

A Coal Mine Ventilation Survey Method



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A COAL MINE VENTILATION SURVEY METHOD

by

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Joseph D. Hadden, Jr.¹ and Robert L. Smith²

ABSTRACT

This report presents a practical, working tool for conducting mine ventilation surveys under conditions found in most coal mines. It describes a method used by the Pittsburgh Health Technology Center, Mine Safety and Health Administration for conducting these surveys. The procedures outlined include conducting air pressure and air quantity surveys underground, and fan pressure readings on the surface. A brief description of how the data gathered is prepared for a digital computer program simulator evaluation is included in the report.

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INTRODUCTION

Underground coal mine ventilation systems are particularly complex because the mining laws mandate multiple split ventilation methods. In addition to the main intake and return air splits, there are separate splits for belt entries, track entries, and escapeways. These systems should be designed to insure that adequate amounts of ventilating air reach each working area. Higher quantities of methane are often encountered at the face because today's quest for coal necessitates the mining of deeper, gassier coalbeds. The proper operation of the ventilation system at maximum efficiency is essential for providing a safe and healthy underground working environment. To gain an understanding of the complex networks incorporated in the system, a coal mine ventilation survey is required. The information obtained from this survey can be used to determine the most efficient methods to accomplish any proposed improvements. Most bituminous coal mines in the United States currently operate in relatively flat coalbeds and employ an exhaust (negative pressure) ventilation system. The survey method in this report is presented for these conditions but can also be applied to mines using a blow (positive pressure) ventilation system.

When the price of electrical energy is \$0.01 per kilowatt hour for power, a continuously operating fan costs \$65.00 per brake horsepower per year (12)³. This yearly charge does not include the power required to compensate for the losses in efficiency of the fan motor or fan drive which may increase the power costs by 50 percent. If a fan uses 300 brake horsepower to operate at an

³ Underlined numbers in parentheses refer to items in the list of references preceding the appendix

energy cost of \$0.04 per kilowatt hour, then the minimum charge to run it continuously for a year is approximately \$78,000. Reducing these costs and maintaining adequate ventilation underground should be of great concern to all. When a mine ventilation system is designed and operated to provide the maximum safety for the miners at a minimum use of electrical energy, then everyone benefits. A study of the mine ventilation system is necessary to ascertain where power savings are feasible.

This report is intended to be a practical, working tool for field conditions found in most coal mines. It describes a method for conducting a mine ventilation survey. The procedures outline include conducting air pressure and air quantity surveys underground, and fan pressure readings on the surface. The data gathered is prepared for a digital computer simulation (15) by which an analysis of the overall mine ventilation system can be made. The mine ventilation simulator was developed over many years with federal research funds, and is available to the public. This simulator is used extensively by the Pittsburgh Health Technology Center, Mine Safety and Health Administration.

VENTILATION SURVEY OBJECTIVES

For almost a hundred years, the importance of the overall mine ventilation network was realized. Attempts to understand these systems were prompted by the desire to improve the safety of mining conditions. Ventilation surveys of the overall network were conducted to evaluate the existing conditions of the mine

airways. This data was used to determine the resistance to airflow in each aircourse branch. As more circuits were added to the overall network, it became more complex and thus, more difficult to comprehend. Long-hand methods of calculation are time consuming, and the number of ventilation surveys made was limited. When digital computer modeling had progressed so that computer programs were available that could simulate the complex, overall mine ventilation networks, the problems of calculating all the necessary information were overcome (15). If the correct data for any ventilation survey is evaluated by this simulator, it is possible to determine those areas where improvements are feasible (5).

The following general procedures are suggested to help expedite the completion of all phases of the field survey at the mine:

Familiarize everyone concerned with the mine ventilation system. One of the most helpful aids is a colored map of the mine ventilation system with different colors to indicate the intakes, the returns, the belts and the track entries. With large mines that are complex, this is particularly important because data measuring points are easily overlooked and forgotten. The overall mine ventilation layout is best depicted in a ventilation schematic of all the branches in the system.

An ideal time to conduct the ventilation survey (10) is when the weather is calm and the mine is idle because airflow disturbances caused by moving elevators, hoists, supply trains, etc., can adversely effect the readings. This is

particularly true of the altimeter or pressure survey. If it is not possible to schedule the data gathering for such an idle period, then additional time may be required to recheck some of the information.

The collection of the survey data may be divided into three main phases as follows:

Altimeter or Air Pressure Survey: The air pressure survey is required to determine the total ventilation pressure at the junctions of all airsplits or branches and selected stations between the junctions of the airsplits. The ventilation pressure loss or head loss between stations is used to calculate the resistance of the aircourses between successive stations.

Air Quantity and Pressure Differential Survey: The air quantities in all airsplits or branches in the mine must be measured or determined by subtraction at the beginning and end of each split of air. The difference between the air quantity measurements at these locations is the air leakage in that airsplit. In addition to determining air leakage in an airsplit, the air quantity is used in computing the resistance to airflow in the aircourse using the formula:

$$H = RQ^2$$

where

H = pressure loss or head loss in an airsplit (inches water gage),

R = resistance factor of airway, and

Q = air quantity in branch (cubic feet per minute in units of 100,000).

The head loss in an airsplit is the difference between the total ventilation pressure at the beginning and end of an airsplit. The air quantity would be the average air quantity flowing in the split in units of 100,000. (if the air quantity is 100,000 cfm, then $Q = 1$; if the air quantity is 50,000 cfm, then $Q = 0.5$. Anytime the equation $H = RQ^2$ is used, the quantity is expressed as cfm in units of 100,000). The resistance (R) is a function of the physical characteristics of an aircourse of a mine and remains approximately constant unless there is a physical change such as a roof fall or additional mine development.

Pressure differentials across stopping lines separating adjacent aircourses are measured using a Magnehelic gage or U-tube manometer. These pressure differentials are correlated to a total ventilation pressure established by the altimeter survey. This procedure is used to determine the total ventilation pressure in the aircourses adjacent to the aircourse used for the altimeter survey.

Mine Fan Survey: The mine fan survey requires measuring the total, static, and velocity pressures of the mine air at the fan. A Pitot tube traverse is made in the four fan quadrants in by the blades to obtain these measurements. The total fan pressure measured at this location is used with the fan manufacturer's appropriate fan characteristic curve to indicate the fan operating point. The static pressure measurement is used as a check on the total and velocity pressure measurements and in calculating the fan air density as discussed later in this report.

$$\pm \text{ Total Pressure (TP)} = \pm \text{ Static Pressure (SP)} + \text{ Velocity Pressure (VP)}$$

The velocity pressure is used to calculate the mine air velocity through the fan. In addition to the fan air measurements, the mine air density, the fan speed, the position of the fan blades and the fan manufacturer's name, model number and serial number are determined. When more than one mine fan is operating in the mine ventilation network, the above data is gathered at each fan site.

SURVEY EQUIPMENT

The following list of equipment is adequate for one underground ventilation survey team and one base team:

2-altimeters (aneroid barometers)

2-wrist watches

2-sling psychrometers

1-barometer

1-4-inch rotating vane anemometer (calibrated)

1-anemometer extension rod

1-measuring tape (engineer's scale)

1-Pitot-tube

1-stop watch

1-aspirator bulb with smoke tubes

Magnehelic gages with rubber tubing

FIGURE 1. - Altimeter with scale ranging between 0 and 7,000 feet.

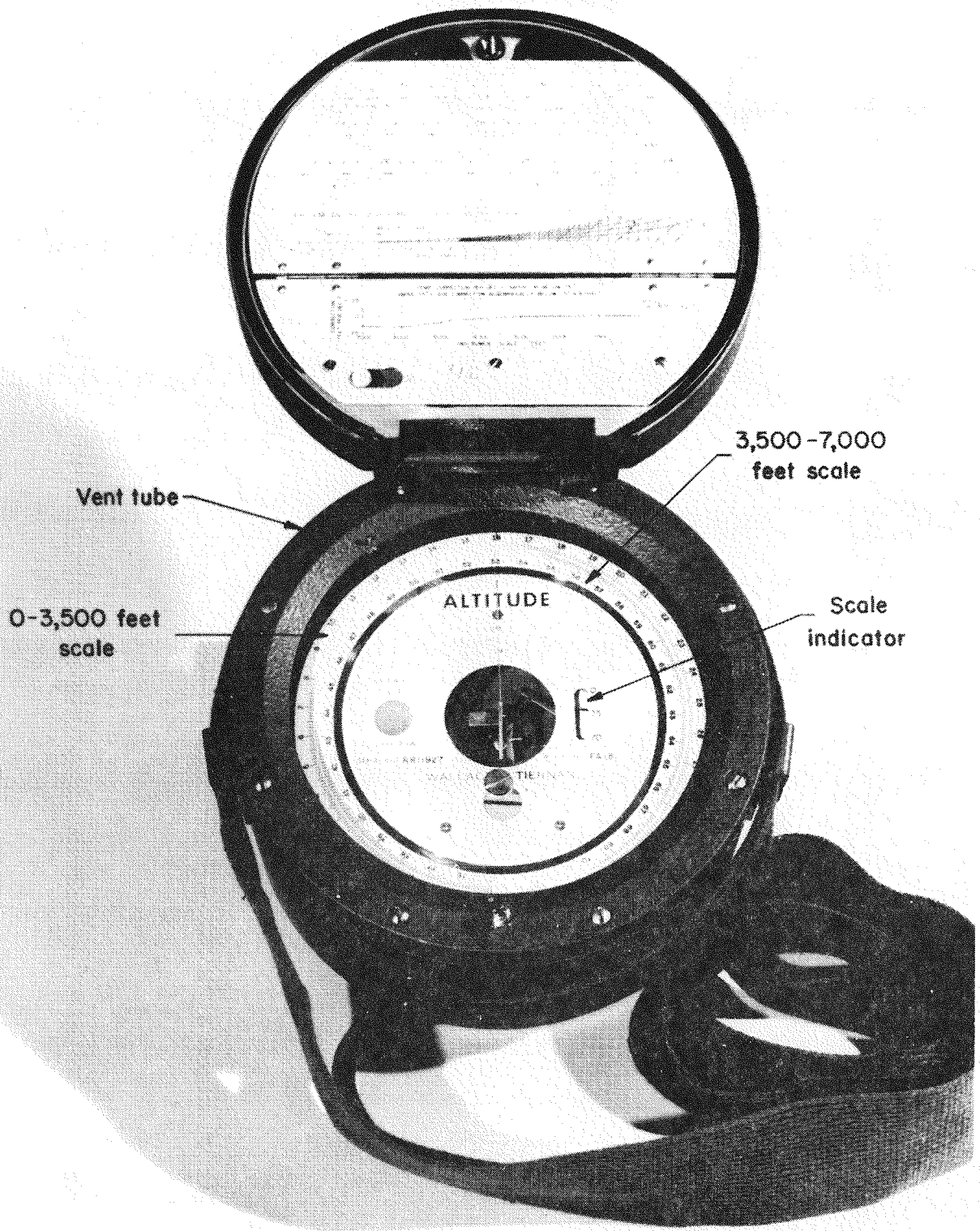


FIGURE 1. - Altimeter with scale ranging between 0 and 7,000 feet.

The altimeter (fig. 1) normally reads in feet of air column with an appropriate range suitable for the elevation and depth of the mine to be surveyed (10). The chosen range of the altimeter permits pressure readings to be made to the nearest foot which is approximately 0.014 inch water gage pressure. The scales of the altimeters are normally offset 1,000 feet, (0 = -1,000 feet) to avoid negative readings during a survey. Altimeters with scale offsets other than 1,000 feet are also available.

The wrist watches for the underground team and the base team are synchronized. This aids in making the altimeter readings simultaneously. Sling psychrometers are employed to measure the wet-bulb and dry-bulb temperatures of the air at the surface and in the mine. These measurements are utilized in calculating the ratio of air densities between selected stations. Temperature and air density measurements can also be used in determining the natural ventilation pressure acting on a mine during a survey.

A barometer is used to determine the barometric pressure. Some coal mining operations have a barometer at the mine site. This instrument is usually corrected to sea level (1). Only the absolute barometric pressure at that elevation should be used in calculating air densities. As an example, if the barometer at the mine office reads 30.54 inches mercury (Hg) corrected to sea level and the mine office is 750 feet above sea level, the barometric pressure at that elevation would be approximately 29.77 inches mercury. (Correction is approximately 1.029 inches of mercury per 1,000 feet of elevation near sea level).

$$(30.54 \text{ Hg} - \frac{750 \text{ feet} \times .014 \text{ inch w.g. per foot of air}}{13.6 \text{ inches w.g. per inch Hg}} = 29.77 \text{ inches Hg})$$

Figure 2.- Low and high speed van anemometers with correction charts and extension rod.

Figure 3.- Pitot-tube and pressure gage connection for measuring total pressure (TP).

Figure 4.- Pitot-tube and pressure gage connection for measuring static pressure (SP).

Figure 5.- Pitot-tube and pressure gage connection for measuring velocity pressure (VP).

Figure 2 shows the 4-inch rotating vane anemometer in both low and high speed types. This is the accepted instrument for determining air velocities in underground coal mines, and should be calibrated at least annually. At locations where air speeds exceed the limits of the vane anemometers, the use of a Pitot-tube is recommended. Figures 3, 4 and 5 illustrate the proper connection between the Pitot-tube and pressure gage to measure the total (TP), static (SP), and velocity (VP) pressures. When air speeds are below the range of the vane anemometer, timed smoke cloud travel measurements using chemical smoke (fig. 6) are advised for measuring the air velocities. Measuring tapes are necessary for measuring the height and width of locations where air velocities are taken.

