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VERNEUIL-EN-HALATTE, le May 1973.

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FINAL REPORT

DEVELOPMENT OF A PERSONAL DUST SAMPLER

by C. FROGER and P. COURBON

Bureau of Mines contract n° H 0122032 CERCHAR

CONTENTS

I - INTRODUCTION

Since its creation in 1950, the Centre d'Etudes et Recherches des Charbonnages de France at Verneuil-en-Halatte (Oise) has been conducting many investigations concerned with airborne dust measurements, particularly in underground mines.

The work has resulted in the development, a few years ago, of a new process of dust sampling, whereby the airborne dust particles are collected by a rotary filter of polyurethane foam rotating at high speed within a housing.

The interesting possibilities of this collecting process has led to the design :

- of a new dust sampler for measuring air pollution, the CPA,
- then of a further device intended for use at a fixed point of a mine or of any working place for gravimetric measurement of the respirable dust, the CPM 3.

Recent progress in dust sampling techniques in different countries and particularly in the U.S.A. led us to propose to the Bureau of Mines the development of a miniature device based on the same principle and intended to be worn by man. Our proposal was accepted and was the subject matter of a contract : "CERCHAR H 0122032 - Development of a personal dust sampler".

The study to be conducted for a one year period from February 16, 1972, is now completed and it is the purpose of this report to describe its development and results.

II - CHARACTERISTICS OF THE POLYURETHANE FOAM ROTARY FILTER

Polyurethane foam with open pores is a fibrous material having a high porosity. It consists of an interweaving of small fibres connected together and more or less spaced according to the grade of the filter. Among the grades commercially available, the finest grade was selected, i.e with 100 pores per linear inch ; the average pore diameter being 250 μ . Figure 1 shows a 50 x enlarged view of the filter used. The volume of the pores represents 97 % of the total volume, the fibrous material representing only 3 % of this volume.

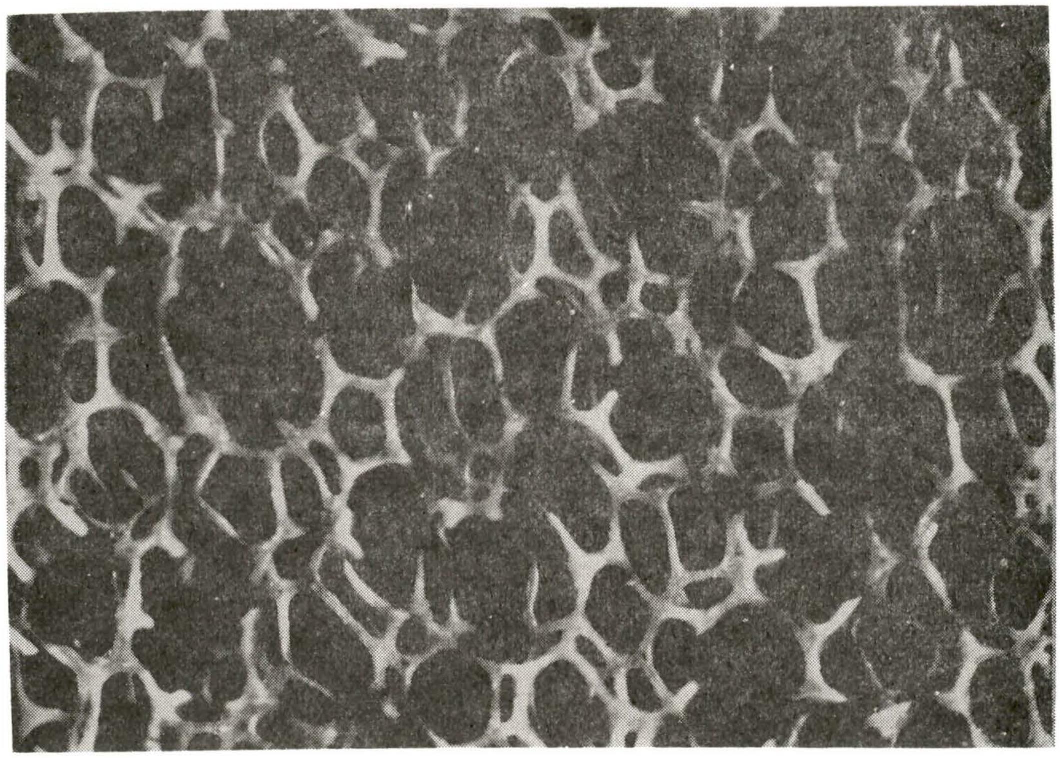


Figure 1 : Polyurethane foam filter. × 50

At rest, such a filter has a very low retention capacity for fine particles. For example, a filter 20 mm thick retains less than 10 % of the particles of a few microns. On the other hand, when cut in the form of a perforated disk and rotated, it has the following characteristics :

- the rotation has a ventilation effect. A natural circulation of air is created from the center towards the periphery of the filter.

- the trapping of the particles by impact on the large number of moving fibers that make up the filter becomes considerable. Figure 2 shows a 50 x enlarged view of a rotary filter after operation in dusty air ; each fiber is surrounded with a coat of particles.

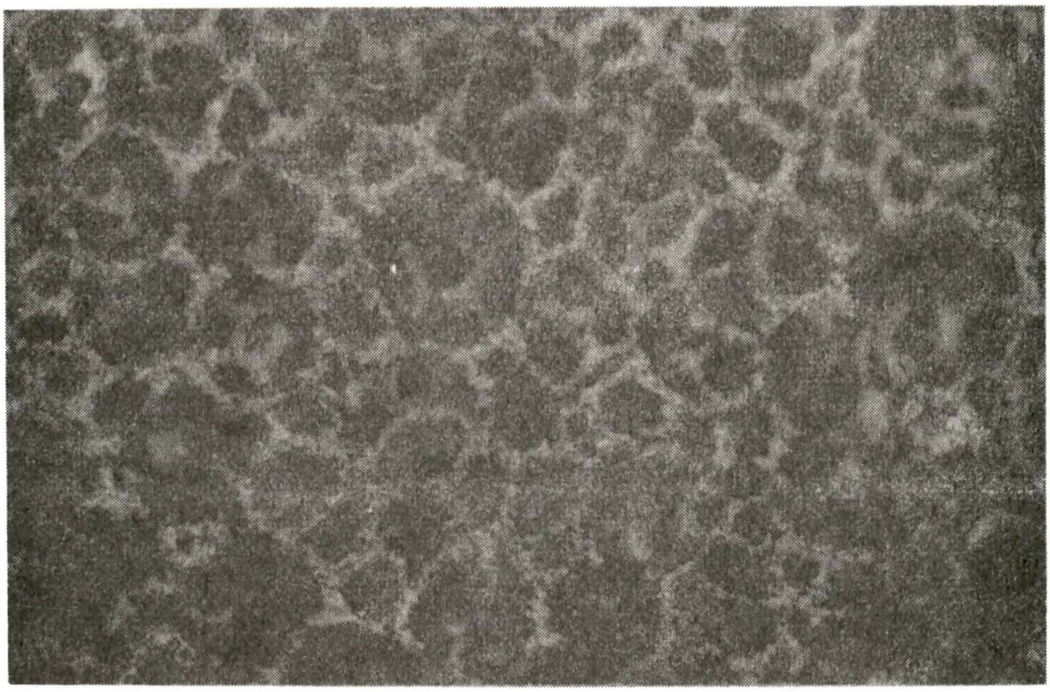


Figure 2 : Polyurethane foam filter with trapped particles. × 50

The efficiency of such a filter trapping particles by impact on the fibers depends on the particle size, the dimensions of the filter, the speed of rotation and the flow rate. For example, in the case of the CPA for measuring air pollution, a filter 20 mm thick and 70 mm in diameter rotating at 5 000 rpm within a housing, retains 99.5 % of the 1 μ particles, 90 % of 0.5 μ and 70 % of 0.2 μ, with a flow rate of 600 l/hr. With twice the flow rate, 1 200 l/hr instead of 600 l/hr, the efficiency becomes respectively, all other conditions being equal, 99 % for the 1 μ particles, 80 % of 0.5 μ and 40 % for 0.2 μ. Finally, in the case of the CPM 3 type for gravimetric measurement of the respirable dust underground, with a flow rate of 3 m^3/hr and a filter operating approximately under the same conditions, the corresponding figures are 90 % of the 1 μ particles and 50 % of 0.5 μ (the 2 μ particles being practically totally trapped).

Another important feature of the rotating filter is that it cannot clog up. Each fiber retains a limited quantity of dust (Fig. 2). The dust in excess is not retained and is trapped farther deep in the filter. The pores remain widely open, so that :

- the retention capacity of the filter is limited by the trapping power of the fibers.

- a filter whose fibers are already heavily loaded with dust has a decreasing efficiency which becomes nil when the fibers are saturated. However, the admissible limit beyond which the efficiency decreases is large : a few hundred milligramms of fine dust, for a filter 20 mm thick and 70 mm in diameter.

- the pressure loss, which is small in any case, remains constant over the entire sampling period. For a given apparatus and at a given speed of rotation, the flow rate remains constant. When operating with a d.c. motor, this amounts to maintain the supply voltage constant. In addition the energy required is small.

Such advantages have led us, in recent years, to design simple types of apparatus for measuring air pollution or dust concentrations underground.

III - PROBLEMS ASSOCIATED WITH THE DESIGN OF A COMPACT DEVICE

The design of a compact apparatus comprising a preselector cyclone and a rotating filter, intended for gravimetric measurement of the respirable dust that normally settles in the alveoli of the lung, is associated with the following problems :

- the flow rate must remain high enough to ensure collection throughout a shift of sufficient quantities of dust for weighing in routine operations on precision laboratory balances.

- the apparatus must have such dimensions and weight that it can be worn by man without discomfort.

- the energy requirements must be such that the current supplied by the cap lamp battery has no marked effect on the operation time of the battery. A self powered version should be provided with a small sized, lightweight battery which, like the apparatus itself, is worn without interfering.

- the device must also be adapted to withstand underground conditions and comply with mine safety requirements.

IV - SCOPE OF WORK PURSUANT TO THE CONTRACT

Taking into account our experience in this field from the development of the CPA and CPM samplers and in accordance with the Bureau of Mines requirements concerning dust concentrations, the soope of work was defined as follows :

The apparatus will have a minimum air flow rate of 10 liters per minute. Following our conversation with Dr. Welby G. Courtney at Pittsburg on March 27 and 28, 1972, this flow rate was reduced to 9 l/mn to permit the use of the UNICO cyclone of same flow rate and already approved in the U.S.A. (modification of November 13, 1972).

There will be two designs :

- In the first one, the apparatus will be powered by the cap lamp battery and attached to the helmet. It will weigh less than 150 g. Owing to mechanical difficulties the weight of the metal-worked prototypes was slightly increased. But in production manufacture, it will be possible to reduce the weight markedly.

- In the second design, the apparatus will be powered by a separate battery. The assembly will weigh less than 500 g.

In both cases, the power consumption will be less than 500 milliwatts and the running time will be 10 hours. The lifetime of the motor will be 2 000 hours.

The equipment will comply with the Bureau of Mines safety requirements.

Finally, three prototype models of each of the two designs will be fabricated, tested and delivered with attached calibration curves. In addition, the following items will be supplied : 3 cups for each apparatus, 50 filters, 3 spare motors for each apparatus and the corresponding battery charger for the self-powered devices.

V - DEVELOPMENT OF WORK

The investigation conducted for the development of the personal dust samplers in accordance with the contract involved three main phases :

1 - Study of component parts.

2 - Design, construction and testing of experimental models.

3 - Construction and testing of the prototypes.

Figure 3 shows in detail the different phases.

V.1 - Study of component parts

The device comprises : a preselecting cyclone, a rotary filter, an electric motor and a power source.

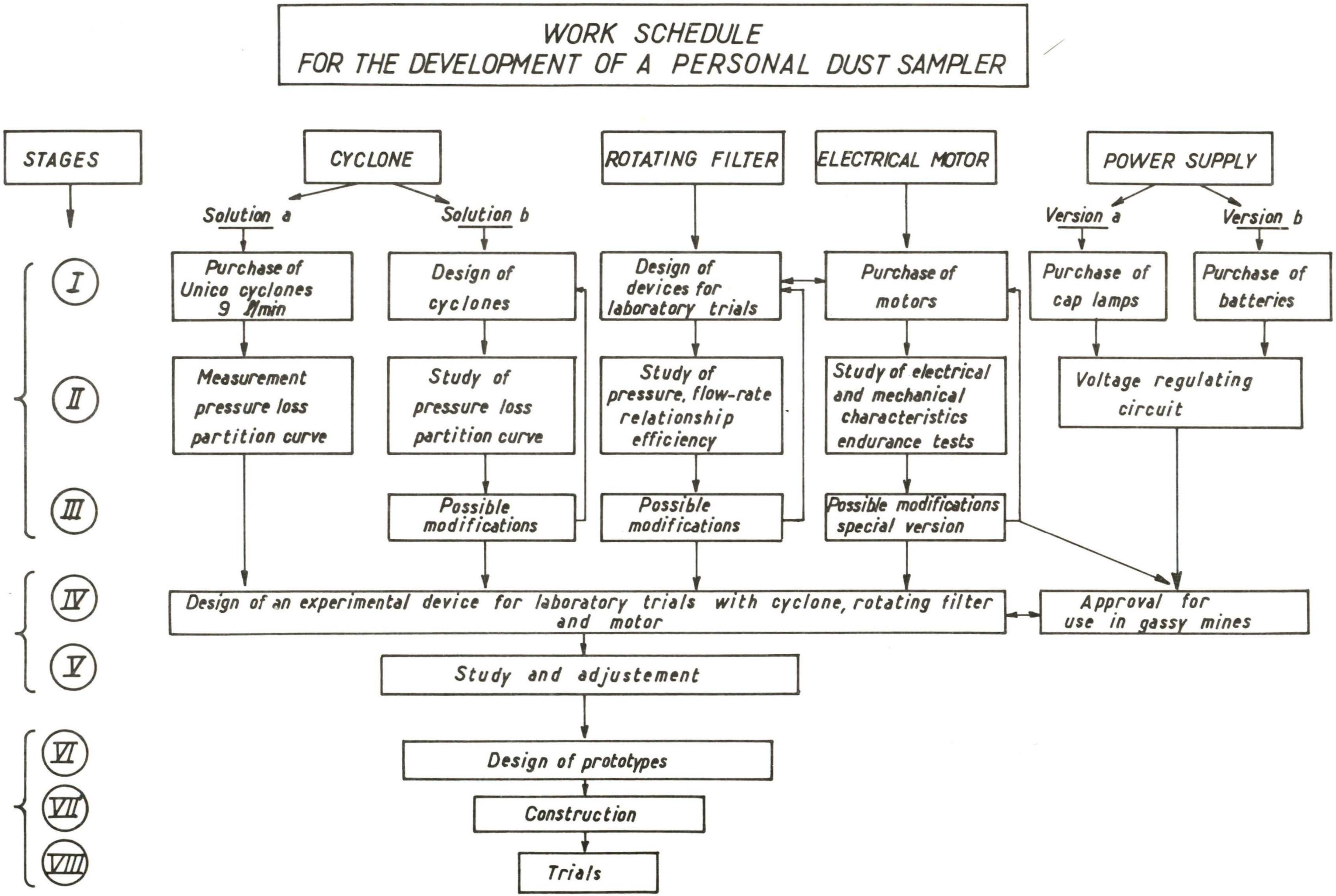
V.1.1 - The cyclone

The first solution envisaged (solution b) consisted in designing and testing a number of cyclones with a view to obtaining a cyclone with characteristics in accordance with the AEC curve.

