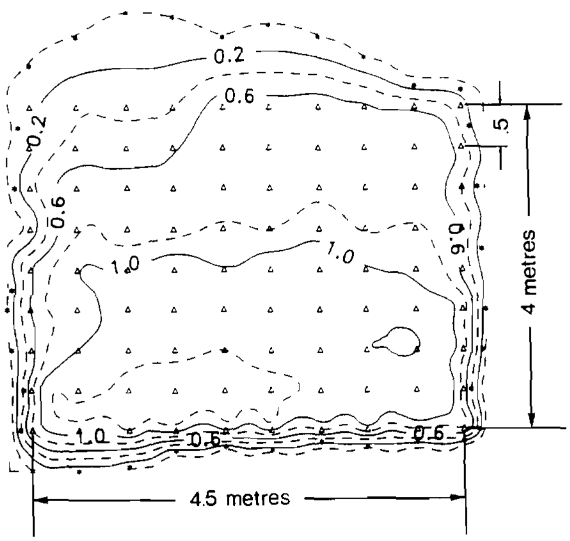

Figure 16. Roadway profile and velocity contours at location #3.

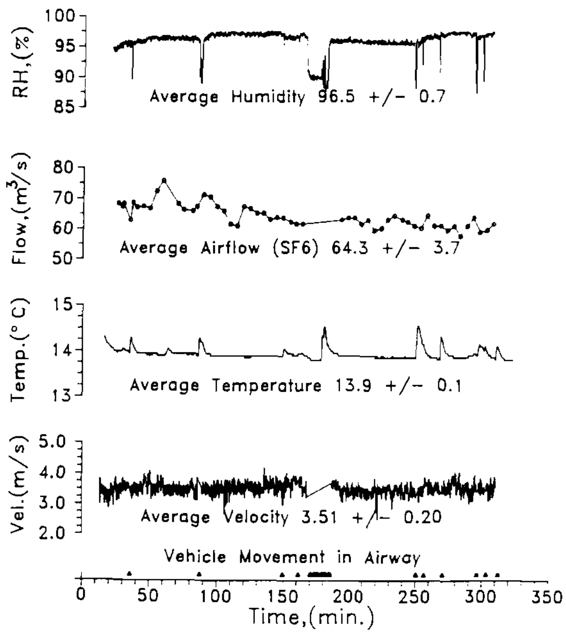

Figure 17. Time variations of humidity airflow, temperature and velocity monitored during tests at location #2.

At both locations #2 and #3, there was good agreement (i.e. within 10%) between instruments using a continuous traverse. There was also good agreement between the air quantities derived from tracer gas and the contour profile. However, the anemometer values showed disagreement with the average velocity derived from the contour profile and the tracer gas analysis. Depending on the location, the anemometer traverse seems to over-estimate the airflow, these ranged from 50% at location #1 down to 26% and less at location #2. Without further research it is not possible to state whether the anemometer average traverse velocities are representative of the cross-section. However, as a group they were consistent.

Test Series #2

The second part of the field evaluation, was to determine whether any of the instruments were effected by traversing speed. This was achieved by traversing selected instruments at 0.2, 0.4 and 0.6 m/s. Again the same route was followed for a continuous traverse by each instrument at every speed.

The results of the traverse speed tests are shown in Table 5. Of the eleven tests reported only three demonstrated any consistent trend with increasing traverse speed; these were the Davis, the AM5000 and the DVA30VT (100 mm), all for an average air velocity of 0.9 m/s (170 fpm). The three units demonstrated increases of 7 to 8% as the traversing speed increased from 0.2 to 0.6 m/s.

Generally this test proved inconclusive for the range of air velocities experienced. However, for comfort of the instrument operator 0.4 m/s is probably the optimum traversing speed.

Table 4. Condensed field evaluation results from the three survey locations.