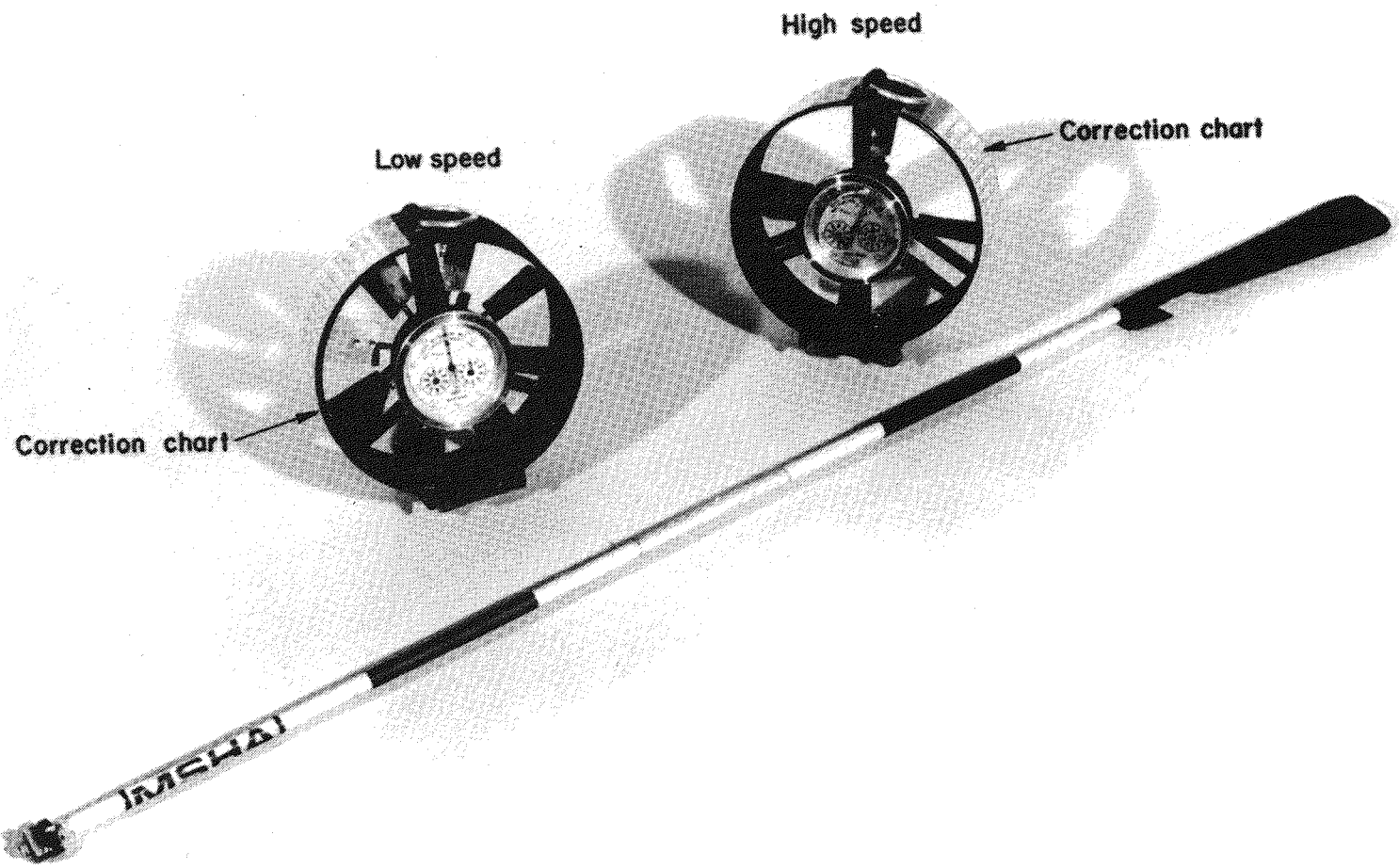


FIGURE 2. - Low and high speed vane anemometers with correction charts and extension rod.

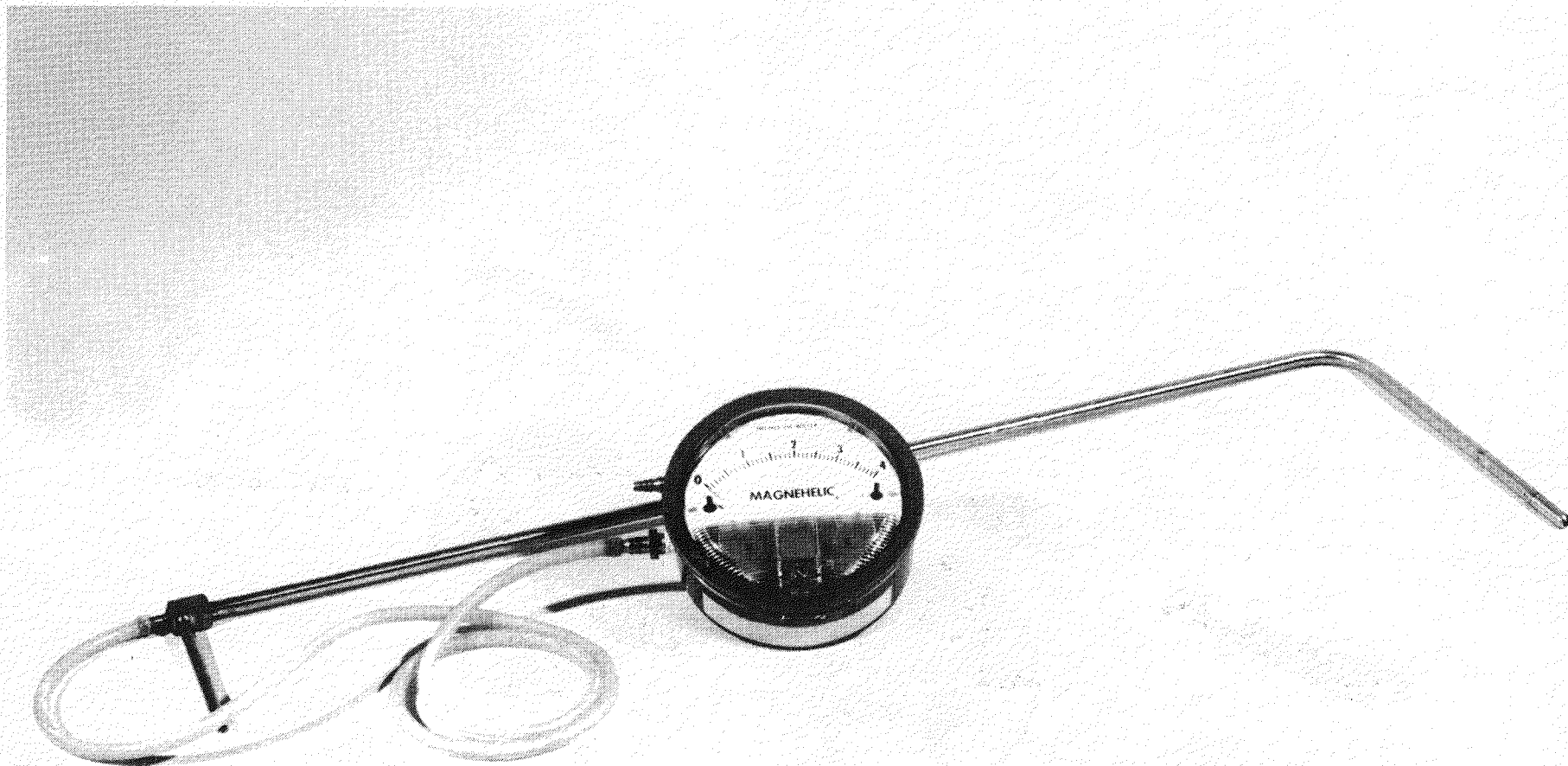


FIGURE 3. - Pitot-tube and pressure gage connection for measuring total pressure (TP).

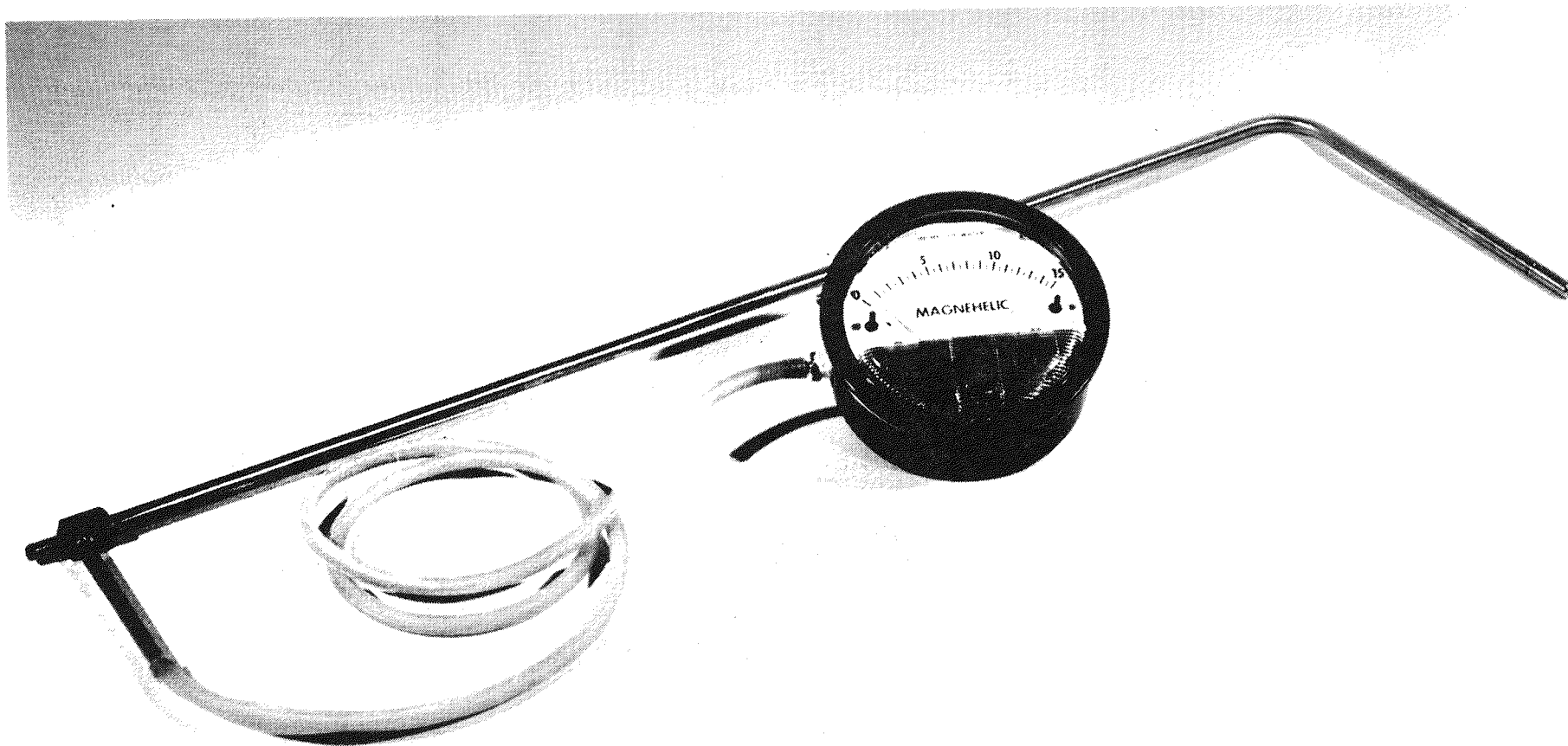


FIGURE 4. - Pitot-tube and pressure gage connection for measuring static pressure (SP).

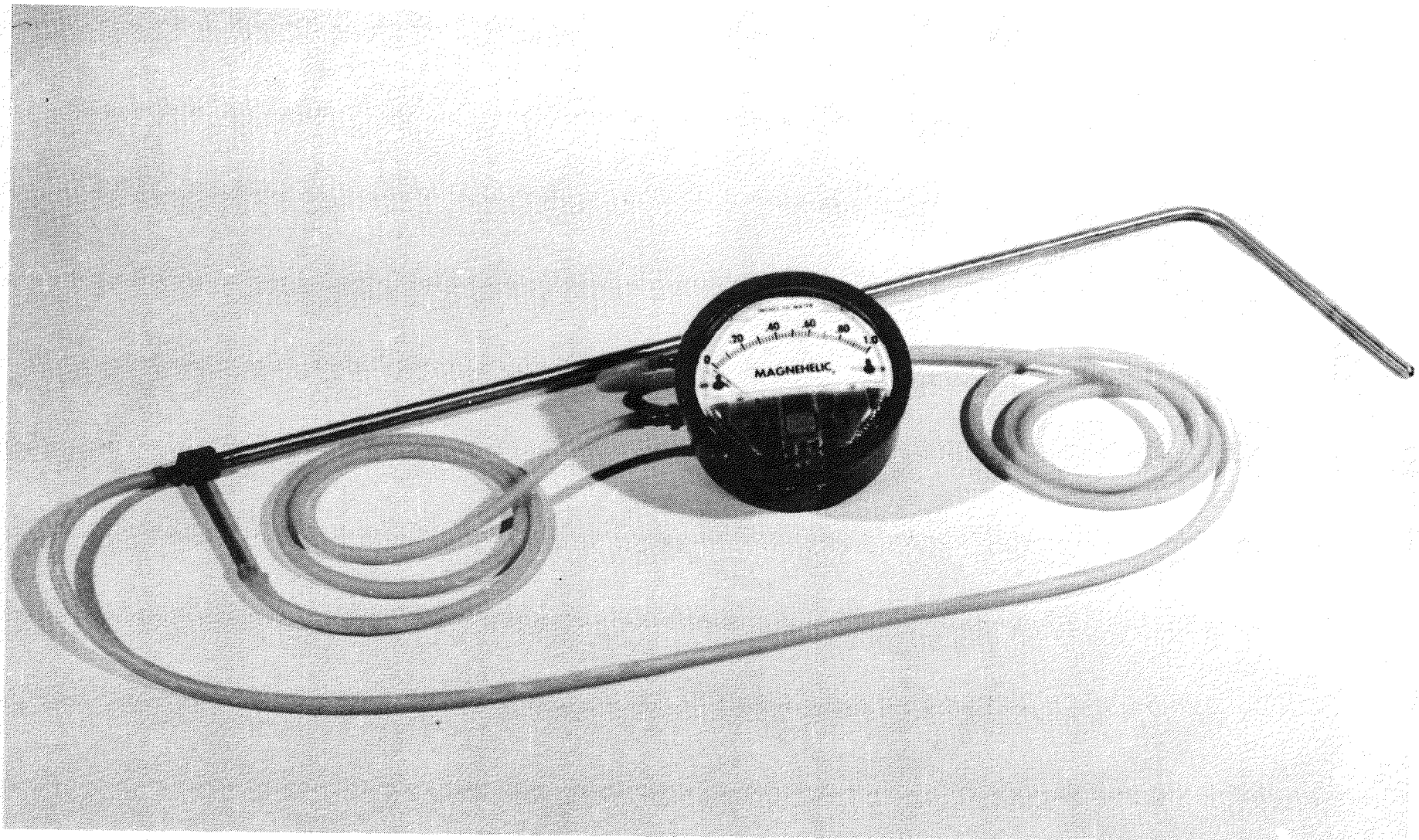


FIGURE 5. - Pitot-tube and pressure gage connection for measuring velocity pressure (VP).

Using a tape with a scale in tenths of a foot eliminates the need to convert inches to feet. The average height and width are used to determine the entry cross sectional area in square feet. The area is multiplied by the corrected air velocity measurement to obtain the air quantity in cubic feet per minute at that location. A stop watch is used to time anemometer measurements.

Figure 6.- Chemical smoke tube equipment.

Figure 7.- Equipment for measuring ventilation pressure drops.