This solution however was not adopted. As a matter of fact, during the visit to Bruceton of Mr. Froger and Mr. Courbon on March 28 and 29, 1973, it appeared that it would be preferable to use a UNICO cyclone having about the same flow rate and already approved in the U.S.A. Thus, as proposed by Dr. Welby G. Courtney it was decided not to study a new cyclone, but to adapt the existing UNICO cyclone (solution a).

We then ordered from the U.S.A. first, 2 cyclones for investigating their possibilities of adaptation, in particular their pressure loss, and 7 more cyclones for the prototypes. The first delivery was in May and the second in August 1972.

Fig.-3-


WORK SCHEDULE
FOR THE DEVELOPMENT OF A PERSONAL DUST SAMPLER
STAGES
CYCLONE
ROTATING FILTER
ELECTRICAL MOTOR
POWER SUPPLY
Solution a
Solution b
Version a
Version b
I
II
III
IV
V
VI
VII
VIII
Purchase of Unico cyclones 9 l/min
Design of cyclones
Design of devices for laboratory trials
Purchase of motors
Purchase of cap lamps
Purchase of batteries
Measurement pressure loss partition curve
Study of pressure loss partition curve
Study of pressure, flow-rate relationship efficiency
Study of electrical and mechanical characteristics endurance tests
Voltage regulating circuit
Possible modifications
Possible modifications
Possible modifications special version
Design of an experimental device for laboratory trials with cyclone, rotating filter and motor
Approval for use in gassy mines
Study and adjustement
Design of prototypes
Construction
Trials

The cyclones had the following characteristics :

cyclones	1	2	3 ⊗	4	5 ⊗	6	7	8	9
diameter of outlet tube mm	3.6	3.9	3.9	4.0	4.0	4.0	4.1	4.1	4.1
pressure loss mm water gauge at a flow rate of 9 l/mn	30.0	25.5	24.1	22.5	21.6	21.5	21.4	20.6	20.6

⊗ first cyclones received

The cyclones received give large discrepancies between the pressure loss values, but with an appreciable grouping between 20.5 and 22.5 mm wg. These last values were then retained in our study.

It should be noted that the cyclones comprised two opposite air inlets, rectangular in shape, 20 mm high and 4 mm wide. Farther on we shall see how it was found that the cyclones were defective by the terms of the contract.

V.1.2 - The rotary filter

The point was to arrive to the best compromise between the dimensions of the filter and the admissible speed of rotation.

Our prior study leaving us no choice in the quality of the polyurethane foam filter, the criteria for specifying the characteristics of the respirable dust sampler are as follows :

- the apparatus must be as compact as possible,

- the volume of the foam must be adequate to ensure the collection of sufficient quantities of dust, with a good efficiency,

- the speed of rotation must be as high as possible, but without causing deformation of the foam, due to the centrifugal force ; in addition the apparatus must not be made fragile,

- the aerodynamic characteristics of the device must be related to the operation of the cyclone (pressure loss and flow rate),

- the energy required must be as low as possible.

To investigate these factors, we first designed two experimental devices, using a motor at our disposal. In one of them the filter was 40 mm in diameter and in the other one 35 mm. In both cases its thickness was 10 mm. The foam filter had a central orifice 15 mm in diameter.

Figures 4 and 5 show the plots of rate of flow versus pressure for the two experimental devices.

The efficiency was measured using small latex spheres in monodisperse aerosol suspensions, at an initial flow rate of 600 l/hr. The results are as follows :

	40 mm filter		35 mm filter	
	0.7 µ	1.1 µ	0.7 µ	1.1 µ
8 000 t/mn	71.7 %	94.4 %	63.4 %	87.5 %
10 000 t/mn	82.7 %	96.8 %	74.6 %	95.4 %

The results and the general aspect of the first experimental devices, led us to adopt a 35 mm filter which was appreciably less voluminous than a 40 mm filter for a personal sampler and had a good efficiency for particles of about 1 µ . In addition, the draught produced was rather considerable (18 mm of water gauge at a flow rate of 600 l/hr).

The depression was 19 mm of water gauge at a flow rate of 540 l/hr. This depression might appear to be rather small, compared to the 20 or 22 mm of water gauge required to operate the cyclone. But it applied to an experimental device which was improved in the course of the study.

The total efficiency and the retention capacity of the polyurethane foam filter for fine coal dust were also measured. The quantity of ultrafine dust leaving the apparatus was determined as a function of the quantity of respirable dust retained by the foam. With a 35 mm filter rotating at 10 000 rpm, the results are :

- the ultrafine dust which is not retained by the apparatus represents less than 2 % in weight of the respirable dust trapped by the foam filter.

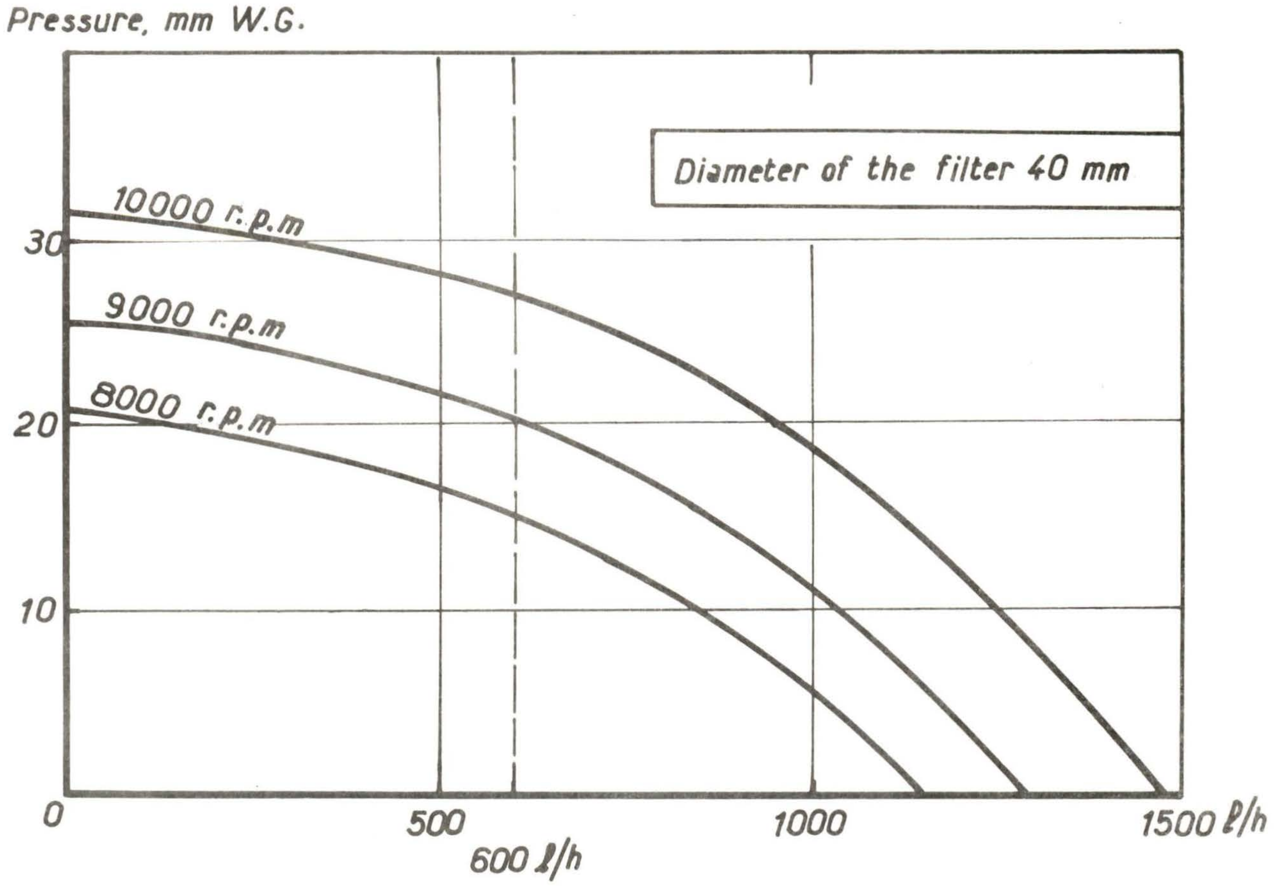


Fig.-4- FLOWRATE VERSUS PRESSURE FOR THE EXPERIMENTAL DEVICE EQUIPPED WITH A FILTER 40 mm IN DIAMETER

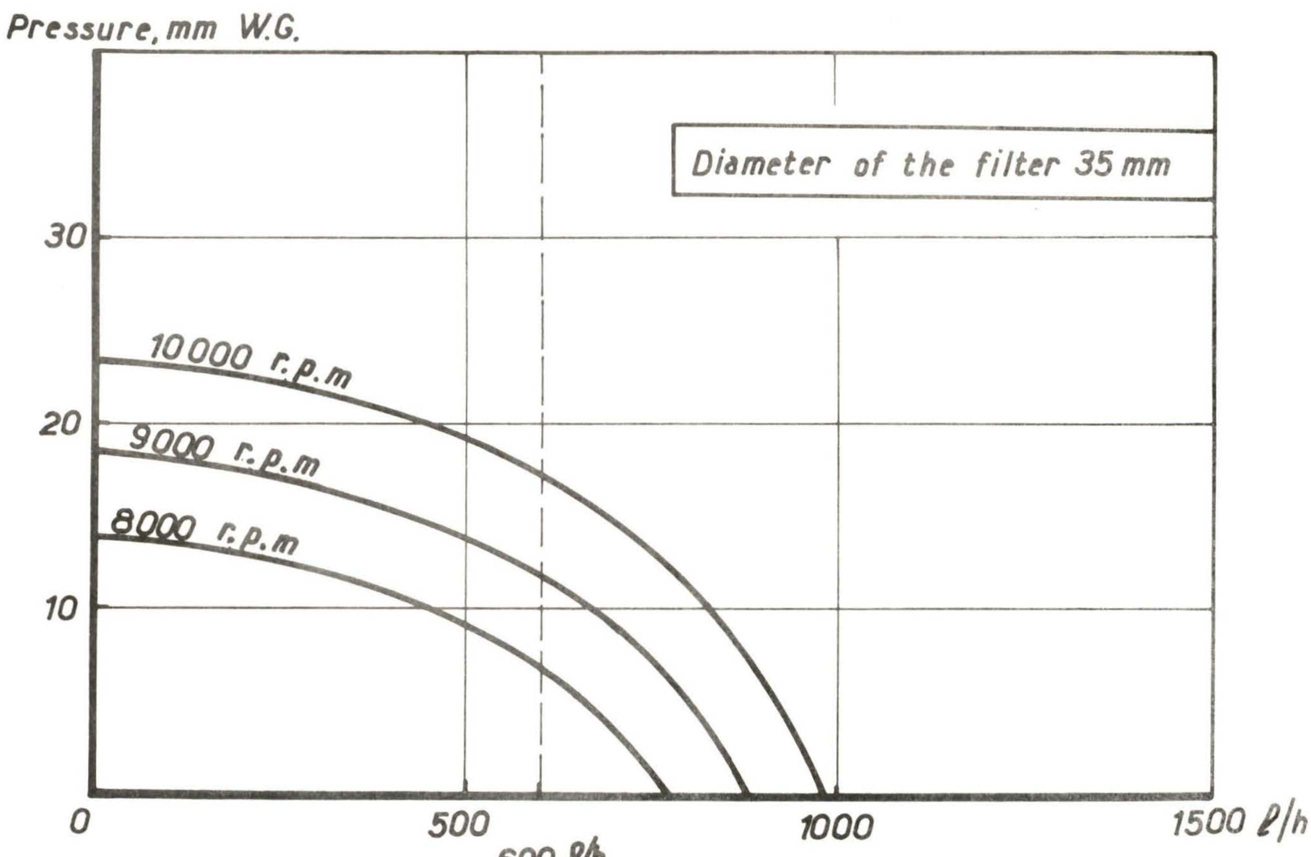


Fig.-5-FLOWRATE VERSUS PRESSURE FOR THE EXPERIMENTAL DEVICE EQUIPPED WITH A FILTER 35 mm IN DIAMETER

- this percentage was fairly constant throughout the tests and in particular during the longest test period during which 50 mg of respirable dust were collected in the foam.