Instrument	Average Corrected Velocity from Continuous Traverse							
	Location #1 (m/s)	Rel.to Davis #1	Location #2 (m/s)	Rel. to Davis #1	Location #2 (m/s)	Rel. to Davis #1	Location #3 (m/s)	Rel. to Davis #1
Davis #1	0.47±0.01	1.00	2.98±0.11	1.00	2.76±0.09	1.00	0.93±0.01	1.00
Davis #2	Not available		2.99±0.06	1.00	2.75±0.09	1.00	0.91±0.02	0.98
AM5000 #1			2.88±0.05	0.95	Not tested		(0.57±0.02)[1]	
AM5000 #2			3.04±0.10	1.02	2.77±0.03	1.00	0.88±0.02	0.95
DVA30VT (100 mm)	Not available		Not available		2.90±0.01	1.05	0.98±0.01	1.05
4510			3.04±0.06	1.02	2.85±0.09	1.03	0.97±0.01	1.04
TX5081			3.13±0.03	1.05	Not tested		[3]	
Average Velocity								
From profile (m/s)	0.31	0.66	2.63	0.88			0.73	0.78
From SF_6 (m/s)	0.29±0.03	0.62	2.71±0.13	0.91	2.84±0.13	1.02		
Cross Sectional Area								
From profile (m^2)	30.08		23.99		23.99		31.53	
From weighing (m^2)	30.72		23.26		23.26		31.78	
Average Air Quantity								
From profile (m^3/s)	9.33		63.14				22.90	
From SF_6 (m^3/s)	9.00±0.76		63.9±3.23		67.13±3.00		(17.38±3.44)[2]	

Notes: 1 - Old AM500 unit no longer reliable at this flow.
2 - Poor injection location, gas lost to other air split.
3 - The TX 5081 did not prodice consistent results at this flow.

Table 5. Comparison of instrument performance depending on traversing speed.

Instrument	Average Corrected Velocity @ 0.2 m/s (m/s)	@ 0.4 m/s (m/s)	@ 0.6 m/s (m/s)
Davis #1	2.94±0.02	2.98±0.11	2.95±0.07
	2.76±0.09	2.77±0.04	2.77±0.01
	0.88±0.01	0.93±0.01	0.95±0.05
	0.45±0.01	0.47±0.01	0.44±0.01
AM5000 #2	2.86±0.08	3.04±0.10	3.00±0.06
	0.84±0.01	0.88±0.02	0.90±0.02
4510	3.16±0.04	3.04±0.06	3.05±0.01
	0.96±0.01	0.97±0.01	0.97±0.01
TX5081	3.09±0.03	3.13±0.03	3.09±0.04
DVA30VT (100 mm)	2.90±0.02	2.90±0.01	2.85±0.05
	0.94±0.01	0.98±0.01	1.02±0.01

Despite their susceptibility to errors due to misalignment, "micro" head anemometers were generally in good agreement with standard 100 mm heads.

ERGONOMIC ANEMOMETER EVALUATION

This section lists characteristics of each instrument tested in respect to quality of construction, ergonomic design and ease of operation.

Biram Type Anemometer (Figures 2 and 3)

This is the basic time integrating unit, using cumulative dials to measure meterage or footage through the unit. To obtain an average velocity a manually operated stopwatch and calculations are required. In the case of the Davis instrument (Figure 3) it is possible to misread the dials depending on needle location.

DVA30VT (Figure 7)

This unit manufactured by Airflow Development (Canada) is capable of measuring average airflows without the need of a stopwatch or calculator, however, it is not ideal for traversing roadways, because it requires a two-hand operation to use its time integrating mode. The 'read' button must be kept depressed for the duration of the traverse, this only leaves one hand to perform the traverse. The unit will calculate and display the average on releasing the 'read' button. The instrument will automatically reset on initiation of the next measurement.

LCA6000VT (Figure 6)

This hand-held unit also by Airflow Developments is capable of directly providing an average airflow and is very similar in operation to the DVA30VT, again with the same requirement to keep a button depressed. Again this limits the units use as a traversing instrument as it must be kept in the hand making it impractical for large airways. These problems are presently being addressed by Airflow Developments who are developing another version of the LCA6000VT.

This new unit has a detached head that would make it better suited to the mining industry. An evaluation of this instrument was not done due to its unavailability during the test period.

MPM500e (Figure 8)

Depending on the choice of probe this modular instrument can read, air velocity, temperature, humidity, rpm and differential pressure. This study solely evaluated the vane anemometer attachment. The MPM has an averaging capacity and can also provide the maximum and minimum readings.

Some of the disadvantages of the unit include the difficulty in determining whether the small head is facing the airflow. Also the body of the instrument does not lend itself to one hand operation due to the location and nature of the keyboard. The body is heavy and unevenly balanced. The probe is connected to the body by a 9-pin "D" shaped connector with a stiff cable. This caused some problems because the cable tended to detach itself when the unit was used at full extension.