The Magnehelic pressure gage (fig. 7) is an instrument used for measuring air pressure differentials in a ventilation system. Normally Magnehelic gages with scales in inches water gage pressure are used for the study. Gages with other scale units are also available. The size and ruggedness of the Magnehelic makes it a suitable instrument for underground use. To accurately measure the range of air pressure differentials that may be encountered during a survey, a set of Magnehelic gages for each underground survey team is as follows:

- 1 Magnehelic gage 0 to 1.0 inches water gage
- 1 Magnehelic gage 0 to 4.0 inches water gage
- 1 Magnehelic gage 0 to 8.0 inches water gage

In this example, the range of the Magnehelic gages is adequate for the underground portion of the survey. A gage with a higher range may be required

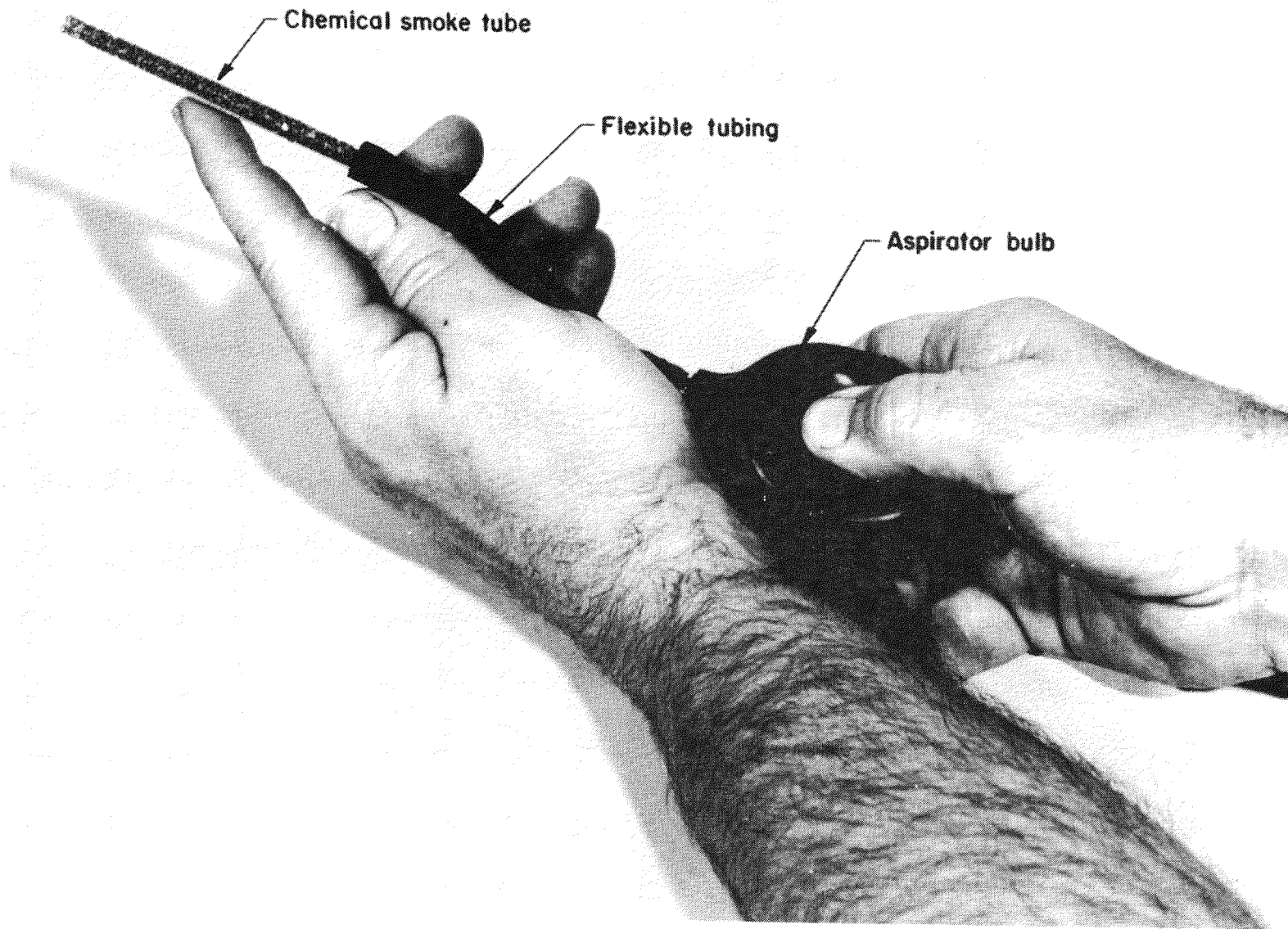


FIGURE 6. - Chemical smoke tube equipment.

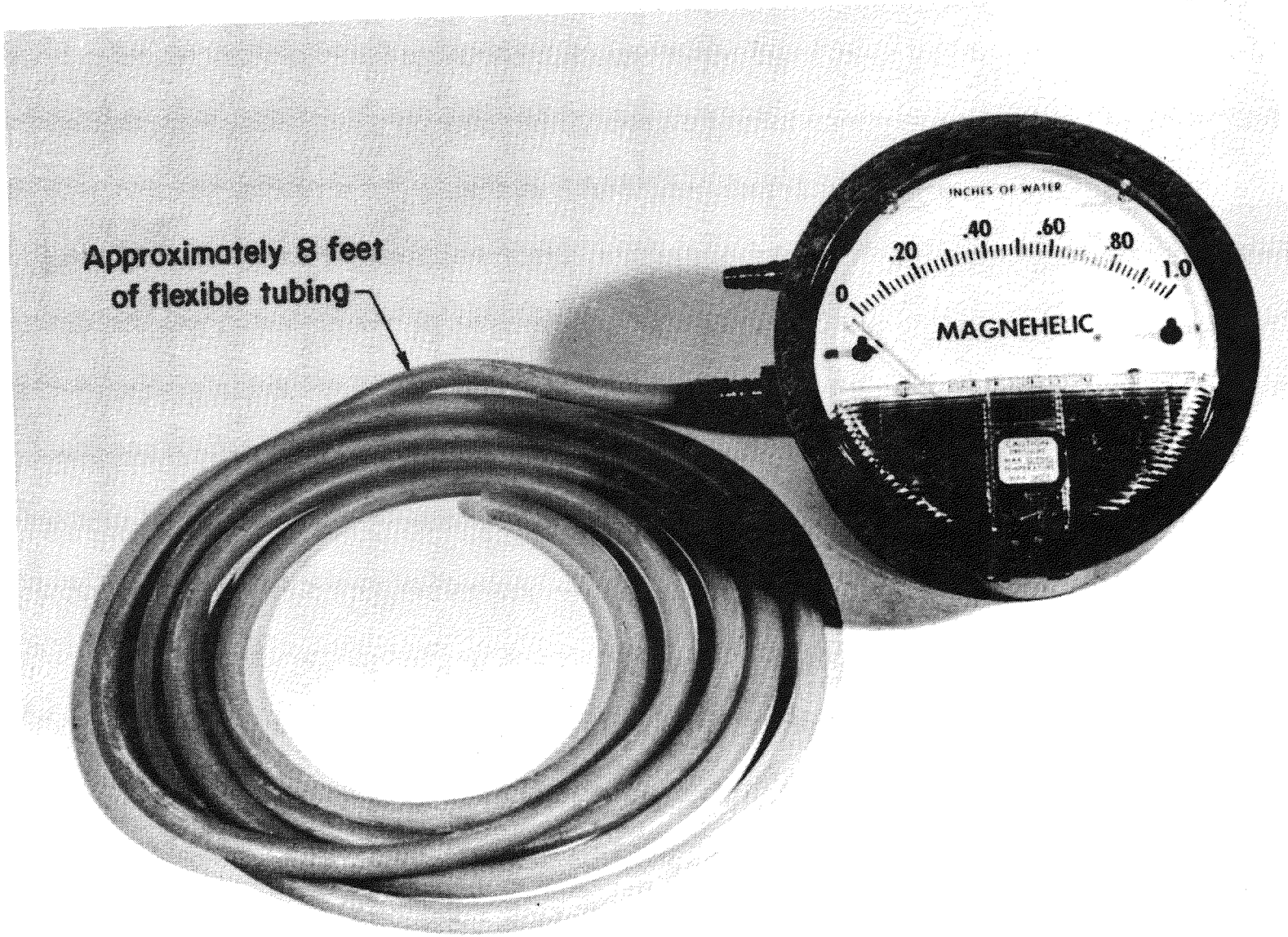


FIGURE 7. - Equipment for measuring ventilation pressure drops.

to measure the static pressure of the air at the fan. This is discussed in more detail later in the report.

ALTIMETER SURVEY

Airflow is the result of air moving from a higher total pressure to a lower total pressure (3) (8). The total pressure (TP) of air at any point in an underground ventilation system is equal to the algebraic sum of the static pressure (SP) and velocity pressure (VP) at that point. The measurements from a precision aneroid barometer or altimeter are used in calculating the static pressure of the air underground. The velocity pressure is computed from velocity determinations taken with a 4-inch rotating vane anemometer (8).

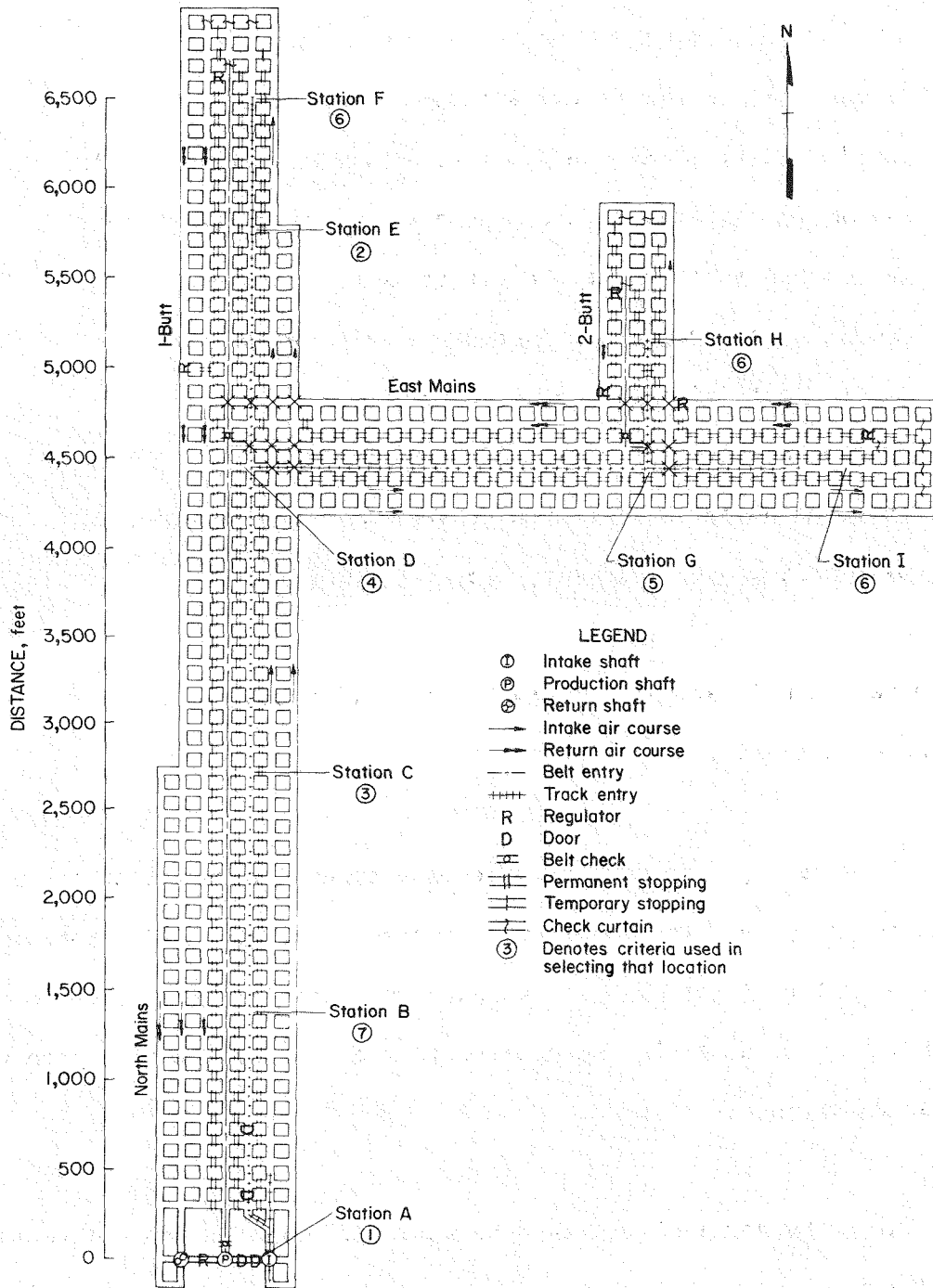
The altimeter survey method used by Mine Safety and Health Administration, Ventilation Division, at the Pittsburgh Health Technology Center, establishes a total pressure gradient for an aircourse as a base line from which pressure differentials may be obtained to determine the total pressures in other aircourses in the mine (10). This procedure requires one stationary altimeter to be used as a base and one or more roving altimeters to be employed underground at various stations or locations selected for measurement. Underground stations can be selected in belt, track or intake aircourses that have known elevations. The elevation of each station is required before the survey data can be applied with a degree of accuracy. Other criteria that may be used in selecting underground altimeter stations are as follows:

1. At the bottom of a shaft or slope opening.
2. At a location in the mine where a major change in the area of the intake aircourse occurs.
3. In the intake aircourse opposite a location where a major change in the area of the return aircourse takes place.
4. At a major split of intake air or in the intake aircourse opposite a major junction of the return air.
5. At the mouth of coal producing sections.
6. In the face area of coal producing sections.
7. In areas where the distance between stations selected by the first six criteria, exceed 2,000 feet.

Figure 8.- Mine map with location of altimeter survey stations based on seven criteria.

Figure 8 is a mine map with the location of altimeter survey stations based on the seven criteria above. The locations selected to be altimeter stations are designated by the letters A through I. The numbers appearing in circles, beside the letters, indicate which of the seven criteria are used in the selection of that location as an altimeter station.

For deep mines where the vertical distance between the base station and roving altimeters is 300 feet, the average error will be approximately 2 feet. If



the vertical distance between instruments is 2,000 feet, the average error will be approximately 5 feet. For section surveys, the base should be established at a point close to the area surveyed.

The base altimeter must be located at a known elevation either on the surface or underground. A surface location will provide more consistent readings when the mine is working because the base instrument will not be effected by hoist or elevator movement in the shaft or the operation of doors along the haulageway. However, if the base instrument is located in a surface building that is connected to the hoist or elevator housing, the movement of the cage in the shaft may cause air pressure changes that effect the base altimeter readings. The readings made during these changes should be noted by the base operator and disregarded when analyzing the altimeter data collected during the survey. The initial preparation requires that the roving altimeter or altimeters for use underground, be placed beside the base altimeter and readings made with each instrument at 5 minute intervals. The purpose of these readings is to allow time for the instruments to come to equilibrium with the ambient conditions and to determine if all instruments respond equally to barometric changes occurring during this time. The altimeters do not need to be adjusted to read the same but they should respond the same to barometric changes. Wet-and dry-bulb temperatures of the air that enters the mine can be taken with a sling psychrometer while the altimeters are being checked. In addition, the barometric pressure at the base station can be recorded and the watches used by the base and roving altimeter operators synchronized. The following is an example of the type of information collected at the base station.

July 9, 1980

Base station elevation above sea level - 750 feet

Barometric pressure at 8:10 a.m. - 28.21 inches mercury

<u>Time</u>	<u>Base Altimeter*</u> <u>Feet of air</u>	<u>Roving Altimeter*</u> <u>Feet of air</u>	<u>Temperature</u> <u>Degree F°</u>	
			<u>Wet</u>	<u>Dry</u>
8:00 A.M.	1746	1766		
8:05	1748	1767	58	63
8:10	1751	1771		
8:15	1752	1773		
8:20	1754	1774	58	64
8:25	1755			
8:30	1755			
8:35	1756		59	64
8:40				
8:45				
8:50				
8:55				
9:00				

* The altimeter scales are offset 1000 feet.