This favourable result confirmed the suitability of the 35 mm foam filter for the personal dust sampler.

V.1.3 - The motor

To bring the project to a successful conclusion, it was essential to find an adequate motor adaptable to the rotary filter.

After inquiring at about 20 European and American motor manufacturers, a Swiss firm was found (Portescap, la Chaux-de-Fond) which supplied us with some motors for trials.

The rotating assembly comprising the cap and the filter was directly mounted on the shaft of the motor, as is the case in our devices type CPA and CPM. After an operation time of 15 days the motor was quite out of order. The shaft, unduly thin, could not withstand long the load of the more or less well balanced rotating assembly at 10 000 rpm.

After an interview with the motor supplier, it was decided to suppress the axial load, so that the only force acting on the motor is the driving torque. As a matter of fact, the manufacturer warranted an operation time of 2 000 hours provided the motor had no axial load.

The device was then provided with an intermediate shaft, with a ball-bearing supporting the rotating assembly, so that the motor had only a driving function. A 2 000 hours test was carried out successfully and this arrangement was adopted. The necessity to use an intermediate shaft resulted in an increase in the length and weight of the apparatus.

At this stage, we had then to specify the electrical characteristics of the motor in accordance with the possibilities of the power source.

V.1.4 - Power source

During the testing of the motors, the torque necessary to rotate a cup 35 mm in diameter at 10 000 rpm and a flow rate of 9 l/mn, was found to be equal to 2 cm × g. We had now to specify the supply voltage of the motor, in order that the manufacturer supplies us with a motor operating with the maximum efficiency under the above conditions.

To this end 5 cap lamps were bought from MSA, Pittsburgh, pursuant to Mr. Courtney's indications.

The limit operation voltage of the battery of these lamps was found to be equal to 3.6 V. Taking account 0.2 V necessary for the regulation, the limit supply voltage of the motor is 3.4 V. Allowing for some margin of safety, we asked the manufacturer to supply us with a motor liable to rotate with maximum efficiency at 10 000 rpm, under a torque of 2 cm × g and a supply voltage between 3.0 and 3.2 V. The manufacturer offered his new motor type ESCAP 16 C 112101 giving an efficiency of 80 % under the operating conditions specified. The first motors were received in October 1972. We adopted this type of motor after checking its characteristics.

For the self powered version, the same system (motor - filter) was adopted and four series mounted Ni-Cd batteries of 1.2 Ah were used as power source.

For each version an electronic voltage regulation circuit was designed in accordance with gassy mines safety requirements. Thus, the cap lamp version comprises a P.T.C. thermistor and the self powered one has a 2 Ω resistance (3 watts) between each battery. The circuits were tested by our safety department concerned with the approval of electrical equipment and considered as being safe for underground use.

V.2 - Construction and testing of experimental models

V.2.1 - Cap lamp version

The first solution contemplated consisted in mounting the cyclone and the fine dust collecting system on either side of the lamp on the helmet, for the sake of balance. A first model was constructed on this principle. It comprised in particular a connecting tube accross the lamp between the cyclone and the fine dust collecting system.

From the test results, it was soon clearly evident :

- that the additional pressure loss of the tube made the operation of the whole system questionable. To meet the difficulty, it would have been necessary to use a 40 mm cup or to increase the speed of rotation of the 35 mm cup up to 12 000 rpm.

- that the dust deposited in the tube was detrimental to the accuracy of measurement and made the cleaning of the apparatus after use more difficult.

These considerations led us to design a compact apparatus in which the fine dust collecting system is held upside down and the cyclone directly mounted on the axis of the filter as indicated on Figure 6. It was found later that the expected unbalance of the helmet is negligible.

This second device comprised a foam filter with a central orifice of 10 mm instead of 15 mm and the design of the air discharge opening was modified to improve the ventilation effect. The tests were conclusive and this arrangement was adopted.

Another problem to solve concerned the printed circuit for control of the apparatus (location and control button).

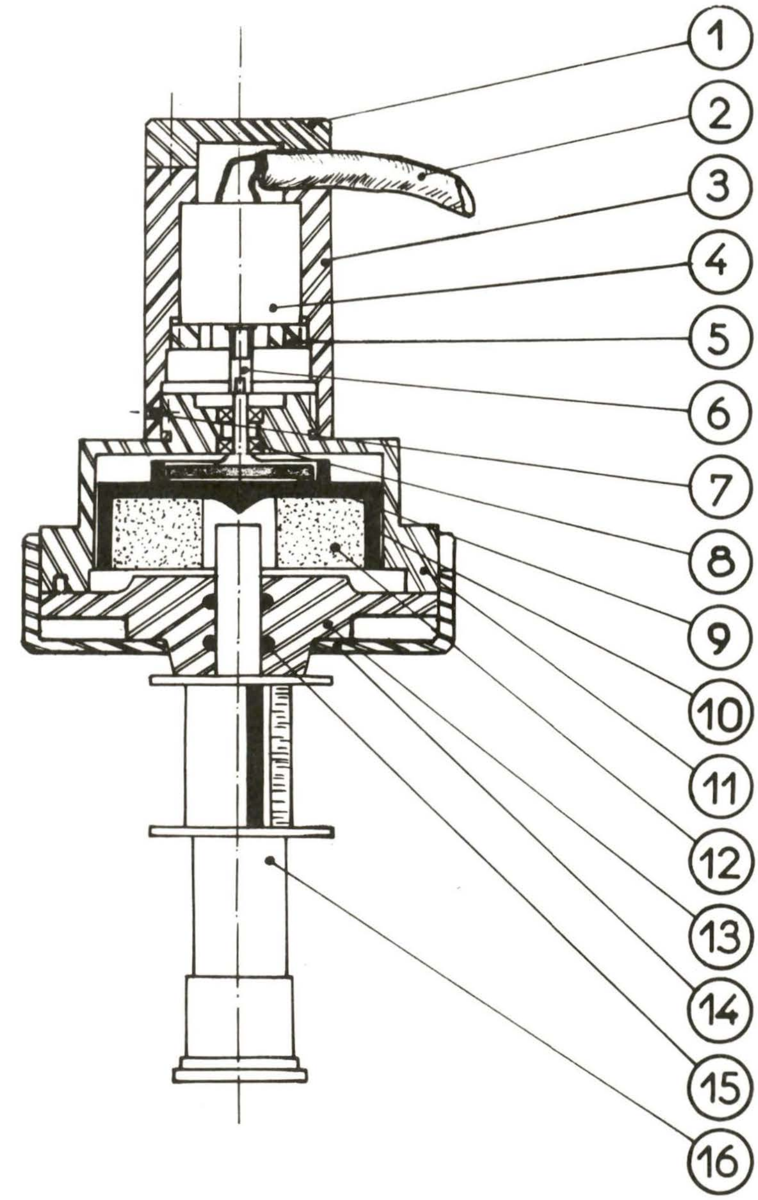
The solution has been to accommodate the printed circuit in a little housing mounted on the projector of the lamp and using the switch of the lamp to control the apparatus. The peculiarity of this arrangement, besides the compact form of the housing on the lamp, lies in the fact that the starting of the apparatus is synchronized with the switching on of either bulb. Since, underground, the lamp is lit in any case, the sampler is operated automatically. In production manufacture, the electronic circuit could be included in a specially provided projector, instead of being accommodated in a box located outside.

V.2.2 - Self powered version

This design differs from the preceding one essentially in the electric supply, the collecting system proper being the same.

The supply unit first envisaged had a compact form. After discussing with Dr. Welby G. Gourtney during his visit to Verneuil on October 18, 1972, a pocket-size oblong form was studied. The casing comprises the supply battery (four

Fig.-6- PERSONAL DUST SAMPLER



Scale : 1

Ref.	Designation	Ref.	Designation
1	Cover secured by 3 screws	9	Magnetic plate
2	Electric cable	10	Cup
3	Motor compartment	11	Housing
4	Motor	12	Foam filter
5	Adjusting ring	13	Cyclone holder
6	Coupler	14	Clamp plate
7	Set screw	15	Ring joints
8	Ball bearing	16	Cyclone

1.2 Ah elements), the voltage regulation circuit, the on-off swith and the spare metal contacts of the battery.

V.3 - Construction of the prototypes, adjustment and testing

The third phase of our investigation, relative to the construction of the prototypes, their adjustment and testing, was started after Dr. Welby G. Courtney's visit to Verneuil on October 18, 1972.

The prototypes were made of light alloy with less than 2 % magnesium to comply with the American safety requirements. The weight of the sampler is 170 g. For a commercial version of this type of apparatus, it is possible to envisage a lighter construction in plastic material.

The construction is described in greater detail in the operation manuals appended.

For the adjustment of the apparatus, use was made of the available cyclones having an outlet tube of about 4.0 mm. A flow rate of 540 l/hr was obtained at an average speed of rotation of 9 600 rpm. Under such conditions the supply voltage was 3.0 - 3.2 V and the electric current 110 - 120 mA according to the apparatus. These values are in agreement with the power consumption requirement of less than 500 mW.

During the tests, we plotted the efficiency curve of the apparatus at a flow rate of 540 l/hr (speed of rotation of the filter 9 600 rpm) for :

- spherical latex particles in monodisperse aerosol suspensions to determine the efficiency of the polyurethane foam filter,

- spherical fly ash particles in polydisperse aerosol suspensions to determine the efficiency of the cyclones.

The results obtained are as follows :

size consist	0.56 μ	0.7 μ	1.1 μ	2.0 μ
efficiency	61.7 %	79.1 %	97.4 %	100 %

Cyclone (diameter of outlet tube 3.9-4.1 mm)

size ranges measured for particles of density 2.4-2.5	1-2 µ	2-3 µ	3-4 µ	4-5 µ	5-6 µ	6-7 µ
corresponding size ranges for unit density spheres	1.55 to 3.10 µ	3.10 to 4.65 µ	4.65 to 6.20 µ	6.20 to 7.75 µ	7.75 to 9.30 µ	9.30 to 10.85 µ
% passing cyclone	89 %	72 %	60 %	45 %	26 %	17 %

These values are plotted in Figure 7 which also shows the reference AEC curve.

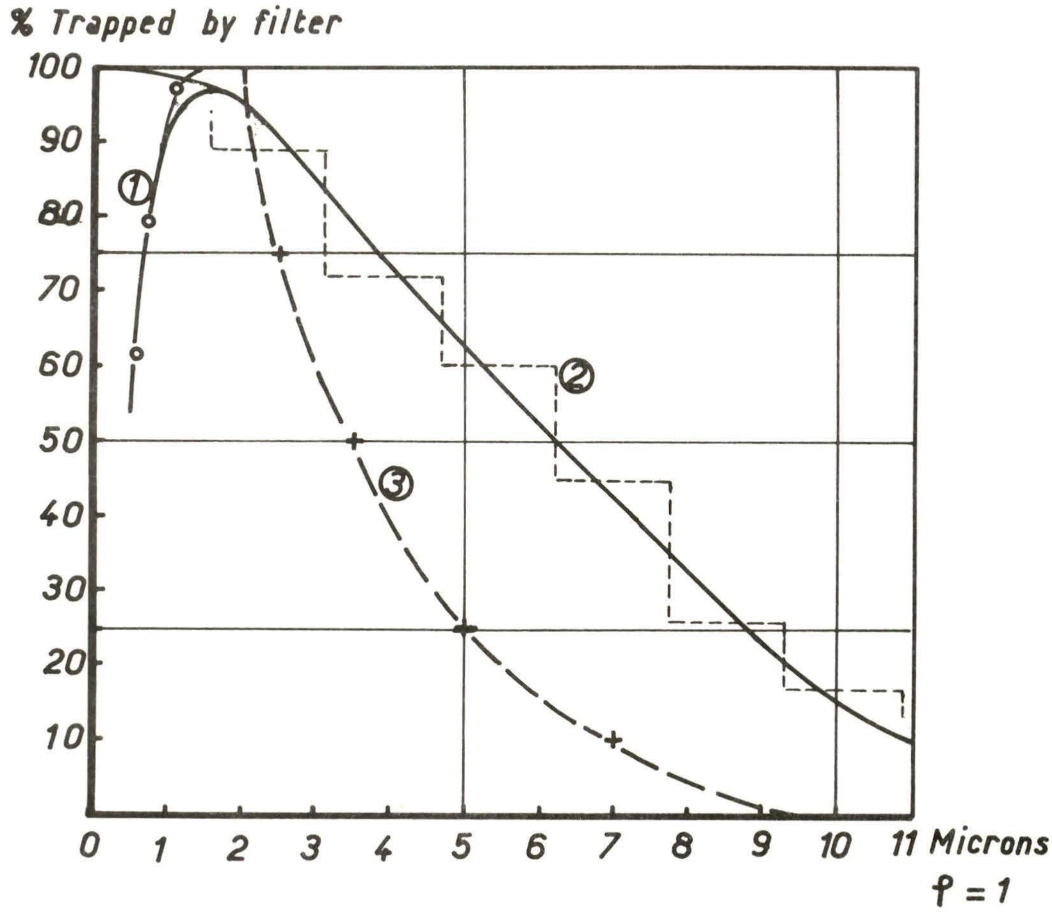
From these results, it can be seen that the polyurethane foam filter has a very good efficiency. On the other hand, there is a marked difference between the curve of the cyclones received and the AEC curve. This agrees with the latest information received indicating that the UNICO cyclones manufactured since March 1972 were defective and not accepted by OSHA of the US Department of Labor because they do not agree with the reference AEC curve, the consequence being that UNICO revised its manufacture.

From the recent information received concerning the new UNICO cyclones, we think that the substitution will be no problem and that the adjustment of the apparatus will be adapted to the new characteristics of the cyclones without difficulties.