The starting and stopping of the averaging process on this unit is preferred to any of the preceding instruments. Depression of the tactile membrane keys is easily felt and the timing sequence is activated and terminated by a single key stroke. However, the recessed keys and their location do not allow optimum operation. The MPM does not require the key to be kept depressed. One disadvantage is a two-key clear function (AVG and Hold) to clear the memory for the next traverse.

The manufacturers of this unit, Solomat, are in the process of redesigning the instrument. At the time of press the probes all had new positive alignment thread to assist coupling connectors. Unfortunately, the connecting cable to the probe is still of the rigid type and can impede usage. Another problem with the MPM is that the new body is not yet available, therefore, a patch connector is being supplied between the 9-pin "D" shaped connector and the new connector. In this transition stage the MPM is not ideal for underground usage. No information is yet available on the new body or as to whether it can be more comfortably used as a hand-held traversing anemometer.

4510 (Figure 9)

The 4510 unit was the easiest to use of the six available units evaluated. The body of the instrument is fairly light and well designed to fit in the user's palm. This instrument seems to be the final version of a successive series of modifications to provide an optimum design, its predecessors being similar in shape to the MPM. The location of the tactile membrane keys is well designed, the keys provide good tactile sensation, and the instrument can be easily operated with one hand.

The body connects to the head via a supple cable and a latch-lock connector that will not easily come apart.

Similar to the MPM, it is also difficult to orientate the head towards the airflow while traversing, especially at full extension. This problem may be more extreme with the two smaller heads available for the unit.

The interchangeable and removable heads may also have some advantages in transport. The heads are held securely on a telescopic pole by high quality latch lock connectors.

Similar to the MPM, the 4510 also has maximum, minimum and averaging capacities, and certain heads also have temperature sensors. The averaging option is activated by simply depressing a start/stop key. During averaging another feature is initiated, a stopwatch to time the length of the traverse or sampling period. The memory is cleared each time the averaging mode is initiated.

The 4510 was also the only unit that can be set up as a continuous monitoring station as it has an output voltage socket.

TX5081 (Figure 10)

This was the only non vane unit evaluated for the traversing technique of airflow measurement. The field tests did show that the instrument can be used in this mode.

It can be used in either instantaneous or averaging mode. In the averaging mode, similar to the 4510 on initiation of the timing sequence, the display registers a stopwatch showing the elapsed time. The field evaluations were performed with an early model of the instrument that automatically stopped sampling at 3 minutes unless a key was activated which hindered some of slower traverses of large airways. This shortcoming has since been remedied by incorporating a programmable time span which allows the unit to run up to 100 minutes unless manually stopped by a keystroke.

The TX5081 does not fit as readily in the hand as the 4510 but is not as cumbersome to use as the MPM. The keyboard of the TX5081 is not of the same membrane type as the MPM and 4510, therefore, resulting in the user not always being confident that the keys have been depressed.

One specific attribute of the TX5081 that may make it attractive to coal mines is that it is intrinsically safe.

A disadvantage of the TX5081 is that the head is fairly heavy and requires a heavy duty pole to enable traversing. The interconnecting cable from the head has a positive alignment latch lock connector on the meter body.

CONCLUSION

This paper details tests of six commercially available air velocity meters. Each unit can be used for continuous traversing and is compared against the AM5000 which was extensively used by the mining industry.

The laboratory tests demonstrated that all of these units could be used with confidence above 1 m/s, although some units performed better than others. Below 1 m/s the response of some of the units was no longer linear. The best performing units at low velocities were of the Davis/Biram type or the DVA30VT but the latter is not ideally suited to field use.

The laboratory tests also demonstrated that the "micro" heads, employed by some of the units, were more susceptible to errors caused by misalignment. This, however, did not translate in noticeable errors in the field evaluations. Of those employed the TX5081 vortex meter was least susceptible to yaw.

During field testing of the instruments, all the meters showed good agreement provided the velocity was within their operational range. A second series of field tests investigated the influence of traversing speed on the units; these tests did not conclusively show any dependency for the air velocity ranges experienced.

Ultimately, the deciding factor in the selection of an anemometer, apart from price, is the ergonomics of its design. Specific advantages of some units were: good key placement, single keystrokes to start and stop the averaging mode, good quality tactile keys, secure connections between head and body, and a built-in stopwatch.

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