The readings taken from 8:00 a.m. to 8:20 a.m. in the example, indicate that the altimeters are responding approximately the same to barometric changes. After the reading at 8:20 a.m., the roving altimeter is ready to be taken into the mine while the operator of the base altimeter continues taking readings at 5 minute intervals until the operator of the roving altimeter completes the underground survey and returns to the base station on the surface. In addition to the base altimeter readings, the base operator measures the wet-and dry-bulb temperatures of the

air that enters the mine at 15 minute intervals and records the readings and the time at which they were taken.

The vent hole in the roving altimeter is opened to the atmosphere before entering the mine and remains opened during the entire survey. This allows the instrument to adjust to air pressure changes encountered between stations in the mine. Care must be exercised in the handling of the altimeters, as with any precision instrument. The roving altimeter should be cushioned against the jarring effects of underground transportation between stations. Particular care should be exercised when an instrument must be transported from an intake aircourse through a mandoor or airlock into a return aircourse because of the sudden air pressure changes. These sudden air pressure changes may impair the internal operation of the altimeter, and may alter subsequent readings taken unless sufficient time is permitted for the instrument to readjust.

Before taking the instrument through a mandoor or airlock the vent plug on the lid of the altimeter should be in the closed position and lid shut. Once the altimeter is safely in the other aircourse, the lid should be raised and the vent plug placed in the open position until the instrument is transported back through the mandoor or airlock. This procedure reduces the chances of damage to the sensitive internal workings of the instrument.

After leaving the base station, the roving altimeter is taken to the first station underground which, in the case of a shaft mine, would be near the bottom

of the intake airshaft at a known elevation. The instrument must be read at a point sheltered from direct air velocity effects. Altimeter readings are taken and recorded along with the time that each reading was made. The wet-and dry-bulb temperatures and the velocity of the air current moving in the aircourse common to the location of the altimeter are measured. The next example illustrates how the information at each roving altimeter station may be recorded:

July 9, 1980

Station A - One crosscut inby the bottom of the intake shaft.

<u>Time</u>	<u>Roving Altimeter Feet of air</u>	
8:31 A.M.	1280	Cage on bottom
8:33	1311	Cage going up
8:35	1301	Cage on top
8:37	1305	Cage coming down
8:38	1283	Cage on bottom
8:40	1285	Cage stopped until measure- ments at Station A completed
8:42	1287	
8:45	1289	
8:47	1290	
8:50	1291	
8:52	1291	
8:54	1290	
8:55	1291	

Elevation = + 250 feet to top of coal -5 feet = + 245 feet (altimeter located 5 feet below top of coal seam).

Velocity = 1250 feet per minute (cage on bottom)

Temperature: Wet-bulb = 61°F

Temperature: Dry-bulb = 67°F

The fluctuation in the readings of the roving altimeter were caused by the movement of the man cage in the shaft. The travel of the man cage will have less effect on the altimeter readings the further the altimeter stations are from the intake shaft. The operator should remain at each station until little or no variation occurs in successive altimeter readings and at least two of the readings are made at times corresponding to periods when base altimeter readings are made. These reading fluctuations also occur when opening and closing the doors along supply roads and haulageways.

Stations located at major air splits may be employed as check stations (fig. 8, Station D) and resurveyed before completing the altimeter survey. The purpose for the check stations is to assure that changes to the mine ventilation system have not occurred during the survey and that the roving altimeter is still performing the same as observed at the beginning of the survey. The total pressure calculated from the check survey data will not necessarily be the same as the total pressure calculated from the survey data collected at that station the first time. Some difference can be expected due to minor changes in the mine ventilation system caused by the movement of equipment, or the opening and closing of ventilation controls in the mine. Another reason for differences in total pressures at a station may be attributed to a change in the natural ventilation pressure in the shaft openings caused by a change in the surface air temperature from the time the station was first surveyed. If a change in the total pressure at a station is confirmed by the check survey and the above information does not explain the change, it may be suspected that the altimeter did not have sufficient time to stabilize at the check station or the altimeter was damaged. In either

case, the altimeter survey should be repeated or at least that portion of the survey that was made before the check station data revealed a change in total pressure at that station.

The last station surveyed underground should be a check survey at the bottom of the intake shaft prior to bringing the roving altimeter to the surface and then repeating the readings with the base altimeter in the same place as at the beginning of the survey. This comparison is to determine if the difference in the response to barometric change of the two instruments is the same as at the start. A change in the variation of the readings may indicate the roving altimeter has not had sufficient time to stabilize at the surface or it was damaged during the underground survey.

The data collected during the altimeter survey can be handled two ways. The first procedure (10) employs long-hand calculations to determine the total ventilation pressures that existed at the underground stations. The second (2) obtains the results with a computer or calculator by using the survey data in the single equation described in the Appendix for determining total pressure differentials between stations. If a programmable calculator is used a rapid solution of the pressure equation can be made.

AIR QUANTITY AND PRESSURE DIFFERENTIAL

Accurate air quantity measurements can be obtained with a properly calibrated 4-inch rotating vane anemometer using a split-area, continuous traversing method.

This technique requires that 1 minute air velocity readings are taken in each half of an entry, and the results averaged to determine the mean entry air velocity. In figure 9, a diagram of the anemometer traverse route is shown starting at the centerline of the entry. A stop watch times the instrument's travel, and when 30 seconds has elapsed, the anemometer is at the rib of the entry. It then retraces the same route and returns to the center during the remaining 30 seconds. No error due to motion is introduced in the reading of the anemometer at low velocities if the instrument is continuously traversed at a rate less than 60 feet per minute in air velocities less than 400 feet per minute, and at a rate less than 30 feet per minute in air velocities less than 150 feet per minute (7) (16). Care in taking air quantity measurements cannot be over emphasized because the readings are used in the formula, $H = RQ^2$, for calculating the resistance of an airsplit. When using this formula, the air quantity is squared so any error in an air quantity measurement will be greatly magnified.

Figure 9.- Anemometer traverse route.

The following is an example of the data collected at an air quantity measurement station. The station number and a description of the location is recorded in a notebook and marked on a mine map.

Station 1 West intake off A Shaft

Average Height = 6.1 ft., Area = 6.1 ft. x 20 ft. = 122 square feet

	<u>Left Velocity</u>		<u>Right Velocity</u>
	450		440
	470		450
	<u>920</u>		<u>890</u>
Average Left Velocity =	460	Average Right Velocity =	445
Correction Factor =	<u>-15</u>	Correction Factor =	<u>-14</u>
	445		431

445
431
876 ÷ 2 = 438 Feet Per Minute

Average Total Velocity = 438 feet per minute

Air Quantity = Velocity x Area
 = 438 feet/min x 122 square feet
 = 53,436 cubic feet per minute
 = 53,000 cubic feet per minute

The perimeter of the entry is drawn and three height measurements along with a width measurement taken and written down. If the coal ribs are not parallel, then additional measurements are taken to refine the area calculations of the station. The area is divided in half and two 1 minute continuous traverses made in each half with a calibrated, 4-inch rotating vane anemometer mounted on a 2-foot extension rod. The reason for the extension rod is to allow the operator

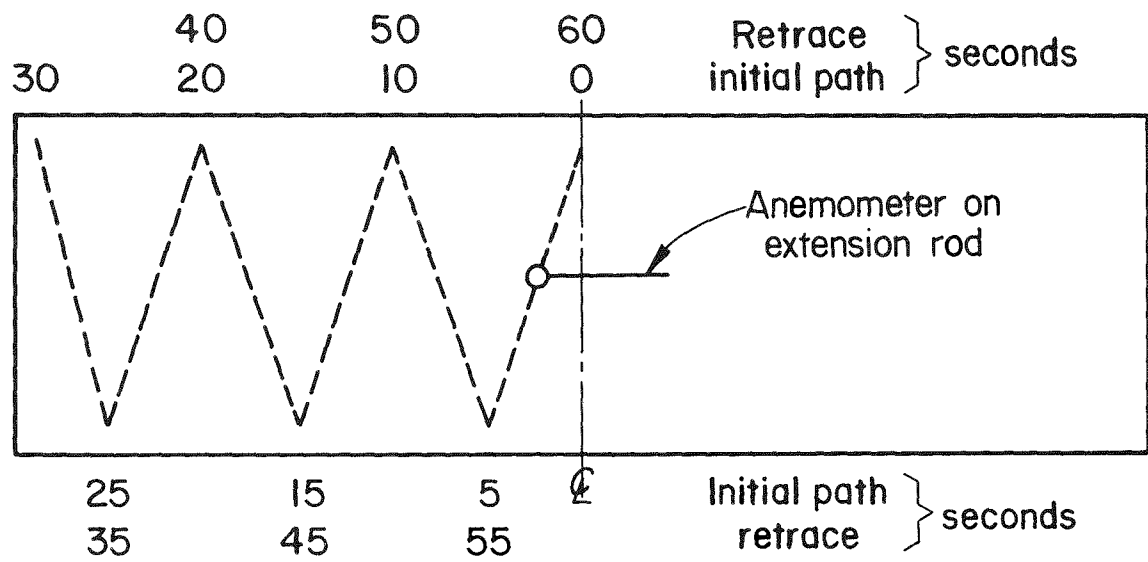
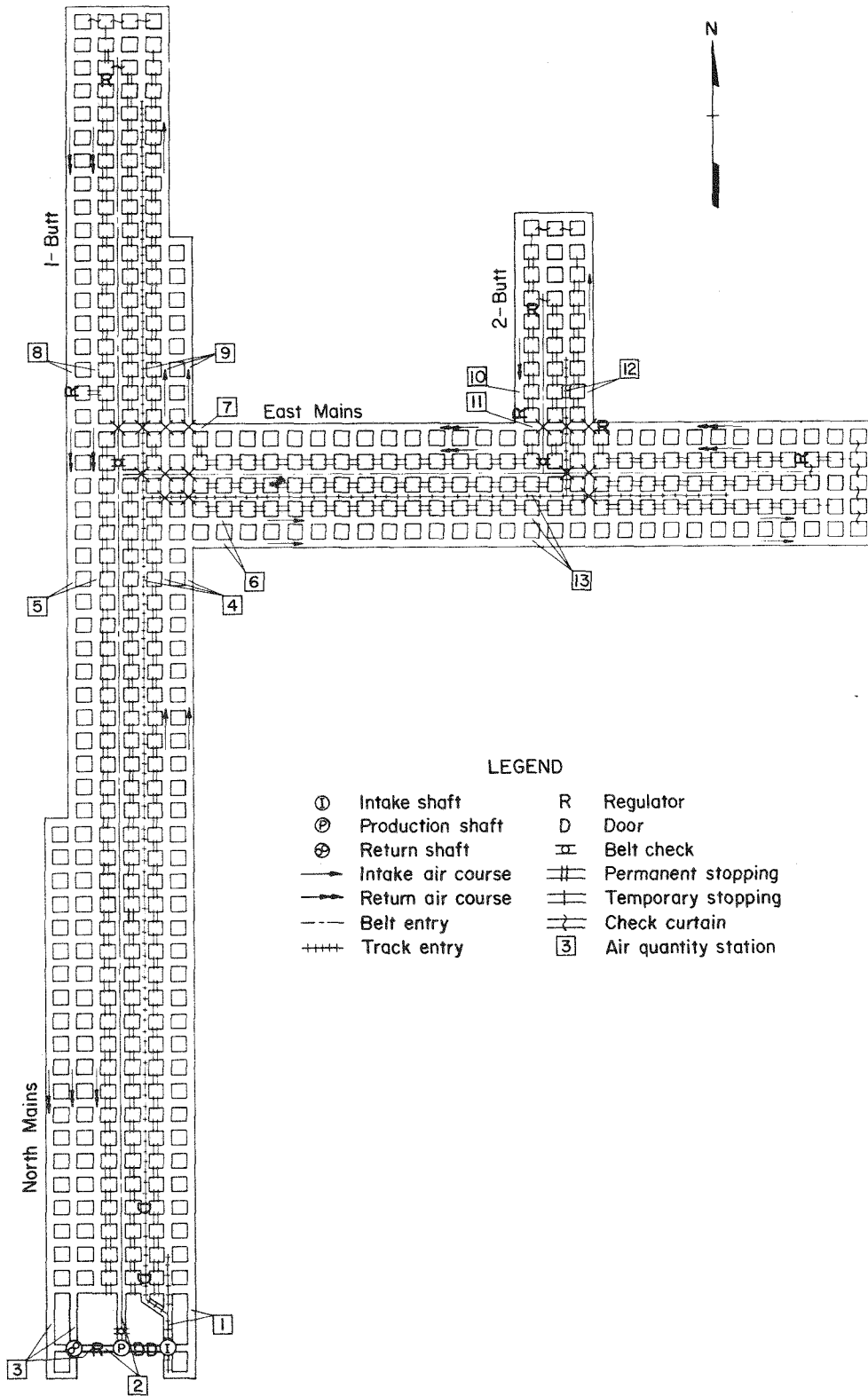


FIGURE 9. - Anemometer traverse route.

to maintain the anemometer between 3 and 4 feet away from the high air velocity zone created by his body in the airstream. The face of the instrument should be held perpendicular to the airflow direction. Repeated experience with this method will produce readings in each half that agree within five percent. Care should be exercised to insure that any erroneous readings taken are not used to calculate the average velocity. The left and right velocity refers to that half of the entry the traverse was made when looking upstream from the point of the air quantity measurement. The anemometer correction factor is applied to calculate the average air velocity in each half of the entry, and the results used to calculate the average air velocity in the entry. The average air velocity is multiplied by the area to determine the air quantity in cubic feet per minute. The air quantity should be calculated for each station before proceeding to the next station. This practice provides an on-the-spot check of the air quantities in the ventilation splits and allows for immediate investigation if the quantities do not balance.

Figure 10.- Mine map of air quantity measurement station locations.

Figure 10 is an example of where air quantity measurements can be taken during a survey. The sum of the air quantity measurements at stations 1 and 2 should be approximately the same as the sum of the measurements at Station 3, provided that the intake air temperature is equal to the return air temperature. The mass flow of the air entering the mine is equivalent to the mass flow of the air coming out, but the air volumes or quantities may be different. Some of the difference between the total intake and return air quantities in deep mines may be attributed



to methane liberation from the coalbed, but the major reason is normally a difference in air temperatures. When the temperature of the intake air is higher than the return air, the cubic feet of air entering the mine is greater than the cubic feet of air leaving the mine. The reverse is true when the temperature of the intake air is lower than the return air. In shallow mines, a difference in total quantities entering and leaving a mine may indicate cracks from the mine to the surface through which air may enter or leave a mine undetected.