VI - CONCLUSIONS AND PROSPECTS

Our contract for the development of a personal dust sampler based on the use of polyurethane foam filters rotating at high speed within a housing has led to the construction of three prototype models of each of the two designs : cap lamp version and self powered version.

For the generalization of this method of collecting airborne dust to control respirable dust exposures, we think it would be advisable to examine which version should be developed. The cap lamp version offers the advantage of



① Rotary filter trapping curve

② UNICO cyclone trapping curve

③ AEC reference curve

Fig.-7- TRAPPING CURVE OF THE PERSONAL DUST SAMPLER

(Provisional figure)

being operated automatically underground without necessitating additional equipment to be worn by man, while the self powered version can be used independently of the cap lamp and is easier to handle for cleaning and maintenance.

The following points should be noted :

- the apparatus have been provided with the UNICO cyclones available in 1972 (9 l/mn). Their collecting efficiency for the biggest particles is too low and they will have to be replaced when the new UNICO cyclones of same flow rate and complying with the AEC curve, are available. The substitution will probably make it necessary :

. to adjust the mounting of the cyclone by a simple boring

. to obturate partly the air outlet of the apparatus to create a pressure loss to compensate for the change of pressure loss owing to the new cyclone and thus maintain the speed of rotation of the filter at about 10 000 rpm.

- in production manufacture it would be better to use moulded plastic materials (weight reduction).

- in case of mass production the manufacturer of the motor could supply motors directly equipped with their coupling.

- from recent indications, it seems that a sintered bronze bearing would be preferable to a ball-bearing for supporting the rotating intermediate shaft (tests to be carried out).

- finally integrated circuits for speed regulation of small motors are becoming available and could replace the present voltage regulation circuit (tests to be carried out).

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VERNEUIL-EN-HALATTE, le May 1973

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PERSONAL RESPIRABLE DUST SAMPLER

(CAP LAMP VERSION)

OPERATING MANUAL

CONTENTS

DRAFT OF OPERATING MANUAL

PERSONAL RESPIRABLE DUST SAMPLER
(CAP LAMP VERSION)

I - GENERAL DESCRIPTION

The personal respirable dust sampler (cap lamp version) is a compact apparatus for gravimetric measurement of the airborne respirable dust liable to be deposited in the lung alveoli.

Integral with the cap lamp and supplied by it, it is attached to the helmet. It is thus worn by man without any discomfort. Since the respiratory tract (nose and mouth) is close to the sampling location, the instrument is reliable for measuring the respirable dust actually breathed at work.

It is intended for use in underground mines, but it can also be used in any dusty atmosphere inside or outside.

Owing to its high flow rate (540 l/hr), it is capable of treating several m^3 of dusty air over a shift, thus collecting sufficient quantities of dust for accurate measurement in routine operation or for any subsequent analytical work.

Figure 1 shows a general view of the instrument attached to the cap lamp.

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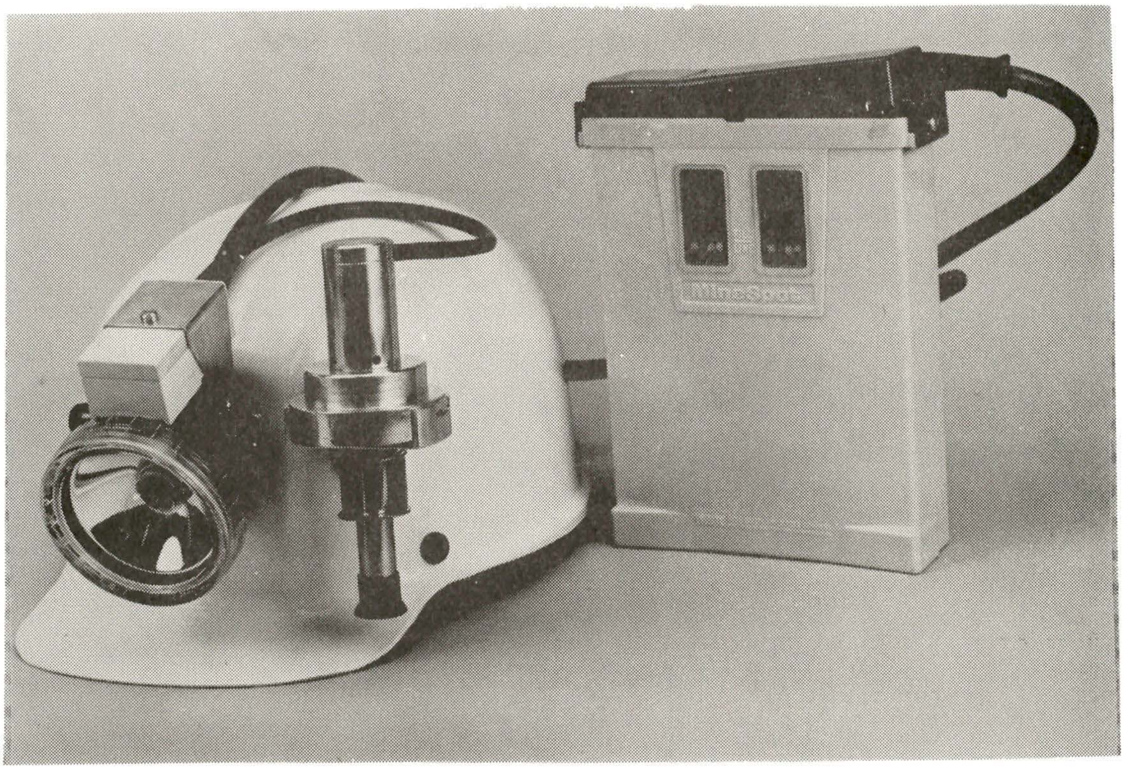


Figure 1 - General view of the sampler attached to the cap

The apparatus comprises two parts :

. the sampler proper in the form of a cylinder attached to the helmet,

. a small rectangular box attached to the lamp, and containing a supply voltage regulation circuit.

Its main characteristics are as follows :

- Dimensions :

. Sampler :

height .... 131 mm
maximum diameter .... 58 mm
weight .... 175 g

. Regulation box :

height .... 23 mm
length .... 57 mm
width .... 30 mm
weight .... 35 g

- Flow rate .... 9 l/mn (540 l/hr)
- Electric current .... 110 - 120 mA

.../...

- Starting synchronized with the operation of the cap lamp.

II - DESCRIPTION OF COMPONENT PARTS

II.1 - The sampler

The apparatus is shown diagrammatically in Figure 2. It comprises the followings parts :

. a cover 1 secured by 3 screws to the motor compartment 3,

. a supply cable 2 extending from the voltage regulation box and firmly maintained in a grooved channel between the cover and the motor compartment,

. a motor compartment 3 containing the electric motor 4 driving the rotating assembly. The motor is held in position by a clamping ring 5. It is also provided with a coupler 6 for connecting the rotating assembly. The motor compartment is screwed on the body 11 and held in position by a set screw 7,

. a body 11 containing the rotating assembly mounted on ball bearings 8. The rotating assembly comprises a magnetic plate 9 upon which is fitted a cup 10 with the polyurethane foam filter 12. The upper part of the body comprises an helical groove which ends in an expanding air outlet,

. a cyclone holder 13 sealing the body and securing the cyclone 16 by means of ring joints,

. a clamp plate 14,

. a cyclone 16.

II.2 - The voltage regulation box

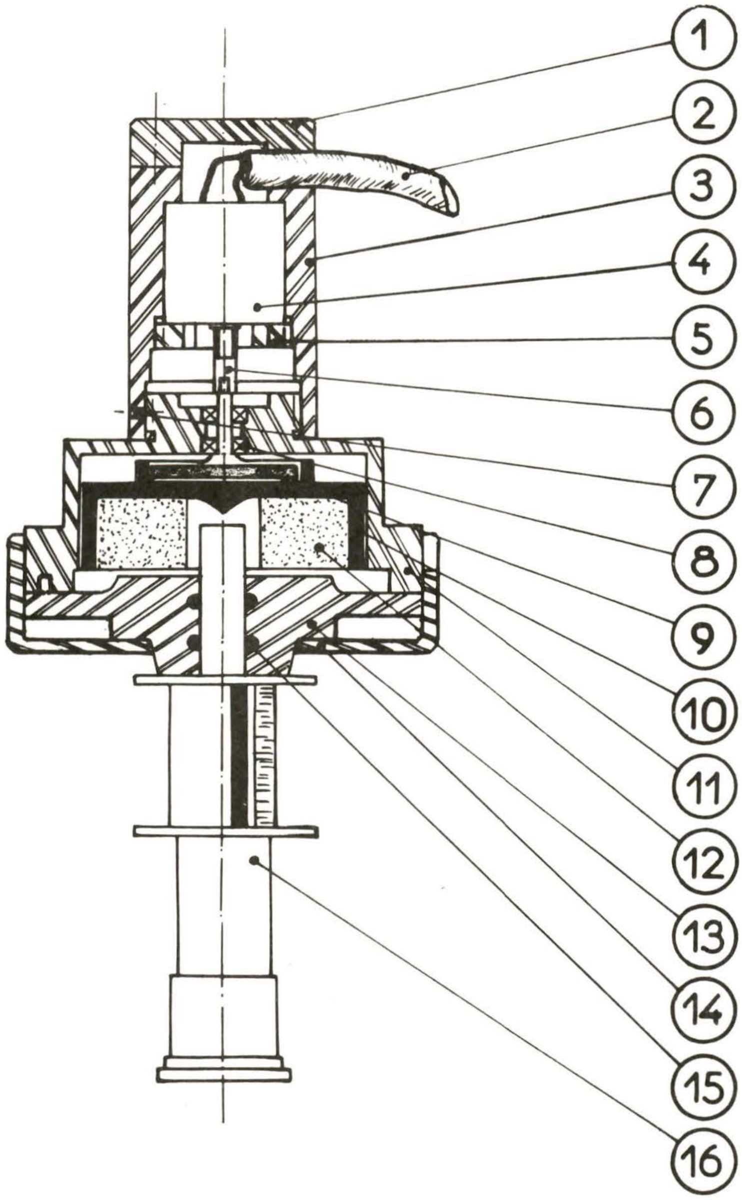
It comprises a voltage regulation circuit supplying the motor with an adjustable constant voltage independently of the charge of the cap lamp battery.

II.3 - Fastenings

The sampler proper is attached to the helmet by a fastening plate integral with the sampler.

The voltage regulation box is fitted on the lamp by means of a yoke and is an integral part of the lamp.

Fig.-2- PERSONAL DUST SAMPLER



Scale : 1

Ref.	Designation	Ref.	Designation
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6	Coupler	14	Clamp plate
7	Set screw	15	Ring joints
8	Ball bearing	16	Cyclone

II.4 - Power supply

The voltage regulation box is supplied from the terminals on the lamp. In addition two wires connect the regulation printed circuit to the lamp terminals inside the projector, so that the switch of the lamp is used to operate the sampler. Thus dust sampling is synchronized with the operation of the lamp. Wire inlets are embedded in araldite.

III - OPERATING PRINCIPLE

Putting the sampler under voltage results in the rotation of the cup with the polyurethane foam filter. The nominal speed of rotation is about 10 000 rpm.

The rotation of the moving assembly (cup with filter) at high speed within the body of the apparatus has a ventilation effect which generates an airflow.

The dust-laden air to be sampled :

. is sucked into the cyclone through two rectangular diametrally opposed aspirating holes,

. enters the body of the apparatus through the cyclone outlet tube,

. goes radially through the polyurethane foam filter,

. returns to the atmosphere via an expanding outlet tube.

The airborne dust is trapped in the following way :

. the biggest particles which are normally stopped in the upper respiratory tract of man are retained in the cyclone,

. the fine dust that normally settles in the lung alveoli is trapped in the polyurethane foam filter,

. the finest particles, usually ejected on breathing out, are discharged via the air outlet.

Special mention should be made of the principle of respirable dust collection by the rotating assembly (cup with filter).

.../...

On leaving the outlet tube of the cyclone the respirable dust-laden air enters at the bottom of the cup at more than 10 m/s and is deflected towards the foam filter rotating at high velocity.

The polyurethane foam filter is a porous material consisting of fibers of graat fineness compared to the pores, as shown in Figure 3.

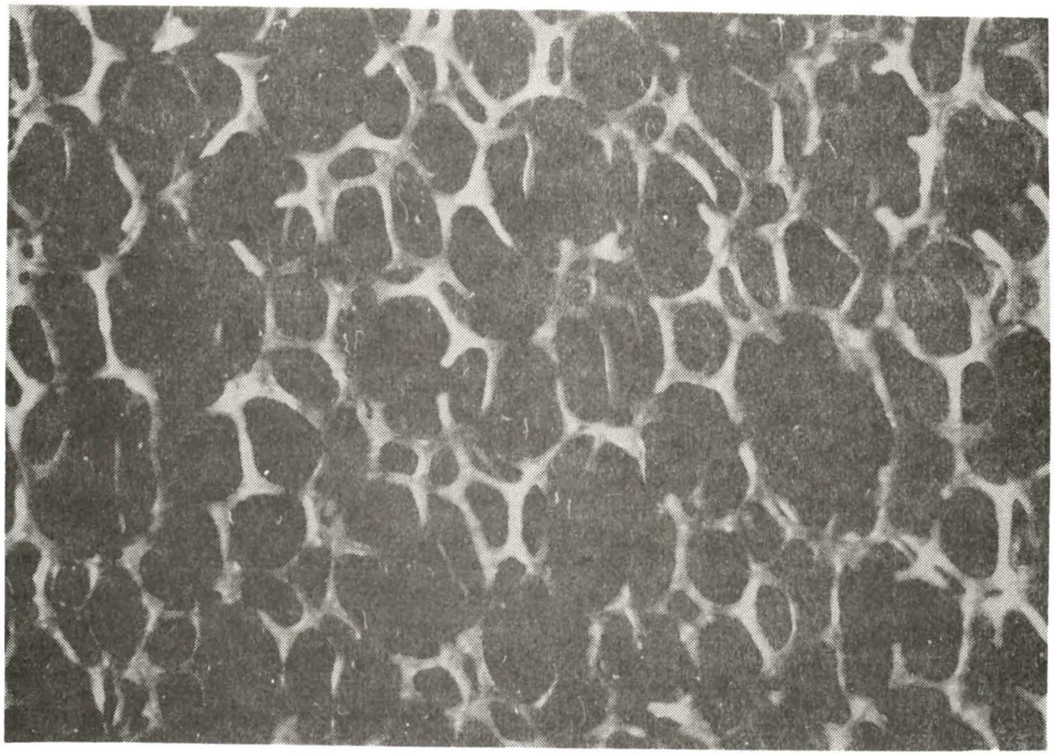


Figure 3 - Polyurethane foam filter. × 50

The dust-laden air which flows in perpendicularly to the rotating filter releases its particles which are trapped by impact on the fibers.