The difference between the air quantities measured at Stations 4 and 5 indicates the air quantity in the belt entry at this point. The location of the air quantity station is critical. Station 4 should be located outby the turbulence created by the right angle turn of the intake air into East Mains. The quantity measurements for Stations 4 and 5 are made in the same line of pillars to assure that air is not being measured twice. An exception to this rule is illustrated by the location of Station 7 in reference to Station 6. At this location, Station 7 required only one air measurement to determine the total return air quantity from East Mains provided that all the stoppings immediately south of the station are intact. A similar relationship between Station 8 and 9 is shown, but in this case, two air quantity measurements are required at Station 8 to determine the total return air quantity from 1-Butt. The reason for not taking one reading where the return is checked down to a single entry is because of the airflow turbulence created by the return regulator. Air quantity measurements should not be made in the highly turbulant airstream immediately inby or outby an air regulator. Air measurements may be made at these regulators by applying a methods factor (14) to

a centerline vane anemometer reading or with the regulator formula that employs the static pressure drop at the regulator and the area of the opening.

Revised Regulator Formula

$$A = \frac{34.2 Q}{\sqrt{h}}$$

where V = air velocity through regulator (feet per minute),
 A = cross-sectional area of regulator (square feet),
 h = static pressure drop at regulator opening (inches water gage),
 and Q = air quantity through regulator (cubic feet per minute in units
 of 100,000).

The Magnehelic gage, along with a section of flexible hose roughly 8 feet in length, is used for measuring air pressure differentials (pressure drops) in a mine ventilation system. The Magnehelic gage is positioned on one side of a ventilation control device such as a door, regulator or stopping and the flexible hose is placed through an opening in the control with the end of the hose out of the effects of the air current flowing through the opening. The Magnehelic gage is held so that the pointer is in the zero position, and then the other end of the hose is attached to one of the two ports on the gage. If the pointer gives a negative response, then the hose should be changed to the other port on the gage. The Magnehelic gage measures the magnitude of the static pressure differential but it is essential that the operator determine the direction of flow.

Pressure differentials are measured across man doors in stoppings, air lock doors, track doors, regulators, and overcasts to determine the pressure loss caused by the control device. When a measurement is made across a man door, the hose connected to the Magnehelic gage is put through the man door opening, and the door closed so as not to pinch the hose. When measuring across a set of air lock doors, the hose is placed across the first door in the same manner as described with a man door, and then the second door in the air lock is opened. This same procedure is used with two track doors that are relatively close to each other. If the distance between the doors is excessive, then each door is measured separately. The actual pressure drop at a regulator opening closely approaches the total pressure drop induced on the airstream (14). To measure the pressure differential created, the hose is placed across the opening, both ends are positioned out of the effects of air turbulence, and the gage connected to one end of the hose. (Do not change the size of the regulator opening to make this reading). The pressure loss across one or more overcasts may be determined by taking the difference between the pressure differentials of the upstream and downstream approaches to the overcasts. These differentials are measured in the same manner as described for measuring the differential across a man door in a stopping. Figure 11 is a drawing of a side view of three overcasts with the locations of the pressure differential measurements.

Figure 11.- Pressure gage measurement locations at overcasts.

Figure 12.- Mine map of pressure drop station locations and altimeter station locations.

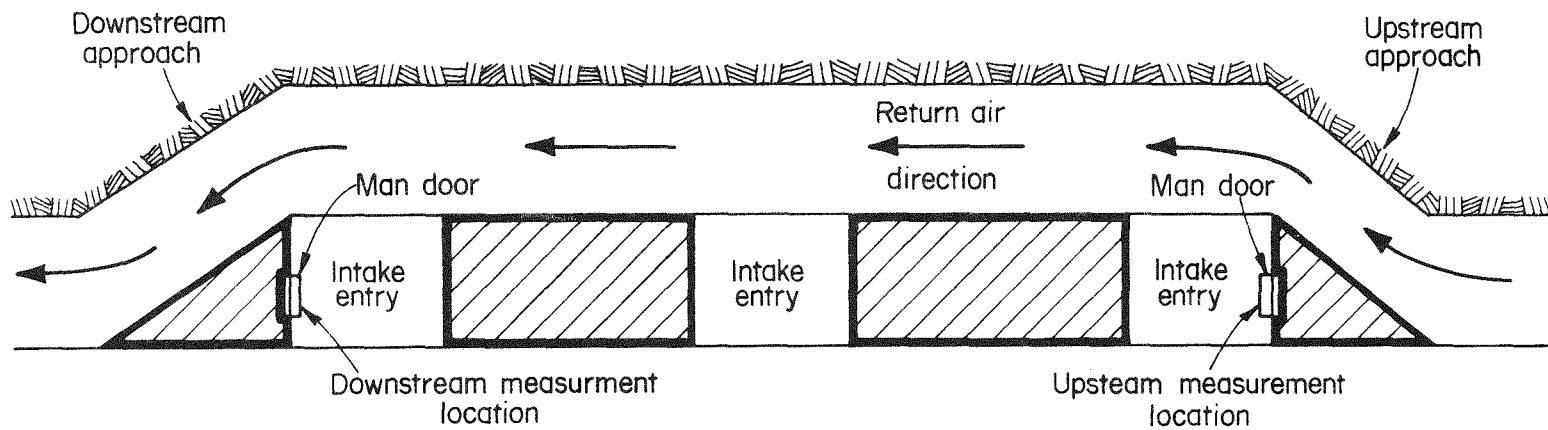


FIGURE 11. - Pressure gage measurement locations at overcasts.

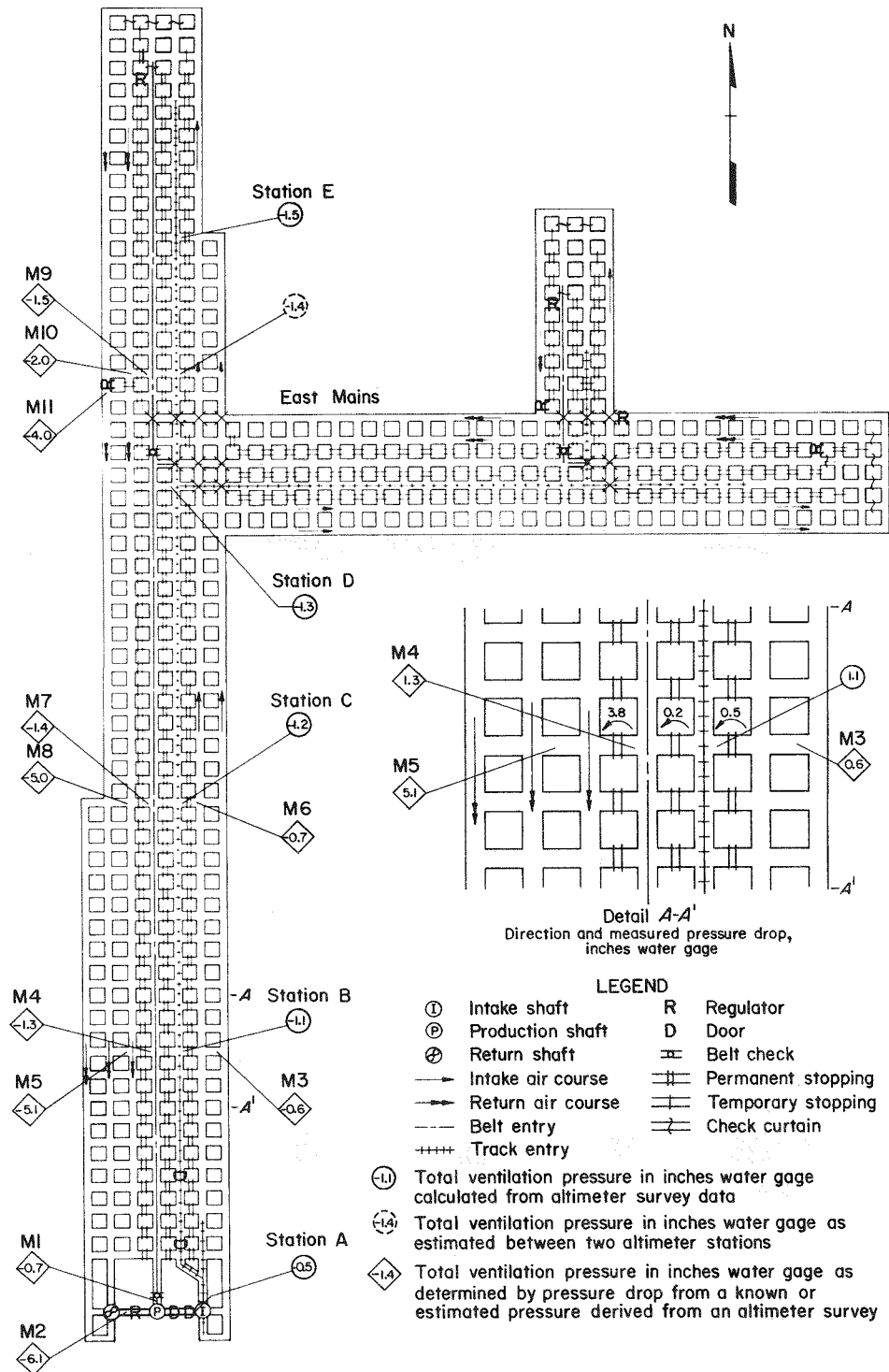


FIGURE 12. - Mine map of pressure drop station locations and altimeter station locations.

Figure 12 is an example of some of the pressure drop station locations that are employed during a ventilation survey. This figure also shows the location of the altimeter stations used during that part of the survey with the total ventilation pressures shown to illustrate how the pressure drop readings are used to determine the total pressures in aircourses adjacent to the altimeter stations.

The total ventilation pressure at Station A is shown as -0.5 inch water gage. A Magnehelic gage is used to measure the pressure differential across the air lock separating station M1 from Station A. The Magnehelic gage reading is 0.2 inch water gage, and the direction of airflow is from the intake entry side of the air lock to the belt entry side. This indicated that the total pressure is lower in the belt entry, therefore, the total ventilation pressure in the belt entry is -0.7 inch water gage. The pressure differential across the regulator that separates the belt entry (M1) from the return entries (M2) is 5.4 inches water gage, and the direction of airflow is from the belt entry side of the regulator to the return entry side. Therefore, the total ventilation pressure (TP) in the return entries at this point is -6.1 inches water gage.

The pressure differential between Station B and M3 is 0.5 inch water gage and the airflow is from the intake entries (M3) into the track entry (B). The pressure differential between Station B and Station M4 is 0.2 inch water gage with the airflow direction from the track entry (B) into the belt entry (M4), which means the TP in the belt entry is -1.3 inches water gage. The pressure differential between Stations M4 and M5 is 3.8 inches water gage and the airflow is from M4 to M5. The

TP calculated for M5 is -5.1 inches water gage. The TP for M6, M7, and M8 are computed in the same manner.

To obtain a TP at M9 requires a TP established from the altimeter survey. The nearest altimeter stations to M9 are Station D and Station E. The TP at Station D is -1.3 inches water gage at Station E, it is -1.5 inches water gage. Station M9 is approximately midway between Stations D and E, so the TP in the track entry opposite Station M9 is assumed to be -1.4 inches water gage. This assumption is valid provided the physical characteristics and air quantity in the track entry from Station D to E are approximately the same. The pressure differential between the track entry and station M9 is 0.1 inch water gage with the airflow from the track entry into the belt entry, which means the TP at Station M9 is -1.5 inches water gage. The differential from the belt entry (M9) into the return entries (M10) is 0.5 inch water gage, which indicates the TP at M10 is -2.0 inches water gage. The pressure differential or drop across the regulator at M11 is 2.0 inches water gage, which signifies that the TP on the downstream side of the regulator is -4.0 inches water gage.

The distance of the three return entries from Station M8 to Station M5 is the same as the distance between M5 and M2, but the ventilation head loss between the stations is not the same. The head loss from Station M8 to Station M5 is 0.1 inches water gage, and the loss between Station M5 and M2 is 1.0 inches water gage. The higher loss between Stations M5 and M2 indicates that a restriction may exist in this area provided the air quantity is constant from Station M8 to

Station M2. The restriction may be a reduction in the area of the entries caused by water or a roof fall, or anything else that decreases the area of an aircourse.

When measuring the pressure drop across a stopping separating two aircourses, the obtained value represents the static pressure (SP) differential. This pressure drop may be applied directly to a total pressure (TP) that was measured during an altimeter survey provided the air velocities in the two aircourses are approximately the same magnitude. If the air velocities are significantly different, the pressure drop should be applied to the known static pressure in one entry to determine the static pressure in the second entry. Then the velocity pressure in the second entry is added to this static pressure to determine the TP in the second entry at the location. As an example, if the air velocity in the intake entries at Station A (fig. 15) were 1,500 feet per minute and the air velocity in the belt entry at Station M1 were 400 feet per minute, the total pressure determined at Station M1 would be -0.83 inch water gage instead of -0.7. The TP measured at Station A was -0.5 inch water gage and the VP for an air velocity of 1,500 feet per minute is +0.14 inch water gage; therefore, the SP equals -0.64 inch water gage ($\pm TP = \pm SP + VP$). The 0.2 inch water gage pressure drop measured from Station A to Station M1 would be added to -0.64 inch water gage (SP at Station A), which indicates that the SP at Station M1 would be -0.84 inch water gage. The air velocity at Station M1 was 400 feet per minute which is +0.01 inch water gage VP. The sum of the SP and VP at Station M1 indicates that the TP at this location would be -0.83 inch water gage.

This example may be expressed as:

$$\Delta TP = \Delta SP = \Delta VP$$

$$\text{or: } TP_2 - TP_1 = SP_2 - SP_1 + VP_2 - VP_1$$

where

TP_2 = total pressure at Station M1

TP_1 = total pressure at Station A (-0.5 inch of water)

SP_2 = static pressure at Station M1 (-0.84 inch of water)

SP_1 = static pressure at Station A (-0.64 inch of water)

VP_2 = velocity pressure at Station M1 (+0.01 inch of water)

VP_1 = velocity pressure at Station A (+0.14 inch of water)

$$TP_2 - (-0.5) = -0.84 - (-0.64) + 0.01 - (+0.14)$$

$$TP_2 + 0.5 = -0.33$$

$$TP_2 = -0.83 \text{ inch of water.}$$

One way to highlight sections of the mine causing particularly high pressure losses is to draw ventilation pressure gradients (8). These diagrams show the ventilation pressure losses incurred by the air current as it flows through the major aircourses. The gradients are constructed by plotting the total ventilation pressure at selected locations in the mine against the distance of the locations from a given reference. A steep slope on the pressure gradient indicates an area in the mine with a high resistance or high airflow. The steep pressure gradient areas are of primary concern when locating portions of the mine where improvements, in terms of reduced mine resistance, would have the greatest effect.

MINE FAN SURVEY

At each of the surface fan sites, a mine fan survey is made to determine the fan operating point, and as a check on the air quantity and pressure measurements taken in the mine (1)(7). To make these determinations, it is necessary to ascertain: the various fan air pressure measurements, the fan air density, and the fan annulus area which requires knowing the fan model and type of drive (direct or belt).

The rated fan static pressure equals the difference between the total pressure at the fan inlet and the static pressure at the outlet (12). An exhaust fan installation with a diffuser or evase has a static pressure of zero at the discharge. Therefore, the rated fan static pressure for an exhaust fan is the total pressure at the fan inlet. The total pressure at the fan inlet may be measured by making a 20-point equal-area Pitot-tube traverse at the fan's inlet. Five pressure points in each of the four quadrants are measured and averaged. Figure 13 shows the boundaries and radii of five equal areas around a fan hub. The following example is used to calculate the distance from the fan housing of the five equal-area traverse points (3).

* A_T = Area of the fan annulus in square inches at traverse location

* R_6 = Radius of the fan housing in inches at traverse location

* R_1 = Radius of the fan hub in inches at traverse location

*These figures should be obtained from the fan manufacturer.

$$R_2 = \sqrt{\frac{A_T + R_1^2}{5n}}$$

$$P_1 = \sqrt{\frac{A_T + R_1^2}{10n}}$$

$$R_3 = \sqrt{\frac{A_T + R_2^2}{5n}}$$

$$P_2 = \sqrt{\frac{A_T + R_2^2}{10n}}$$

$$R_4 = \sqrt{\frac{A_T + R_3^2}{5n}}$$

$$P_3 = \sqrt{\frac{A_T + R_3^2}{10n}}$$

$$R_5 = \sqrt{\frac{A_T + R_4^2}{5n}}$$

$$P_4 = \sqrt{\frac{A_T + R_4^2}{10n}}$$

$$P_5 = \sqrt{\frac{A_T + R_5^2}{10n}}$$

$F_1 = R_6 - P_1 =$ distance of P_1 from fan housing in inches

$F_2 = R_6 - P_2 =$ distance of P_2 from fan housing in inches

$F_3 = R_6 - P_3 =$ distance of P_3 from fan housing in inches

$F_4 = R_6 - P_4 =$ distance of P_4 from fan housing in inches

$F_5 = R_6 - P_5 =$ distance of P_5 from fan housing in inches

Figure 14 illustrates the location of the Pitot-tube ports for the four fan quadrants. The 20-point traverse method should also be used to measure the air velocity pressures at the fan inlet. Air velocity pressures are converted to air velocities and the average of these velocities, corrected to ambient air density, are used in calculating the air quantity flowing through the fan.

Static pressure measurements of the air through the fan can be made and are used for determining the fan air density and to check the total pressure and velocity pressure measurements.

Figure 13.- Boundaries and radii of five equal areas around a fan hub.

Figure 14.- Pitot-tube port locations for the four fan quadrants.

The following is an example of the Pitot-tube data collected for a mine fan survey. It shows how the average velocity is determined from these readings (1) (3).

Fan Description: Joy M72-36 Direct Drive

Fan Annulus Area: 23.59 square feet

Mine Air Temperature at Fan, Dry-Bulb: 63° Fahrenheit

Barometric Pressure: 29.77 inches mercury

Elevation: 750 feet above sea level

$$\pm TP = \pm SP + VP$$

(TP) Total Pressure <u>inches water gage</u>	(SP) Static Pressure <u>inches water gage</u>	(VP) Velocity Pressure <u>inches water gage</u>	Velocity <u>feet per minute</u>
1st Quadrant			
-7.2	-10.2	+3.1	7052
-7.3	-10.3	+2.9	6820
-8.3	-10.1	+2.0	5664
-7.9	-10.0	+2.2	5940
-7.4	- 9.9	+2.5	6332

2nd Quadrant			
-7.0	-10.1	+3.0	6937
-7.0	-10.0	+3.0	6937
-7.0	- 9.9	+2.9	6820
-7.1	- 9.7	+2.8	6702
-7.2	- 9.8	+2.7	6581
3rd Quadrant			
-6.9	- 9.9	+3.0	6937
-6.9	- 9.9	+3.0	6937
-7.0	- 9.9	+2.9	6820
-7.0	- 9.9	+2.8	6702
-6.9	- 9.8	+2.8	6702
4th Quadrant			
-7.1	-10.2	+3.2	7164
-7.0	-10.0	+3.2	7052
-7.0	- 9.9	+2.9	6820
-7.1	- 9.8	+2.7	6581
-7.3	- 9.7	+2.5	6332
Average	-7.2	-10.0	6692

$$\text{Velocity} = 4005 \times \sqrt{VP}$$

If the fan is not equipped with Pitot-tube ports, a static pressure differential across the air lock doors of the fan may approximate the total pressure at the fan inlet. The static pressure measurement is obtained by placing the hose from a Magnehelic gage across the inner air lock door and opening the outer door all the way before reading the gage. Normally this measurement will more closely approximate the total pressure of the fan if the velocity pressure of the air flowing past the air lock doors is known and used in the formula $\pm TP = SP + VP$. This velocity pressure can be measured with a Pitot-tube or determined from the velocity of the air flowing past the air lock doors in the air duct. A method for calculating the air velocity is to use the formula $Q = VA$ and solve for V .

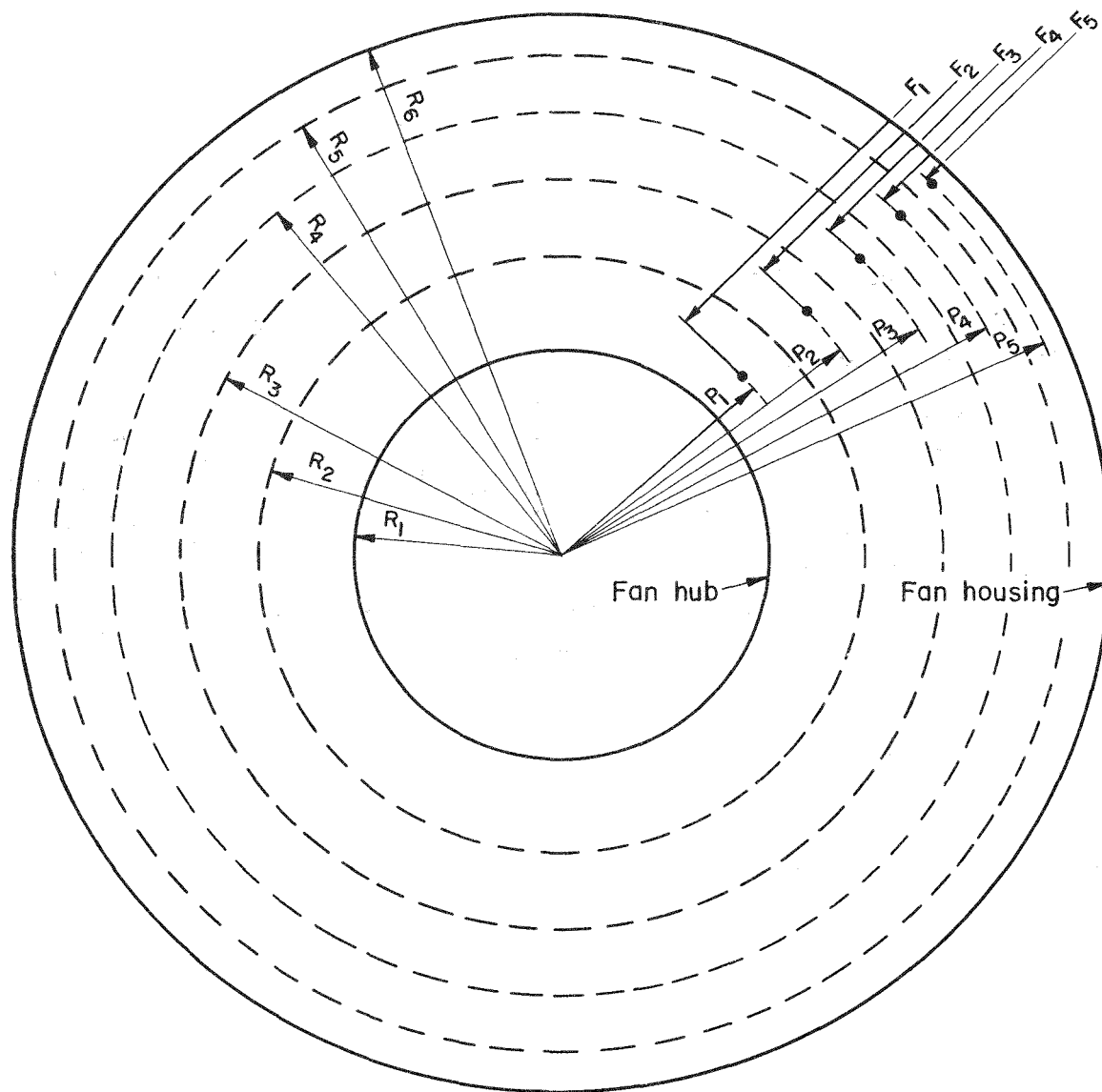
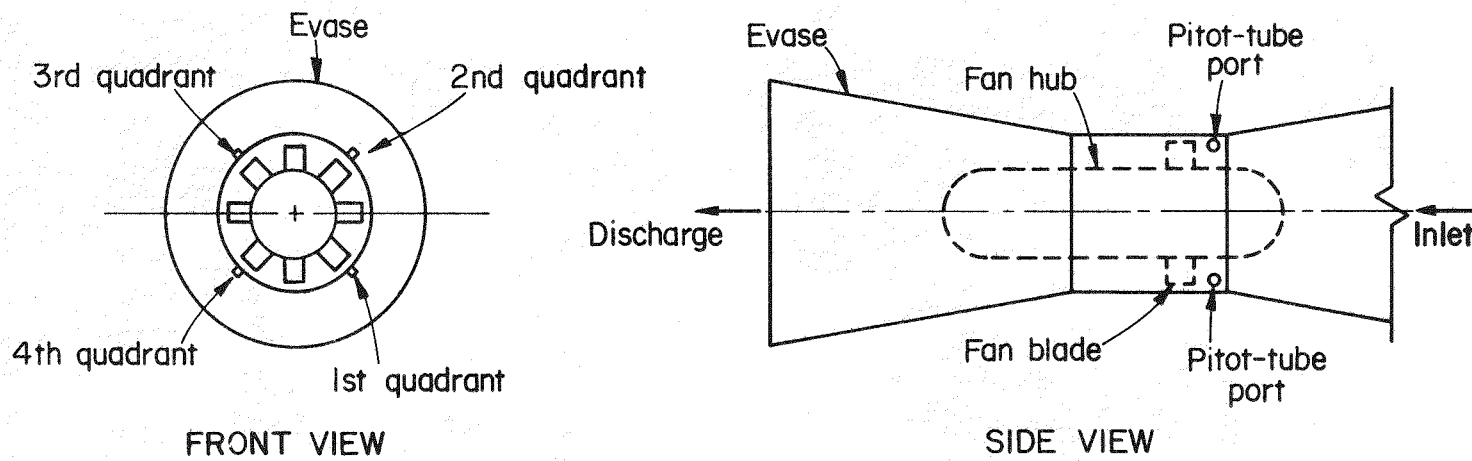


FIGURE 13. - Method for calculating the distance from the fan housing of the five equal-area traverse points.



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FIGURE 14. - Pitot-tube port locations for the four fan quadrants.

where

Q = total air quantity as obtained by underground measurements
(cubic feet per minute),

V = air velocity (feet per minute),

and A = area of the air duct opposite the air lock doors (square feet).

The mine air temperature and barometric pressure are measured to determine the mine air density through the fan. The temperature of the air through the fan is measured inside the fan house. The barometric pressure of the mine air in the fan is the difference between the barometric pressure of the atmosphere at the elevation of the fan site and the static pressure of the fan as measured at the fan Pitot-tube ports. The barometric pressure is in inches of mercury units and the static pressure of the fan is in inches water gage. An example of how to calculate the fan air density is as follows.

63° Fahrenheit	= The mine air temperature in the fan,
29.77 inches mercury	= the barometric pressure at 750 feet above seal level,
-10.0 inches water gage	= the static pressure differential between the outside air and the fan air at the Pitot-tube ports,
1 inch mercury	= 13.6 inches water gage.

$$\therefore \frac{-10.0 \text{ ins. w.g.}}{13.6 \text{ ins. w.g.}} = -0.735 \text{ inch mercury}$$

Because the example used is an exhaust fan, the static pressure reading is a negative number; therefore, the barometric pressure of the mine air in the fan is determined by subtracting the fan static pressure in inches mercury from the barometric pressure at 750 feet above sea level.

$$\begin{array}{r} 29.77 \text{ inches mercury} \\ -0.74 \text{ inches mercury} \\ \hline 29.03 \text{ inches mercury} \end{array}$$

The fan air density in pounds per cubic foot is calculated from the following formula:

$$D = \frac{1.327}{460+T} \times B$$

where:

D = Density (pounds per cubic foot),

T = temperature of fan air ($^{\circ}$ Fahrenheit),

B = barometric pressure of fan air (inches mercury).

$$\therefore D = \frac{1.327}{460 + 63} \times 29.03$$

$$D = 0.074 \text{ pound per cubic foot}$$

This formula is for dry air and is accepted for calculating air densities used in ventilation surveys (7). For precise air densities, the formula is:

$$D = \frac{1.327}{460 + T} \times (B - 0.378 f)$$

where the vapor pressure (f) in inches mercury at the dewpoint is determined from psychrometric charts or tables (9).

The air quantity through the fan is calculated by multiplying the average corrected air velocity through the fan by the fan annulus area at the location

of the velocity pressure measurements (8). The fan annulus area data is obtained from the fan manufacturer. A difference between the fan air quantity and the air quantity measured in the main returns to the return airshaft may indicate air leakage at the fan housing installation. The total return air quantity measured in the mine with an anemometer may be higher than the air quantity measured at the fan with a Pitot-tube. The difference can be attributed to the anemometer procedure used or the influence the operators body has on the air velocity profile in the entry. Over spin (11) on the anemometer may give higher air velocities than actually exist.

The following is an example of how the fan air quantity is calculated:

Average air velocity = 6692 feet per minute

Fan air density = D = 0.074 pound per cubic foot

$$\text{Density correction factor} = \sqrt{\frac{0.075^*}{D}}$$

Area of fan annulus = 23.59 square feet (supplied by fan manufacturer). The fan air quantity at a fan air density of 0.074 pound per cubic foot would be the product of the average air velocity x density correction factor x the area of the fan annulus:

*Note: Standard air density is 0.075 pound per cubic foot based on dry air at 70° Fahrenheit and 29.92 inches mercury barometric pressure.

$$\therefore \text{Fan air quantity} = 6692 \text{ feet per minute} \times \sqrt{\frac{0.075}{0.074}} \times 23.59$$

square feet

$$\text{Fan air quantity} = 158,927 \text{ cubic feet per minute or } 159,000$$

cubic feet per minute

In order to apply the correct fan characteristic curve, the fan speed in revolutions per minute (rpm) must be known. At a direct drive fan installation, the rpm of the fan is usually measured with a tachometer at the shaft of the drive motor (1). With a belt driven fan, a tachometer reading is taken at the fan shaft on the inlet side of the fan, provided the end of the shaft does not have a nose cover on it. (Do not attempt to remove this cover with the fan running). When the fan shaft is inaccessible, the rpm of the fan motor is measured, and the fan speed calculated by multiplying the fan motor rpm by the ratio of the diameter of the fan motor pulley to the diameter of the fan shaft pulley, assuming that the fan belt slippage is zero.

$$\text{Fan rpm} = \text{motor rpm} \times \text{motor pulley diameter} / \text{fan pulley diameter}.$$

If the measured fan speed is not the same as the rpm of the fan characteristic curves supplied by the fan manufacturer, the characteristic curves must be changed to correspond to the speed of the fan. This change may be accomplished by constructing new fan characteristic curves based on the speed of the fan and the fan laws:

FAN LAWS

1. The air quantity varies directly as the fan speed and is independent of air density.
2. The rated fan static pressure varies directly as the fan speed squared and directly as air density.
3. The fan horsepower input varies directly as the fan speed cubed and directly as air density.