The retention capacity of each fiber is limited and beyond a certain limit, dust agglomerates separate and are trapped by deeper non saturated fibers. Ultimately, if the process was continued, they would be discharged outside.

It follows that :

. the pores remain clear and the filter cannot clog up. The pressure loss remains constant over the entire sampling period. Given a constant speed of rotation, the flow rate remains constant. To this end the electric motor is supplied under constant voltage.

.../...

. the retention capacity of the filter is limited by the trapping power of the fibers. The retention capacity is however sufficient to ensure measurement of dust concentrations normally encountered underground.

IV - CHARACTERISTICS

The apparatus has a nominal flow rate of 9 l/mn (540 l/hr) and an operation time of 10 hours. It is thus capable of handling 3 to 4 m^3 of dusty air over an entire shift and collecting sufficient quantities of respirable dust.

The speed of rotation of the moving assembly is about 10 000 rpm. It differs more or less from this value for the different apparatus according to the scattering of the pressure loss values of the cyclone.

Using small latex spheres in monodisperse aerosol suspensions, the efficiency of the rotary filter was measured at a speed of rotation of 9 600 rpm and a flow rate of 540 l/hr. The results are as follows :

particle size	0.56 µ	0.7 µ	1.1 µ	2 µ
efficiency	61.7 %	79.1 %	97.4 %	100 %

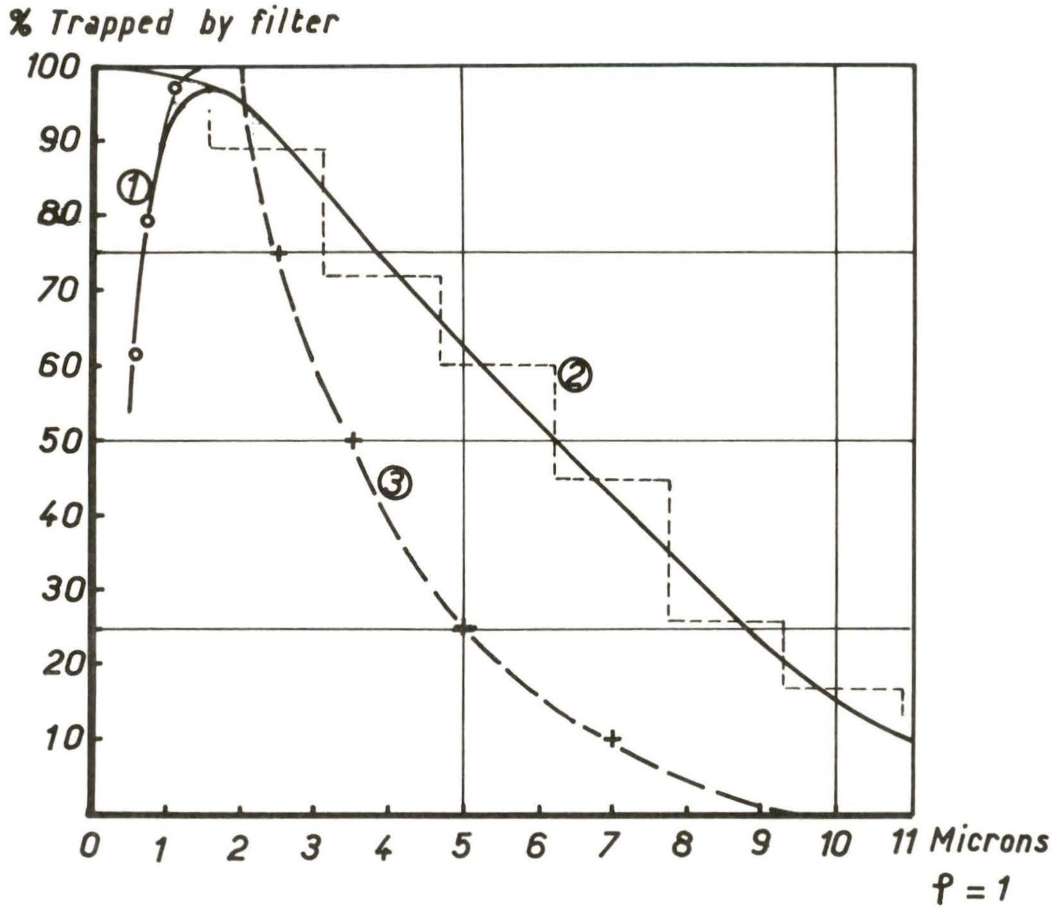
It is apparent that the filter is highly efficient at collecting particles of about 1 µ.

The percentage (in weight) of untrapped ultrafine particles compared with the respirable dust was also measured, using fine coal dust.

. This percentage was found to be less than 2 %.

. It is constant over the entire sampling up to 50 mg of respirable dust collected.

The preselection efficiency of the available UNICO cyclones was also determined using fly ash in polydisperse spherical aerosol suspensions. The curve obtained and the general efficiency curve of the apparatus are shown in Figure 4 (provisional figure).



① Rotary filter trapping curve

② UNICO cyclone trapping curve

③ AEC reference curve

Fig.- 4 - TRAPPING CURVE OF THE PERSONAL DUST SAMPLER

(Provisional figure)

(Note that this is a provisional curve. The UNICO cyclones supplied in 1972 were defective and not accepted by OSHA of the US Department of Labor. A new curve will be plotted as soon as new UNICO cyclones corresponding ot the AEC curve are available).

V - OPERATING INSTRUCTIONS

The different steps in the mode of operation of the apparatus are illustrated in Figures 5 to 9.

- Figure 5 shows the insertion of the polyurethane foam filter in the cup and its removal.

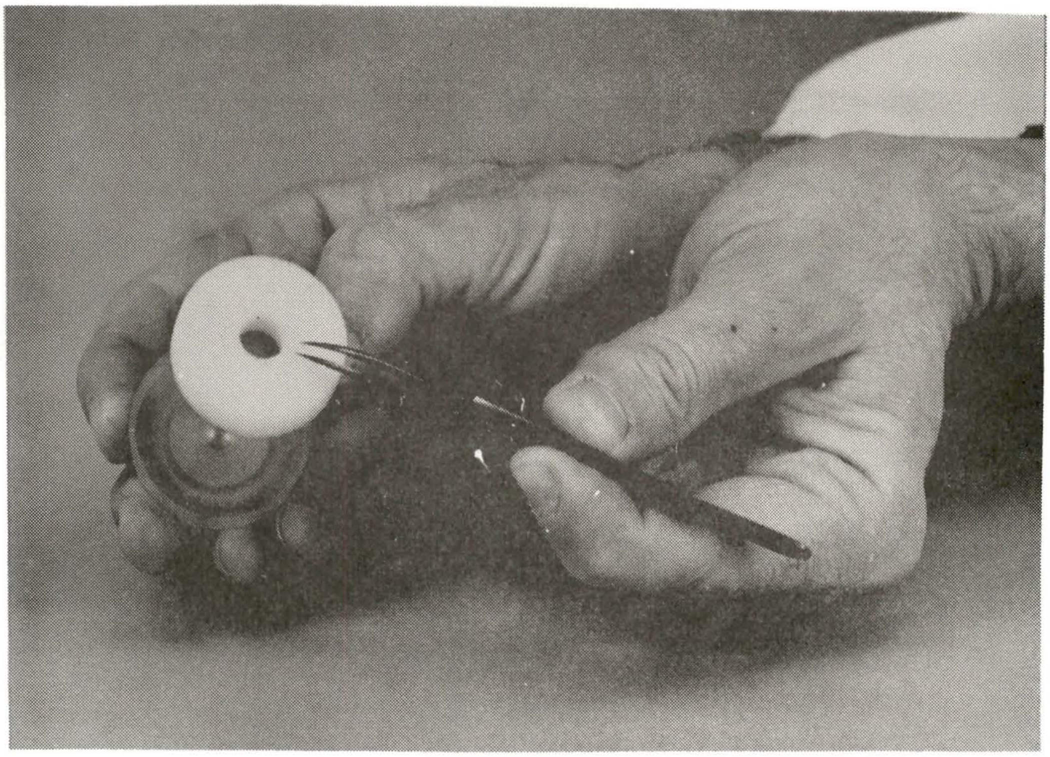


Figure 5 - Insertion or removal of the filter

To insert the filter in the cup :

. seize the filter with sharp pointed pincers,

. place it in the cup,

. press with the back of the pincers.

To remove the filter :

. seize the filter with sharp pointed pincers,

. pull.

- Figure 6 shows the mounting (or removal) of the cup with the filter on (or from) the magnetic plate at the bottom of the body of the apparatus.

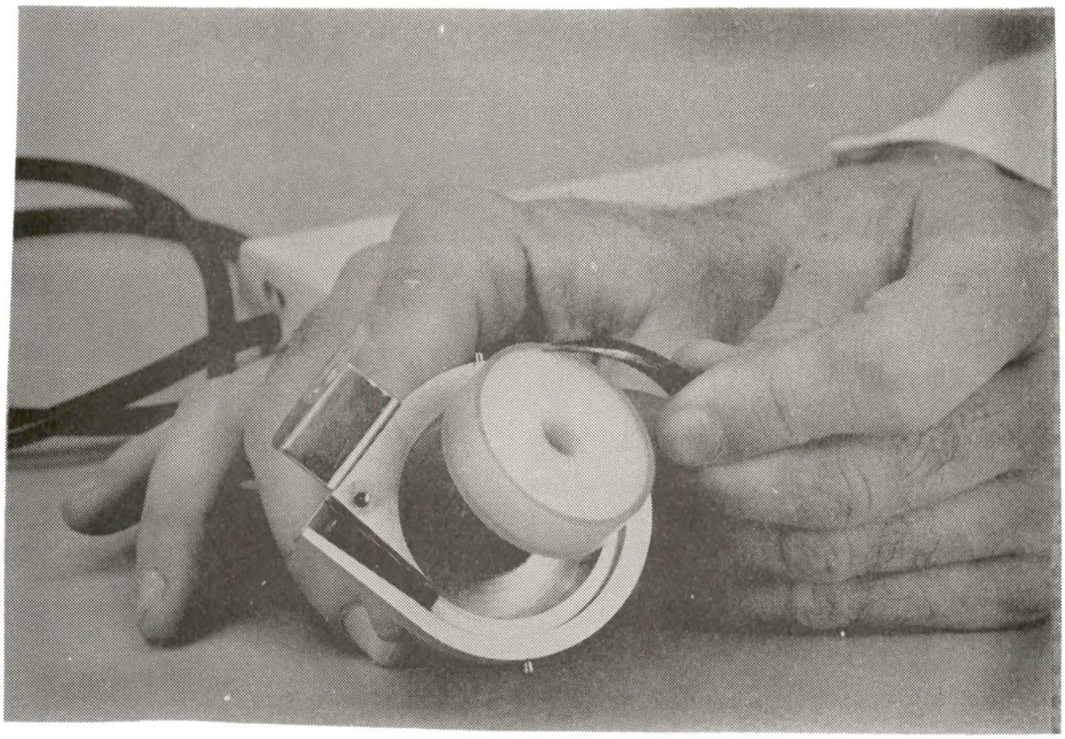


Figure 6 - Mounting or removal of the cup

To mount the cup on the magnetic plate :

. seize the lip of the cup using sharp pointed pincers,

. insert the cup in the body of the apparatus,

. let the cup fall, it will fit in of itself.

To remove the cup :

. seize the lip of the cup using sharp pointed pincers,

. pull.

- Figure 7 shows the closing (or opening) of the instrument before and after use.

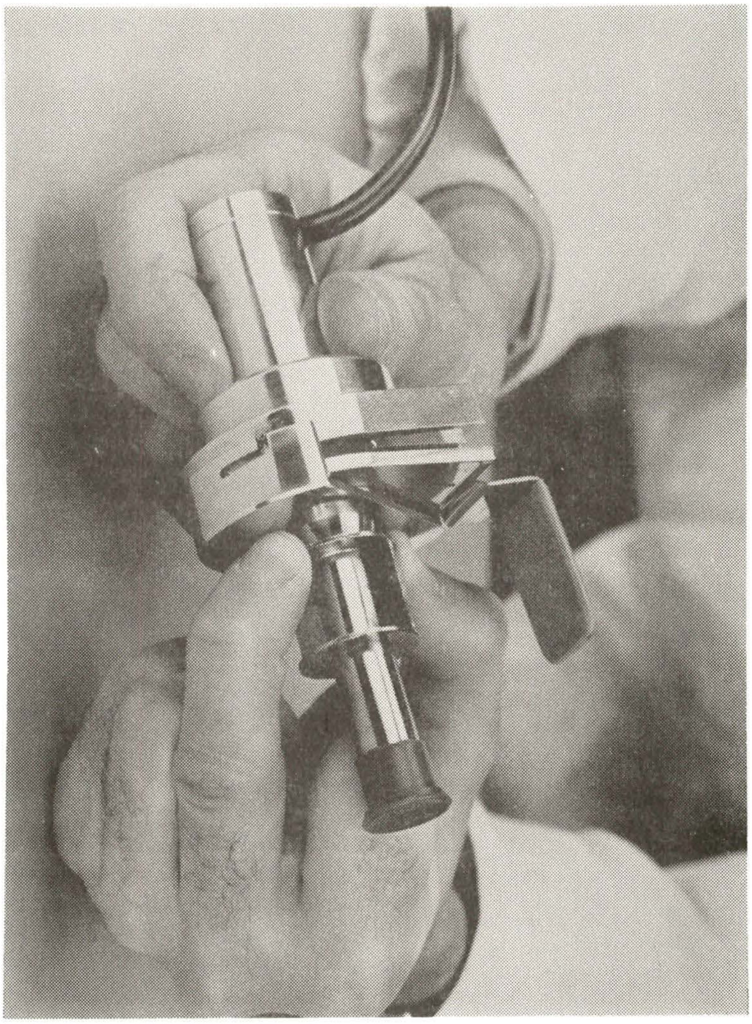


Figure 7 - Closing (or opening) of the instrument

To close the apparatus :

. engage the guide slot of the clamp plate with the outer lock pins on the body of the apparatus,

. turn the clamp plate till locked.

To open the apparatus :

. unlock by turning the clamp plate,

. take the two parts apart.

When opening the apparatus after sampling, it is necessary to hold the cyclone vertically downwards so that the dust collected by the cyclone remains at the bottom and does not fall in the cup through the outlet tube.

- Figure 8 shows the placing in position of the lid.

.../...

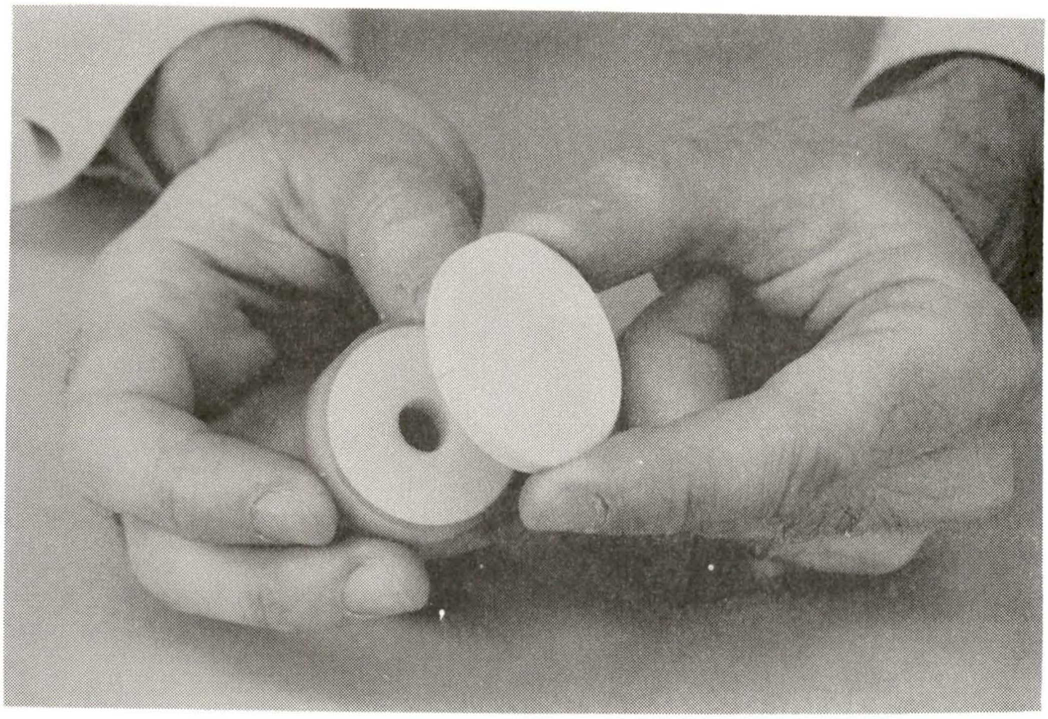


Figure 8 - Placing or removal of the lid

This operation should be performed only in the case of transportation for example to an analytical laboratory far from the sampling point. When the laboratory is near by, it is convenient to bring the samplers each time back to the laboratory. The lids are then of no use.

- Figure 9 shows the sampler worn by man.

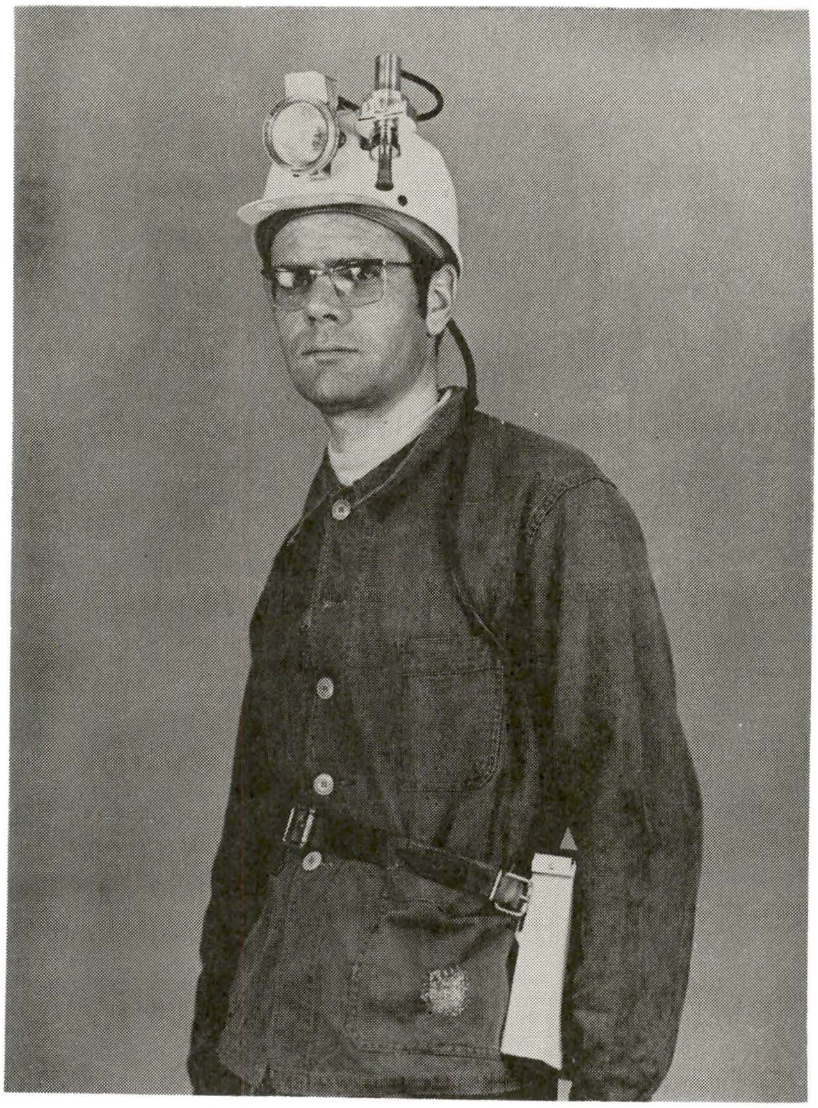


Figure 9 - Sampler worn by man

The instrument is worn without any discomfort since it is attached to the cap.

VI - EVALUATION

Measurement of the respirable dust is carried out by weighing the rotating assembly (cup with filter) before and after taking the sample.

Since the polyurethane foam is sensitive to moisture, the following precautions should be taken :

.../...

Two cases are to be considered :

- There is available a balance room with controlled humidity and temperature or a room which although not air-conditioned has a low degree of humidity (less than 25 %). In this case, it is enough that the cups are stored in the room overnight for instance to attain equilibrium with the room atmosphere ; then they are weighed. The equilibrium can be attained more rapidly by circulating a small quantity of air through the foam to increase transfer phenomena. This is carried out by blowing a small quantity of clean air at the centre of the cup or by rotating the cup in clean air.

The dust concentration is given by the formula :

$$C \text{ mg/m}^3 = \frac{\text{Weight of dust collected in mg}}{\text{Filtered volume in m}^3}$$

- A balance room as above is not available. A reference filter must be used. It is weighed at the same time as the dust loaded filter and the reading is corrected to allow for the change in weight of the reference filter between the two weighings.

If W_1 is the weight of the reference filter weighed before sampling and W_2 the weight of the same filter weighed after sampling, the dust concentration is given by the formula :

$$C \text{ mg/m}^3 = \frac{\text{Weight of dust collected} - (W_1 - W_2) \text{ in mg}}{\text{Filtered volume in m}^3}$$

The respirable dust collected can be recovered in a liquid bath, a wetting agent being added to the liquid. The suspension obtained can be examined under the microscope for dust counts or collected on a filter membrane for further analysis (ash content or quartz determination). For that purpose, the foam filter used must have been handled in a liquid bath to remove preexisting particles and dried before the first weighing.

The larger particles collected in the cyclone can also be recovered, weighed and analysed, if desirable.

VII - CHECKS, ADJUSTMENT, MAINTENANCE, REPAIRING

The nominal flow rate of the instrument is 9 l/mn (540 l/hr).

.../...

The flow rate is sensitive to any additional pressure loss, so that it should be checked by using a device (Figure 10) to balance the pressure upstream and downstream from the instrument. The procedure is as follows :

. pull the cyclone out of the sampler,

. take an air-tight, closed chamber (tin box for instance) comprising an air inlet tube and a pressure gauge connection,

. place the cyclone at the bottom of the box under tight conditions with the cyclone outlet tube emerging from the box,

. connect the outlet tube of the cyclone to the sampler,

. connect a flowmeter (for example rotameter) to the air inlet tube of the box and a sensitive manometer to the pressure gauge connecting tube,

. switch the instrument on and blow air through the air inlet tube of the flowmeter, till the sensitive manometer gives a zero reading,

. check that the manometer reading is 9 l/mn (540 l/hr),

. should the flowmeter give another reading, adjust the control potentiometer mounted on the voltage regulation printed circuit of the battery box, until a correct reading is obtained.

In addition,

. measure the overpressure of the instrument at zero flow rate. To this end, connect (under tight conditions) a manometer to the air outlet and check the reading. The overpressure at zero flow rate for the instrument n° .... is ....

. measure the speed of rotation of the rotating assembly, the instrument being open, with the help of a stroboscope. For the instrument n° .... the speed of rotation is ....

For further quick indirect checking it is sufficient to verify

. either the overpressure of the instrument at zero flow,

. or the speed of rotation of the rotating assembly, the instrument being open.

The instrument requires no maintenance with the exception of periodical cleaning.

.../...

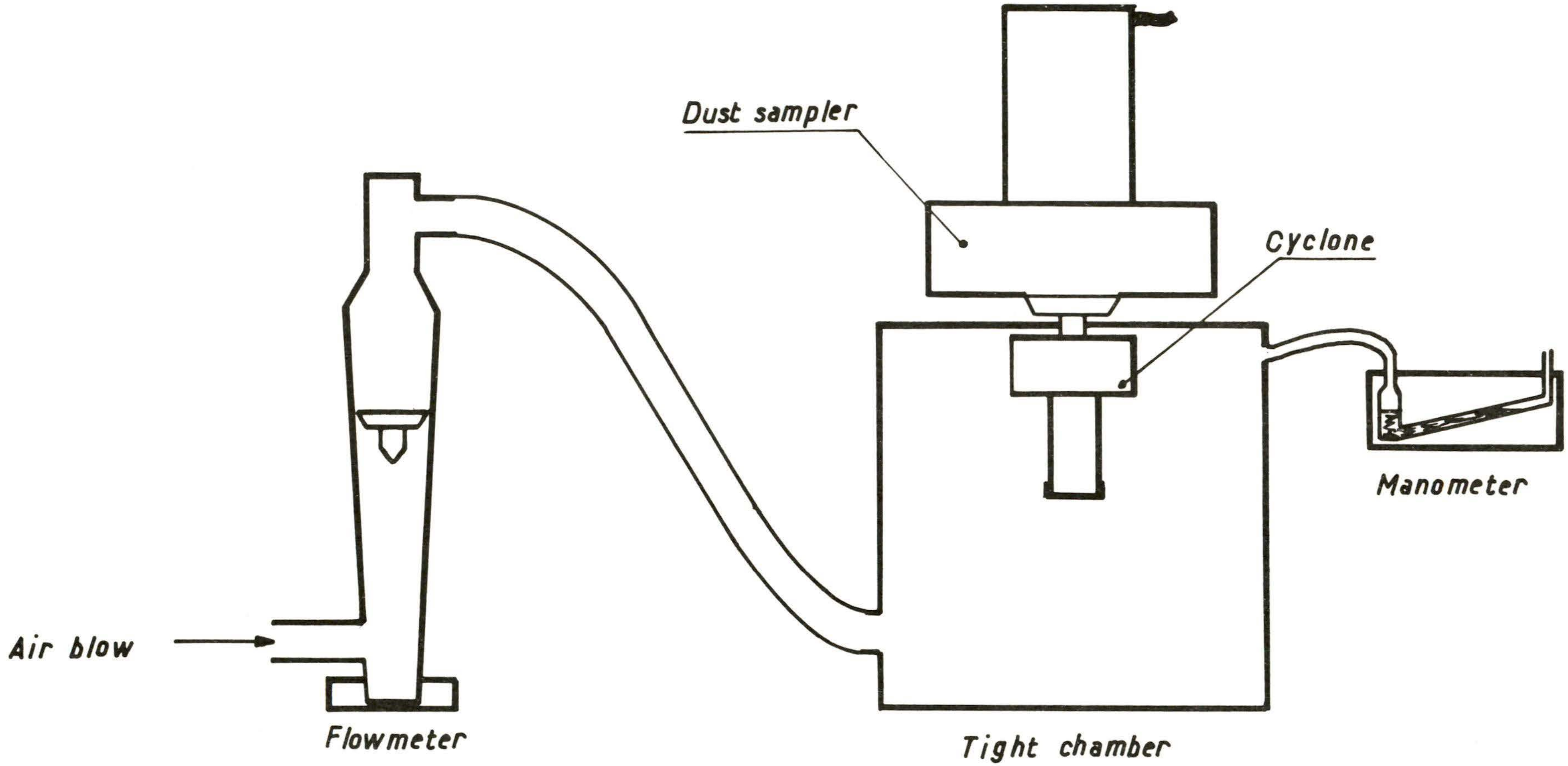


Fig.-10- DEVICE FOR CHECKING FLOWRATE

The risks of failure are small and only with regard to the electronic components (fuse for example) and the motor. In particular, when the motor presents signs of wear, it should be replaced. In principle, the lifetime of the motor is 2 000 hours.