If the speed of a fan were to be doubled, the following example illustrates the changes in fan performance by applying the fan laws.

	<u>Present</u>	<u>Future</u>
Fan speed (rpm)	600 x 2	1,200
Air Quantity (cfm)	100,000 x 2	200,000
Fan Pressure (in. w.g.)	4 x 4	16
Horsepower Input (hp)	100 x 8	800

A fan run at a constant speed and blade position produces only those combinations of pressure and quantity indicated by its characteristic curve for that speed and blade position. The pressures required for flow through a system vary with the quantity, and are defined by the mine resistance curve which can be calculated (12)

by using the equation $H = RQ^2$. Because the system pressure loss caused by flow must equal the pressure causing airflow, only one combination of air pressure and quantity will satisfy requirements of both fan and system. This combination is called the fan operating point, and occurs at the intersection of the mine resistance and fan characteristic curves.

Figure 15.- Fan characteristic curves, fan operating point, and mine resistance curve.

If the speed of a fan was 1,180 rpm, then the blade position that the fan was in could be determined without stopping the fan by applying the measured rated fan static pressure and fan air quantity to the proper fan characteristic curve. Figure 15 provides the fan characteristic curves for the number 5 through the number -2 blade positions of a Joy M72-36 mine fan operated at 1,180 rpm with an air density of 0.075 pound per cubic foot (4). The rated fan static pressure is indicated on the left vertical scale in inches water gage at the standard air density of 0.075 pound per cubic foot, and the air quantity is shown on the horizontal scale in cubic feet per minute in units of 100,000. Along the right vertical scale, the pressures in inches water gage at an air density of 0.074 pound per cubic foot are displayed. Normally, the right vertical scale is not provided and must be calculated using the fan law; pressure varies directly as air density.

The rated fan static pressure was -7.2 inches water gage and the fan air quantity was 159,000 cubic feet per minute at a 0.074 pound per cubic foot air

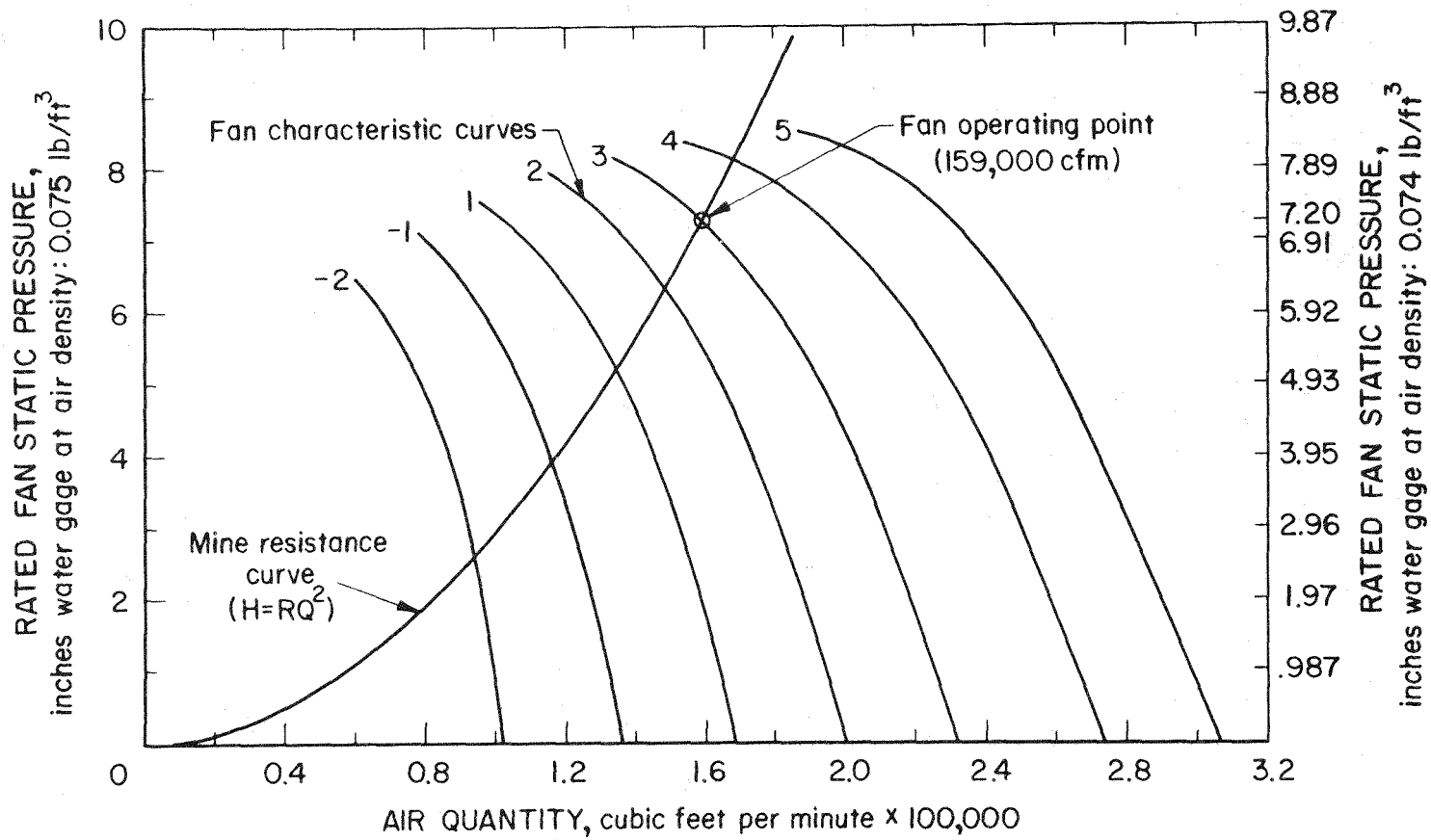


FIGURE 15. - Fan characteristic curves, fan operating point, and mine resistance curve.

density in the fan data example. The fan operating point is shown as the intersection of a line drawn from 7.2 inches along the right vertical scale with a line drawn from 159,000 cfm along the horizontal scale. The location of the fan operating point indicates that the fan is performing in the No. 3 blade position. Figure 15 also illustrates the fan performance to be expected from blade position changes when mine ventilation is induced by a single fan. When a blade position change is made, the new fan operating point will be the intersection of the mine resistance curve with the fan characteristic curve for that blade position. As an example, if the fan blade were changed from the No. 3 to the No. 1 position, the new operating point would be 134,000 cfm at a pressure of 5.05 inches w.g.

An air quantity less than 159,000 cfm for a rated fan static pressure of -7.2 inches water gage may be an indication that the fan is in a lower blade position or the fan efficiency has changed. As the mine resistance to airflow increases, the fan operating point moves higher on the fan curve (higher rated fan static pressure, lower air quantity); the reverse occurs when the mine resistance decreases.

As the fan approaches the top of the fan curve, it is nearing the aerodynamic stall portion of the fan curve which is normally not shown on manufacturer's fan curves (7). The stall portion of the fan curve must be avoided because of the sporadic performance of the fan when operating in this zone and the possibility of physically damaging the fan. It is also very inefficient to operate near the stall zone. As illustrated in figure 15, the fan cannot effectively perform in

the No. 5 blade position because the mine resistance curve passes to the left of the stable zone of its fan characteristic curve. If a mine fan goes into a stall, the quickest remedy is to short circuit air at the fan installation to bring the fan out of the stall zone, and then investigate the mine ventilation system to determine the cause of the high resistance and correct it.

The air horsepower developed by the fan can be calculated when the rated fan static pressure and air quantity are known (1). This value divided by the fan efficiency supplied by the fan manufacturer gives the brake horsepower required at the fan shaft.

$$\text{Air horsepower} = \frac{\text{Pressure (inchs water gage)} \times \text{Air Quantity (cfm)}}{6356}$$

$$\text{Brake horsepower} = \frac{\text{Pressure (inches water gage)} \times \text{Air Quantity (cfm)}}{6356 \times \text{Fan Efficiency (decimal)}}$$

The fan brake horsepower indicates the load on the fan motor and is used to determine what additional motor capacity is available, if any, for increasing the fan's capacity by a fan blade change or increasing the fan rpm. When increasing the fan's speed, it is important not to exceed the fan manufacturer's maximum tip speed for the fan blades. The maximum tip speed of the blades of a new fan normally ranges from 25,000 to 30,000 feet per minute. The tip speed of the fan blades is calculated by multiplying the outer diameter of the fan blades in feet by the constant π (3.14) by the revolutions per minute of the blades. When increasing

the fan speed on a belt driven fan, the speed of the fan belt is also critical. The fan belt speed should not exceed the belt manufacturer's recommendations, which may be set at approximately 6,000 feet per minute maximum. The fan belt speed is determined by multiplying the diameter of the fan motor pulley in feet by the constant π (3.14) by the rpm of the fan motor.

Another factor to be considered when making mine fan surveys is the natural ventilation pressure. Natural ventilation is the result of the difference of air densities in air columns for the same vertical distance (8). The natural ventilation pressure may act with or against the man mine fan depending upon which air column is heavier. In the summer season when the outside temperatures are higher than the return air temperatures, the return air column is normally heavier than the intake air column, in which case, the natural ventilation pressure is against the fan. This results in the mine fan producing less air quantity at a higher fan pressure than when the natural ventilation pressure is zero. The reverse is true during the winter season when the outside air is colder than the return air from the mine. The natural ventilation pressure (NVP) can be quickly estimated as 0.03 inch water gage for each 10° Fahrenheit average temperature difference of air columns per 100 feet increment of vertical elevation. Other methods are available but this is the most practical.

$$\text{NVP} = 0.03'' \text{ water gage} \times \frac{\text{temperature difference } (^\circ\text{F})}{10} \times \frac{\text{vertical elevation (ft)}}{100}$$

The use of this formula requires height of the air column in feet and the average air temperatures of the intake and return air columns in degrees Fahren-

heit. To determine the average temperature of the air in a shaft, the air temperature should be measured at the top and bottom of the airshaft. Normally, the air temperature at the top and bottom of shallow shafts is approximately the same. However, in deep shafts, the temperature may be higher at the bottom due to adiabatic compression of the air in the shaft. The rate of increase in temperature is approximately 5.5° Fahrenheit per 1,000 feet of vertical depth (13).

Figure 16.- Fan operation in combination with NVP assisting mine fan.

Figure 16 illustrates the mine resistance curve when NVP is assisting the mine fan (12). The NVP is calculated from measurements taken in the mine openings and in this example assumed to be 1 inch water gage aiding the fan. A combined characteristic curve is plotted 1 inch vertically above the fan characteristic curve. The rated fan static pressure is measured and this pressure extrapolated until it intersects the fan characteristic curve at a point referred to as the measured fan operating point with NVP in the figure. This indicates that the fan is exhausting 166,000 cfm of air at a rated fan static pressure of 6.9 inches water gage. The measured fan operating point is now extended vertically until it intersects the combined characteristic curve at a point which is designated as the combined operating point. The air quantity and fan pressure (166,000 cfm, 7.9 inches water gage) at this point is inserted into the equation $H = RQ^2$, and the equation solved for R to determine the mine resistance which is used to construct the mine resistance curve. The intersection of the mine resistance curve and the fan characteristic curve is where the fan would perform if the NVP were zero (159,000 cfm at 7.2 inches water

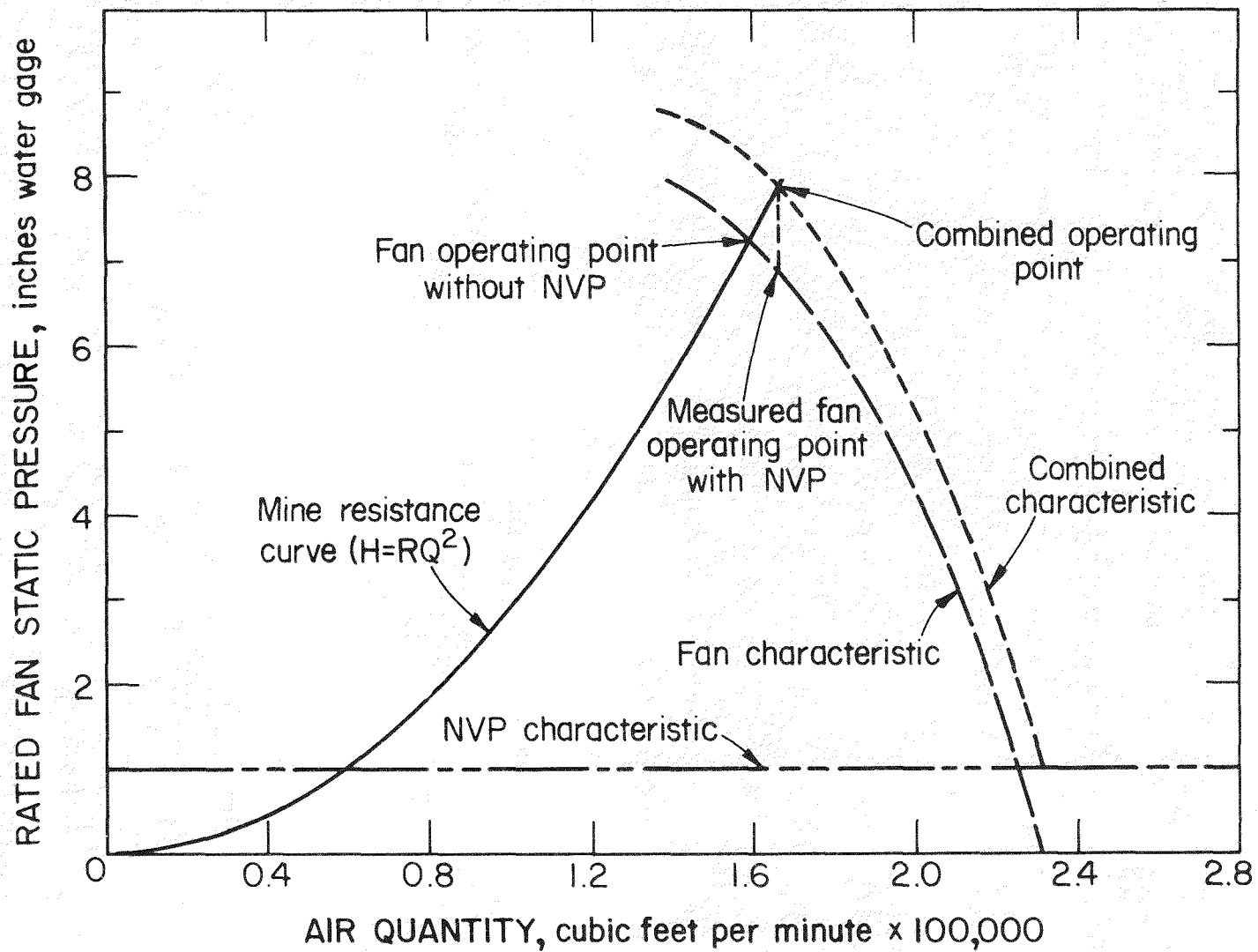


FIGURE 16. - Fan operation in combination with NVP assisting mine fan.

gage) and is described as the fan operating point without NVP. Figure 17 shows the mine resistance curve when NVP is assumed to be 1 inch water gage opposing the mine fan. The combined characteristic curve is plotted vertically below the fan characteristic curve and the remainder of the information determined as in figure 16.

Figure 17.- Fan operation in combination with NVP opposing mine fan.

Figures 16 and 17 illustrate how a measured fan operating point may change due to temperature differences between the intake and return airflow into and out of a mine. When the measured fan operating point is near the top of its fan characteristic curve, an increase in the NVP against the fan may cause the mine fan to go into an aerodynamic stall.

COMPUTER SIMULATION

The field data must be balanced before the survey can be accurately simulated by a digital computer program (15). The first step is to put the air quantity and pressure measurements from the field survey on a schematic of the overall mine ventilation system. An example of a ventilation schematic of the mine map is shown in figure 18. Next, the air quantities are balanced so that the amount of air entering and leaving each part of the mine is the same. Finally, the total air pressures measured are evaluated.

Figure 18.- Ventilation schematic of mine map.

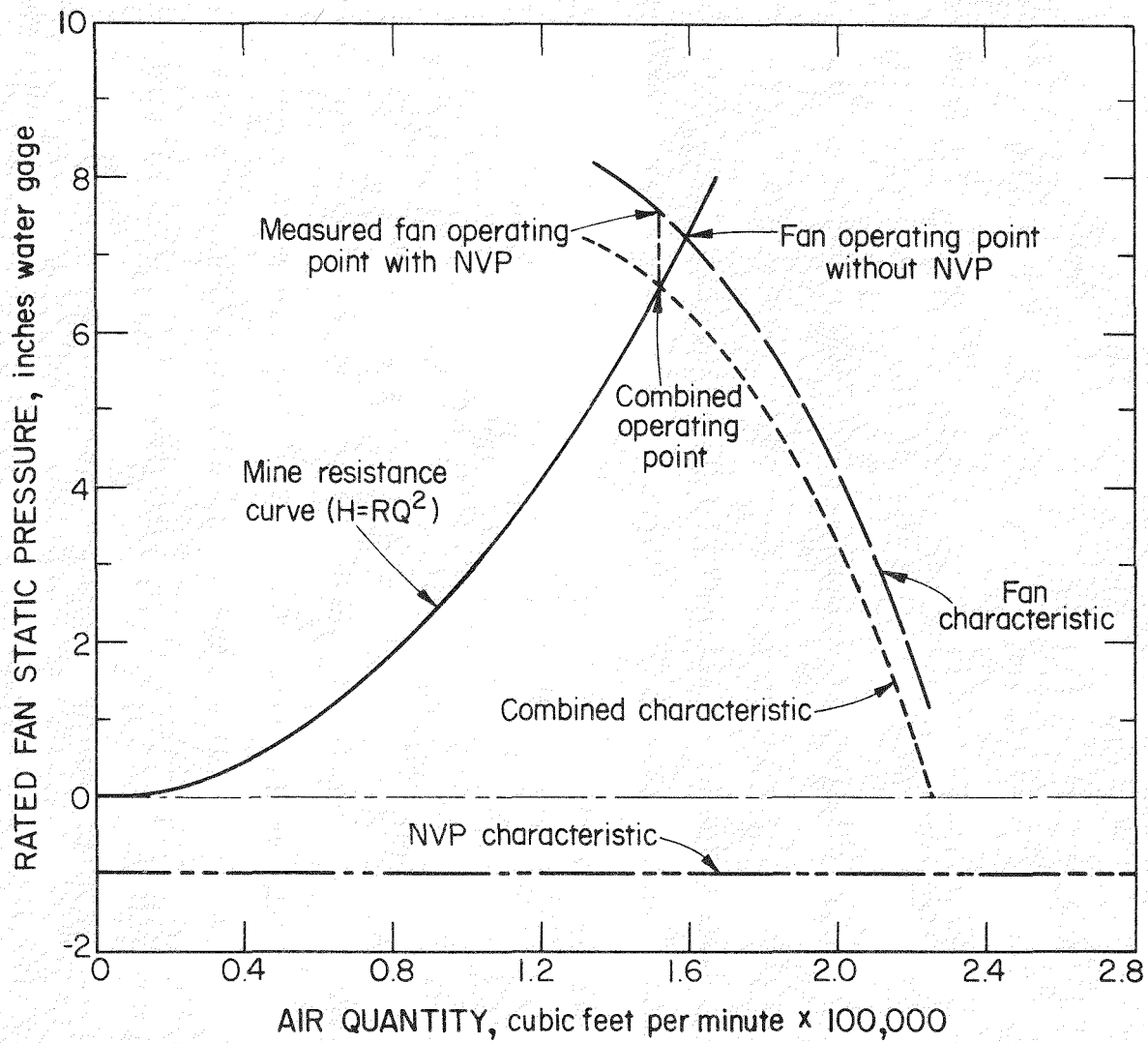


FIGURE 17. - Fan operation in combination with NVP opposing mine fan.

The resistance for each airsplrit (or branch) must be entered in the computer. The resistance of an airsplrit is calculated from the formula $R = H/Q^2$. Where R equals the resistance, H is the ventilation head loss of the splrit in inches water gage and Q is the air quantity flowing through the splrit in cubic feet per minute in units of 100,000. A junction number is assigned to each end of an airsplrit which is used by the computer to identify the splrit and its location in the overall system. A suggested method of assigning junction numbers is illustrated in the legend of figure 18. The computer program requires that Junction 1 be located on the surface. The remaining numbers are assigned in ascending order according to airflow direction to expedite the handling of computer printout data later. The air leakage occuring along the stopping line between Junction 2 and Junction 4 is concentrated in a single leakage path as shown by the arrow between Junction 3 and Junction 102. Other leakage paths are established in the ventilation system as required by following this same procedure.

The surface or top of the intake shaft is assigned Junction 1. The bottom of the intake airshaft is Junction 2. The total ventilation pressure (TP) at Junction 1 is 0.0 inch water gage, the TP at Junction 2 is -0.5 inch water gage, and the air quantity is 1.29 (129,000 cubic feet per minute). The resistance of branch Junction 1 to Junction 2 is $0.5/(1.29^2) = 0.3005$. One of the air branches common with Junction 2 is Junction 2 to Junction 3. The TP at Junction 2 is -0.5 inch water gage, the TP at Junction 3 is -0.6 inch water gage, and the airflow in the splrit is 1.14 (114,000 cubic feet per minute). The resistance of splrit Junction 2 to Junction 3 is $0.1/(1.14^2) = 0.0769$. This procedure is repeated until the resistance of every

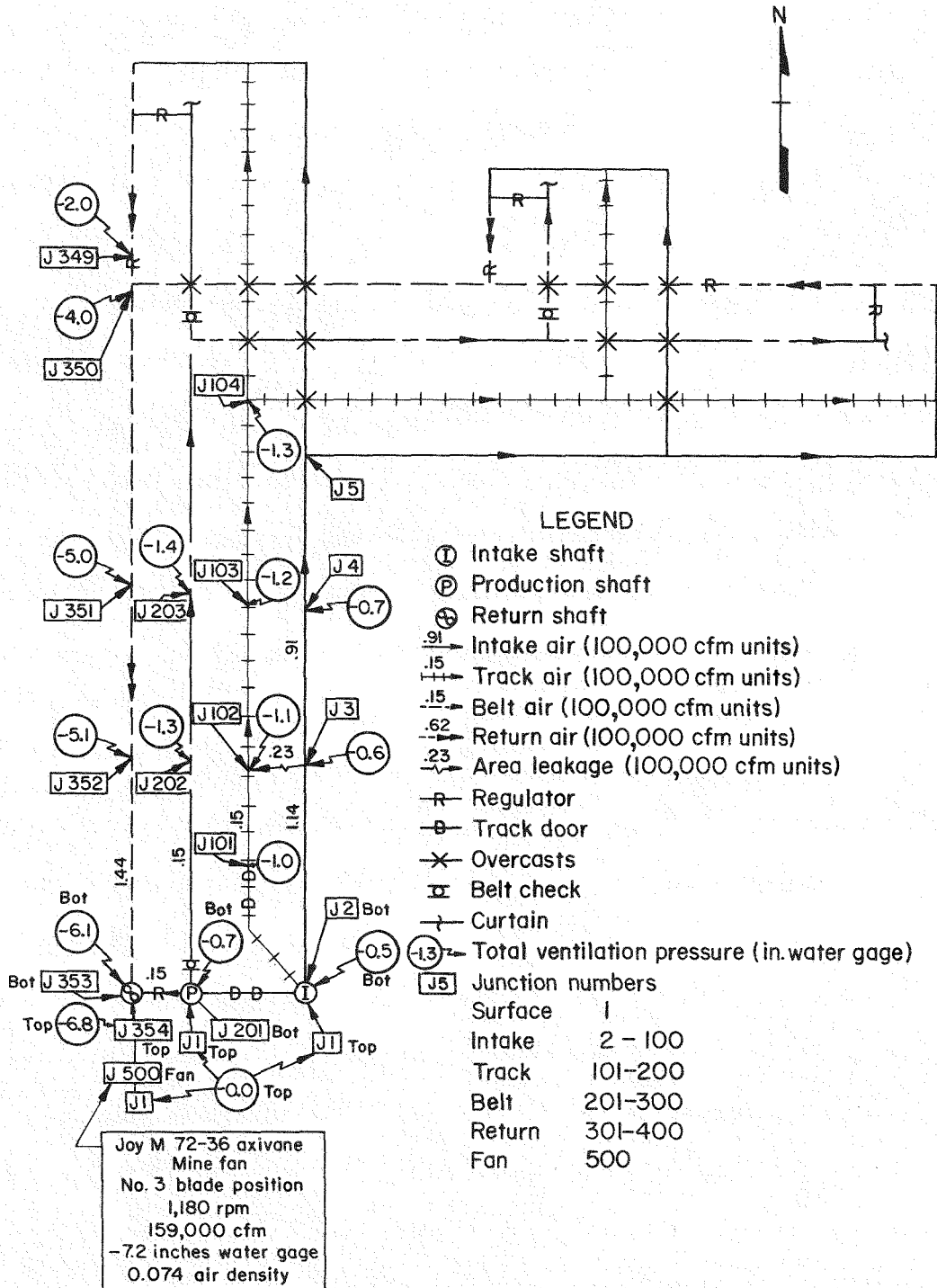


FIGURE 18. - Ventilation schematic of mine map.

airsplit (or branch) is calculated for each split identified with appropriate junction numbers. The last branch identified in the mine ventilation system is the mine fan which is located at the top of the return shaft at Junction 500. It is identified as Junction 500 to Junction 1 because after the air passes through the fan, it rejoins the outside air. No resistance is calculated for this split but the total air quantity flowing through the fan and the data for the fan's characteristic curve are entered into the computer. The program is run after the survey and fan data have been properly entered, and the computer printout used to ascertain that the computer is correctly simulating the mine ventilation system as surveyed.

When the survey information has been correctly simulated in a computer program, changes to the existing system can be assumed and evaluated to determine if the proposed changes would improve the ventilation system. Such changes as increasing the number of aircourses in a split or the best location for an airshaft are examples. The most efficient ventilation system for the future development of the mine can also be projected. The practicality and feasibility of any of these proposals can be determined before any money is expended on the actual projects.

CONCLUSION

There are other methods available for conducting air pressure quantity surveys but the method described in this report has produced excellent results for accurately analyzing mine ventilation systems and forecasting future changes in these systems.

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APPENDIX

Where the survey involves a closed pressure loop, the starting and finishing at the same point then, in the absence of natural ventilation pressures (NVP), the final pressure should be 0, and the closeness of the result to 0 is indicative of the accuracy of the calculations. As computations are carried out only to the nearest foot, or to about 0.014 inch water gage, a final result of 3 to 4 feet or (0.04 to 0.06 inch water gage), representing the error of closure, is to be expected.

Although a small error of closure indicates a high degree of overall accuracy, many errors due to incorrect elevations, incorrect altimeter readings, and incorrect velocity pressure differences result in compensating errors. The loss determined for one section is too high or too low, while that determined for an adjoining section is correspondingly too low or too high. Absolute accuracy can therefore be gaged only by comparing the results of independent check surveys; it depends on the accuracy of elevations and of the calibrations of the instruments used.

The procedure (10) for determining the total pressure differential between two stations can be reduced to a single equation (2):

$$DTP = \frac{\left\{ [(E_2 - E_1) (DR)] - [(A_2 - A_1) - (B_2 - B_1)] \right\} \log^{-1} \left(1.476 - \frac{(A_2 - \text{offset}) + (A_1 - \text{offset})}{(2) (62,584)} \right)}{(4008)^2}$$

1998

$$+ \frac{V_2^2 - V_1^2}{(4008)^2}$$

Re-written in a sequential form to save program steps:

$$DTP = \frac{[(E_2 - E_1)(DR) - A_2 + A_1 + B_2 - B_1] \log^{-1} [1.476 - (8 \times 10^{-6})(A_2 + A_1 - 2 \text{ offset})]}{1998}$$

$$+ (6 \times 10^{-8})(V_2^2 - V_1^2)$$

where:

DTP = Total pressure differential between two pressure stations
(inches water gage),

E_1, E_2 = elevations at two pressure stations (feet),

DR = Density Ratio $\frac{\text{Density of Mine Air}}{\text{Density of Dry Air at } 50^\circ\text{F}}$

A_1, A_2 = roving altimeter readings at same time as roving altimeter readings
(feet of air),

B_1, B_2 = base altimeter readings at same time as roving altimeter readings
(feet of air),

V_1, V_2 = air velocity at two pressure stations (feet per minute),

Offset = the number of feet of air the altimeter scale zero differs from
zero elevation (usually 0 or 1,000 feet).

The subscript No. 1 and 2 denote the first and second pressure stations, between which the differential total pressure is desired.

The density ratio is calculated for five ranges of wet-bulb depression by the following equations:

<u>Wet-bulb depression:</u>	<u>Density Ratio (DR):</u>
0 to 2.5	$1.101 - 0.00214 \frac{T_2 + T_1}{2}$
2.5 to 7.5	$1.104 - 0.00212 \frac{T_2 + T_1}{2}$
7.5 to 12.5	$1.101 - 0.00206 \frac{T_2 + T_1}{2}$
12.5 to 17.5	$1.101 - 0.00201 \frac{T_2 + T_1}{2}$
17.5 to 22.5	$1.096 - 0.00195 \frac{T_2 + T_1}{2}$

Where T_1 and T_2 are the dry-bulb temperatures at two pressure stations in degrees F. The wet-bulb depression is the difference of the average dry-bulb and the average wet-bulb of the two stations.

The program is broken into two parts. The initial program utilizes the density ratio equations and calculates the average density ratio between stations. After the density ratio data for all stations is recorded on calculating form, the pressure equation program is used to calculate differentials of total pressure between two pressure stations and cumulative total pressures.