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VERNEUIL-EN-HALATTE, le May 1973

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PERSONAL RESPIRABLE DUST SAMPLER

(SELF-POWERED VERSION)

OPERATING MANUAL

CONTENTS

DRAFT OF OPERATING MANUAL

PERSONAL RESPIRABLE DUST SAMPLER
(SELF-POWERED VERSION)

I - GENERAL DESCRIPTION

The personal respirable dust sampler (self-powered version) is a compact instrument for gravimetric measurement of the respirable airborne dust that is liable to deposit in the lung alveoli.

Mounted on a holder plate which can be easily slipped into the outside breast-pocket, it is worn by man without discomfort. Owing to its location within a short distance of the respirable tract of man (nose - mouth), it is a reliable apparatus for measuring the weight of dust actually breathed at work.

It is intended for use in underground mines, but it can be used for measuring any dusty atmosphere inside or outside.

With its high flow rate (540 l/hr), it is capable of handling several m^3 of dusty air over a shift, so that it collects enough dust for accurate measurement in routine operation and for subsequent analysis.

Figure 1 shows a general view of the instrument.

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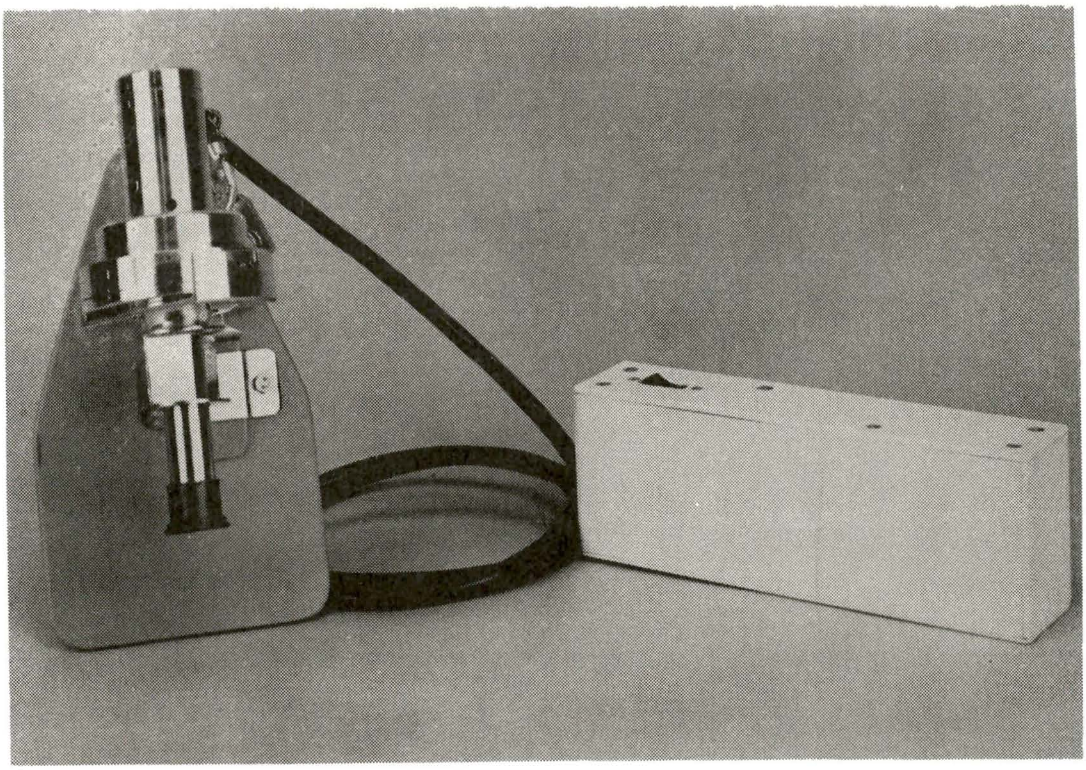


Figure 1 - General view of the dust sampler

The apparatus consists of two parts :

. the sampler itself in the shape of a cylinder mounted on a holder plate,

. a supply box with the power source and the voltage regulation circuit, of oblong shape so that it can easily be put into a side pocket.

The general characteristics of the apparatus are as follows :

- Dimensions :
  - . Sampler :
    - height .... 131 mm
    - maximum diameter .... 58 mm
    - weight .... 175 g
  - . Holder plate :
    - height .... 150 mm
    - width .... 83 mm

.../...

thickness .... 4 mm
weight .... 75 g

. Supply box :
height .... 55 mm
width .... 32 mm
length .... 148 mm
weight .... 380 g

- Flow rate .... 9 l/mn (540 l/hr)
- Current .... 110 - 120 mA
- Starting of the apparatus by means of a switch on the supply box
- Recharging of the batteries by means of an appropriate device.

II - DESCRIPTION OF COMPONENT PARTS

II.1 - The sampler

The apparatus is shown diagramatically in Figure 2. It comprises the following parts :

. a cover 1 secured by 3 screws to the motor compartment 3,

. a supply cable 2 extending from the supply box and firmly maintained in a grooved channel between the cover and the motor compartment,

. a motor compartment 3 containing the electric motor 4 driving the rotating assembly. The motor is held in position by a clamping ring 5. It is also provided with a coupler 6 for connecting the rotating assembly. The motor compartment is screwed on the body 11 and held in position by a set screw 7,

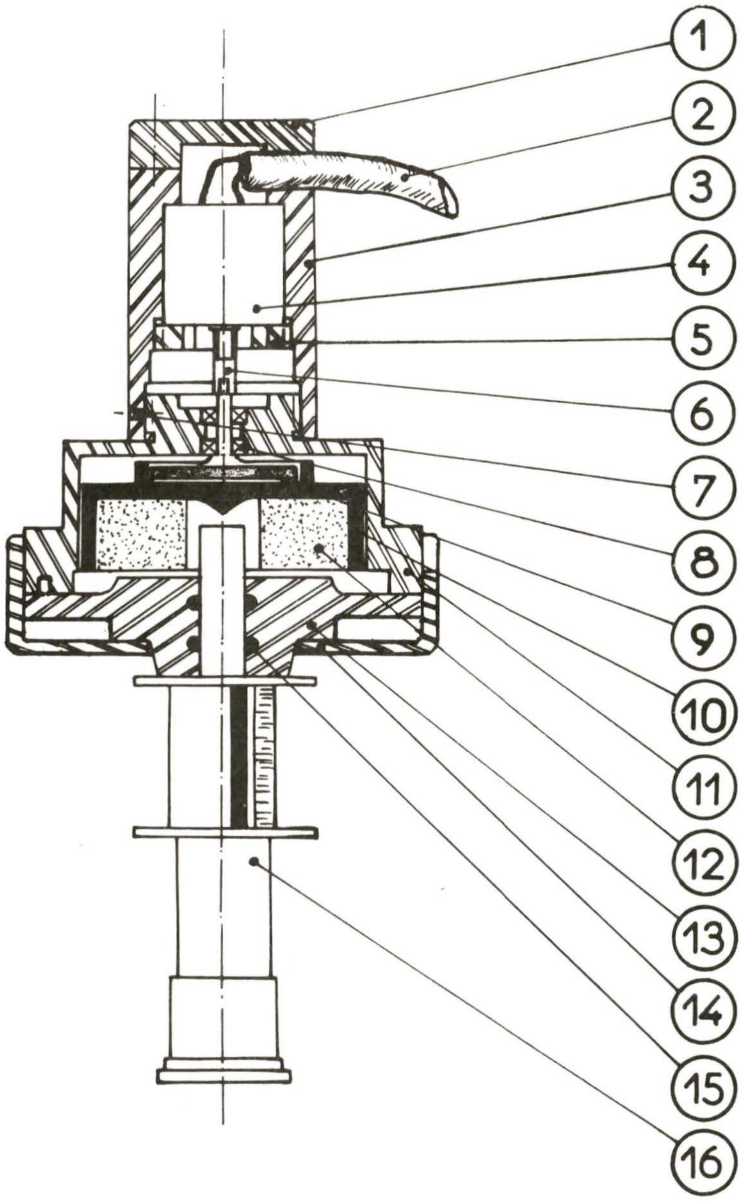
. a body 11 containing the rotating assembly mounted on ball bearings 8. The rotating assembly comprises a magnetic plate 9 upon which is fitted a cup 10 with the polyurethane foam filter 12. The upper part of the body comprises an helical groove which ends in an expanding air outlet,

. a cyclone holder 13 sealing the body and securing the cyclone 16 by means of ring joints,

. a clamp plate 14,

. a cyclone 16.

Fig.-2- PERSONAL DUST SAMPLER



Scale : 1

Ref.	Designation	Ref.	Designation
1	Cover secured by 3 screws	9	Magnetic plate
2	Electric cable	10	Cup
3	Motor compartment	11	Housing
4	Motor	12	Foam filter
5	Adjusting ring	13	Cyclone holder
6	Coupler	14	Clamp plate
7	Set screw	15	Ring joints
8	Ball bearing	16	Cyclone

II. 2 - The supply box

It comprises :

. four 1.2 Ah Ni-Cd batteries which on safety grounds are connected through three $2\,\Omega$ - 3 W resistances,

. a voltage regulation circuit,

. a switch,

. a wire holder for securing the wire,

. two metal plugs for the charging of the batteries.

II.3 - The electrical connection of the supply box to the sampler

It is ensured by an electric cable firmly secured at its ends.

II.4 - Fastenings

The sampler itself is secured in a removable way to the holder plate by means of a clamp integral with the sampler and which fits into its counterpart on the holder plate. The holder plate is also provided with a clasp for attachment to the miner's breast-pocket.

II.5 - Battery charger

It consists of a rectangular box with at its upper part a compartment for inserting the supply box.

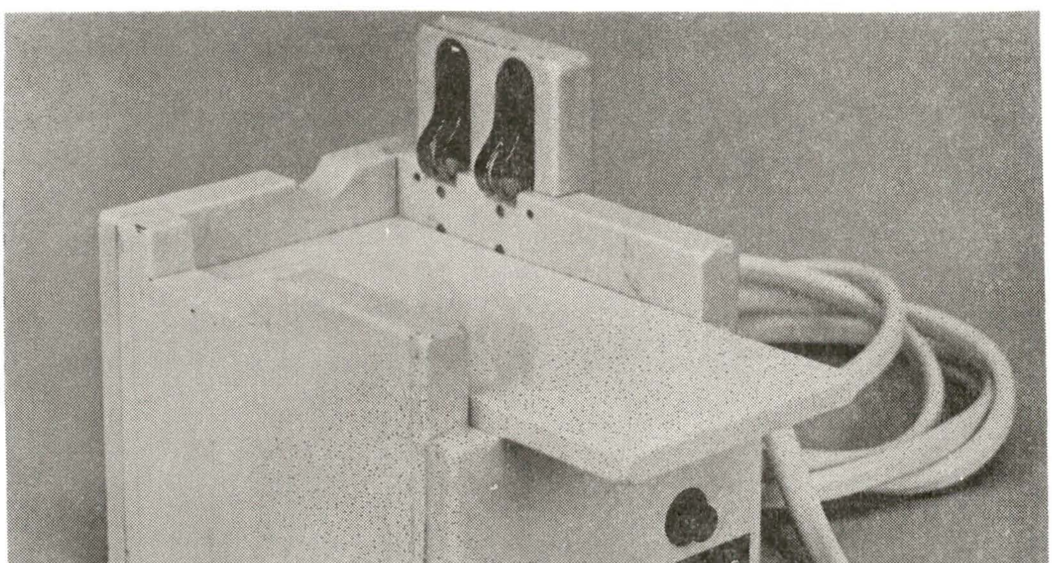


Figure 3 - Battery charger

A charge current control lamp and a flexible lead extension are provided for operation from 110 volts a.c.

III - OPERATING PRINCIPLE

Putting the sampler under voltage results in the rotation of the cup with the polyurethane foam filter. The nominal speed of rotation is about 10 000 rpm.

The rotation of the moving assembly (cup with filter) at high speed within the body of the apparatus has a ventilation effect which generates an airflow.

The dust-laden air to be sampled :

. is sucked into the cyclone through two rectangular diametrally opposed aspirating holes,

. enters the body of the apparatus through the cyclone outlet tube,

. goes radially through the polyurethane foam filter,

. returns to the atmosphere via an expanding outlet tube.

The airborne dust is trapped in the following way :

. The biggest particles which are normally stopped in the upper respiratory tract of man are retained in the cyclone.

. The fine dust that normally settles in the lung alveoli is trapped in the polyurethane foam filter.

. The finest particles, usually ejected on breathing out, are discharged via the air outlet.

Special mention should be made of the principle of respirable dust collection by the rotating assembly (cup with filter).

On leaving the outlet tube of the cyclone the respirable dust-laden air enters at the bottom of the cup at more than 10 m/s and is deflected towards the foam filter rotating at high velocity.

.../...

The polyurethane foam filter is a porous material consisting of fibers of great fineness compared to the pores, as shown in Figure 4.

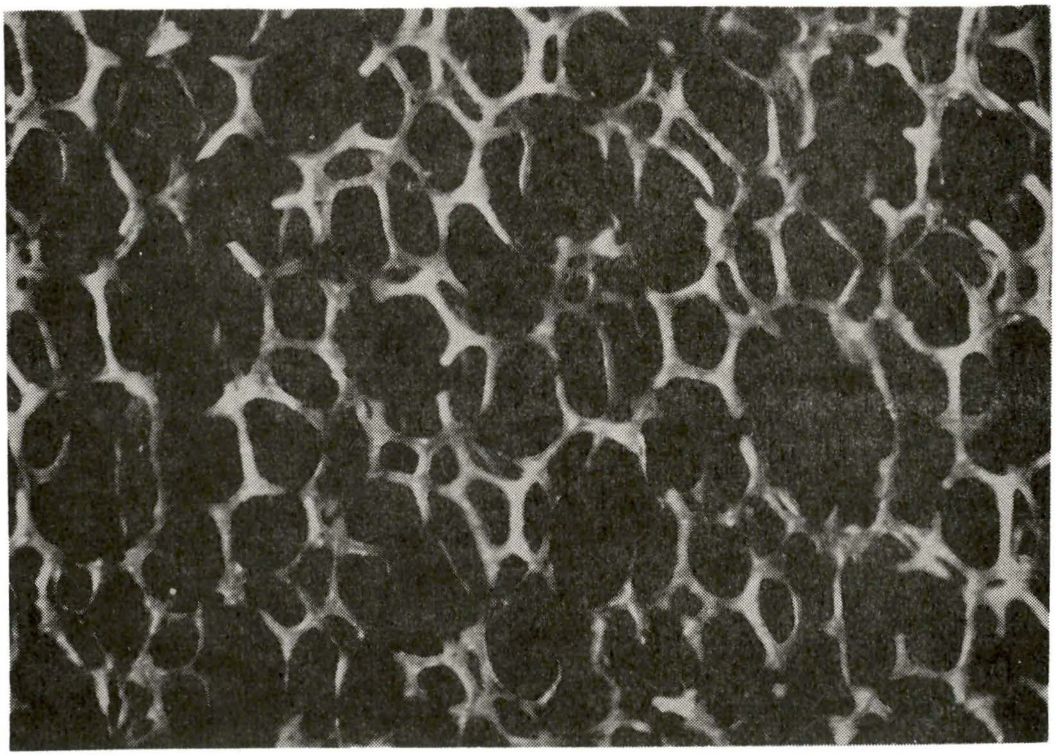


Figure 4 - Polyurethane foam filter. × 50

The dust-laden air which flows in perpendicularly to the rotating filter releases its particles which are trapped by impact on the fibers.

The retention capacity of each fiber is limited and beyond a certain limit, dust agglomerates separate and are trapped by deeper non saturated fibers. Ultimately, if the process was continued, they would be discharged outside.

It follows that :

. the pores remain clear and the filter cannot clog up. The pressure loss remains constant over the entire sampling period. Given a constant speed of rotation, the flow rate remains constant. To this end the electric motor is supplied under constant voltage.

. the retention capacity of the filter is limited by the trapping power of the fibers. The retention capacity is however sufficient to ensure measurement of dust concentrations normally encountered underground.

IV - CHARACTERISTICS

The apparatus has a nominal flow rate of 9 l/mn (540 l/hr) and an operation time of 10 hours. It is thus capable of handling 3 to 4 m^3 of dusty air over an entire shift and collecting sufficient quantities of respirable dust.

The speed of rotation of the moving assembly is about 10 000 rpm. It differs more or less from this value for the different apparatus according to the scattering of the pressure loss values of the cyclone.

Using small latex spheres in monodisperse aerosol suspensions, the efficiency of the rotary filter was measured at a speed of rotation of 9 600 rpm and a flow rate of 540 l/hr. The resultsare as follows :

particle size	0.56 μ	0.7 μ	1.1 μ	2 μ
efficiency	61.7 %	79.1 %	97.4 %	100 %

It is apparent that the filter is highly efficient at collecting particles of about 1 μ .

The percentage (in weight) of untrapped ultrafine particles compared with the respirable dust was also measured, using fine coal dust.

. This percentage was found to be less than 2 %.

. It is constant over the entire sampling period up to 50 mg of respirable dust collected.

The preselection efficiency of the available UNICO cyclones was also determined using fly ash in polydisperse spherical aerosol suspensions. The curve obtained and the general efficiency curve of the apparatus are shown in Figure 5 (provisional figure).

(Note that this is a provisional curve. The UNICO cyclones supplied in 1972 were defective and not accepted by OSHA of the US Department of Labor. A new curve will be plotted as soon as new UNICO cyclones corresponding to the AEC curve are available).

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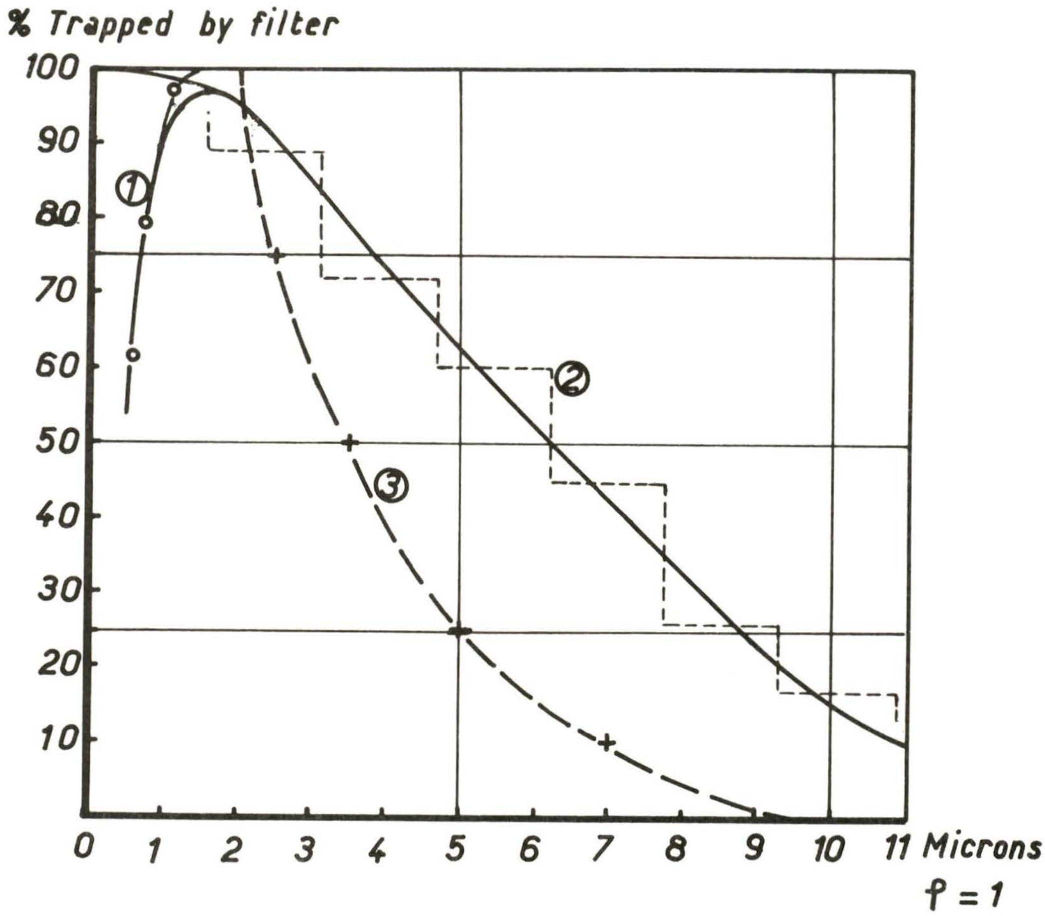

① Rotary filter trapping curve

② UNICO cyclone trapping curve

③ AEC reference curve

Fig.-5- TRAPPING CURVE OF THE PERSONAL DUST SAMPLER

(Provisional figure)

V - OPERATING INSTRUCTIONS

The different steps in the mode of operation of the apparatus are illustrated in Figures 6-11.

- Figure 6 shows the insertion of the polyurethane foam filter in the cup and its removal.

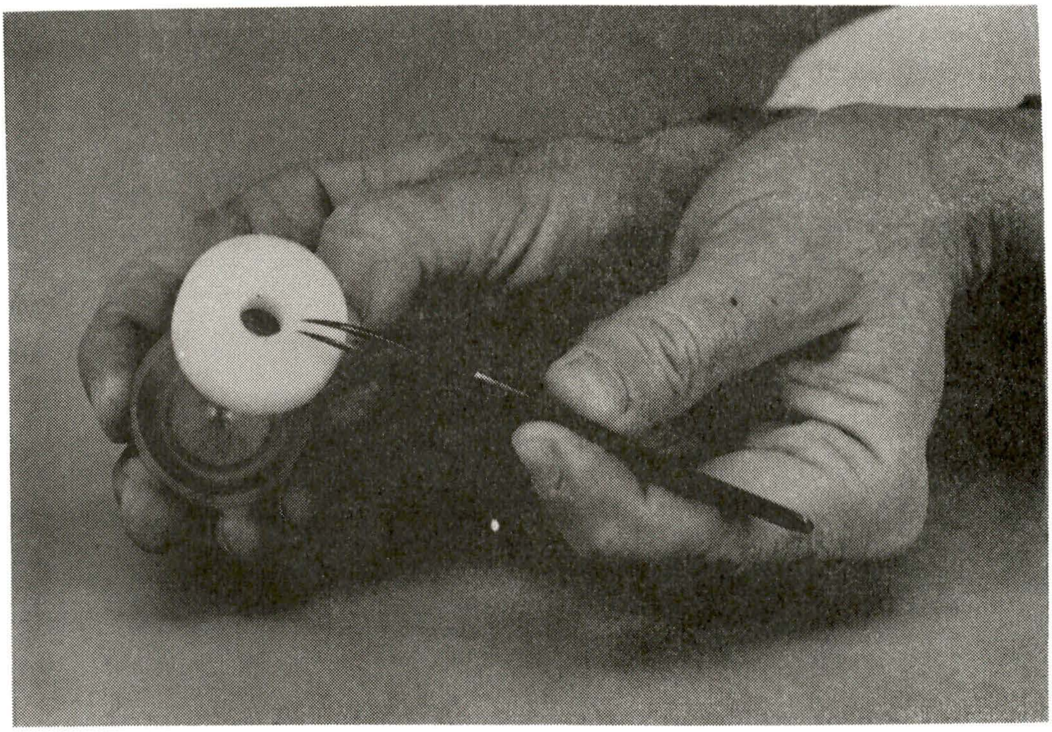

Figure 6 - Insertion or removal of the filter

To insert the filter in the cup :

. seize the filter with sharp pointed pincers,

. place it in the cup,

. press with the back of the pincers.

To remove the filter :

. seize the filter with sharp pointed pincers,

. pull.

- Figure 7 shows the mounting (or removal) of the cup with the filter on (or from) the magnetic plate at the bottom of the body of the apparatus.

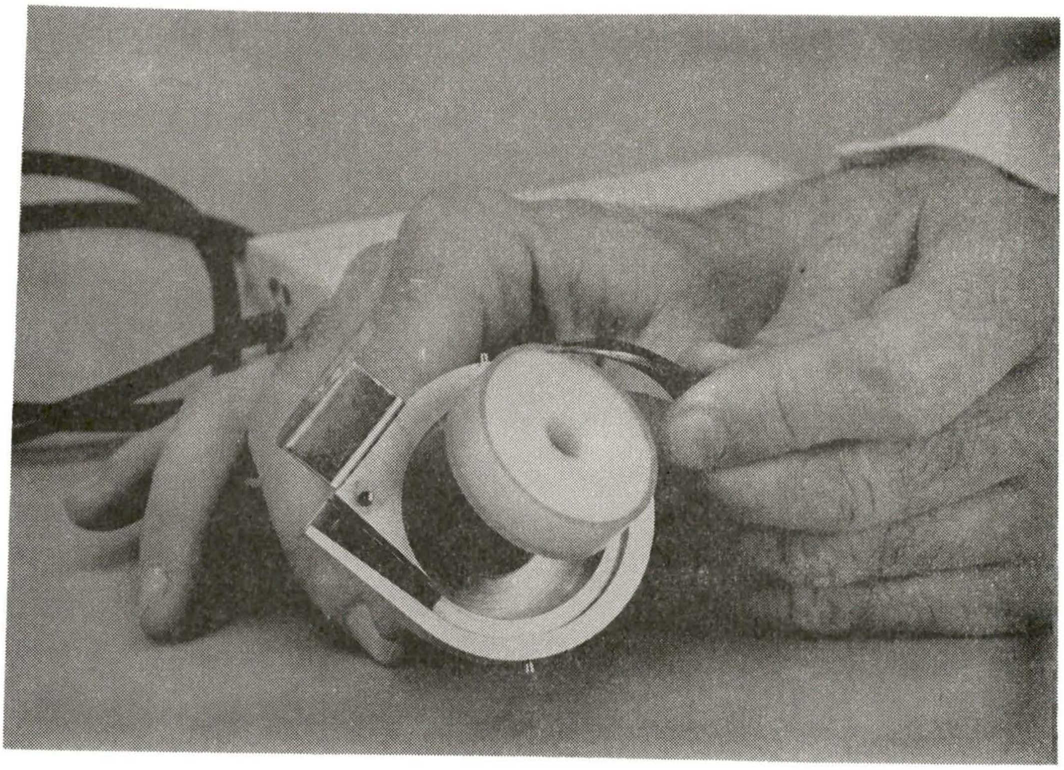

Figure 7 - Mounting or removal of the cup

To mount the cup on the magnetic plate :

. seize the lip of the cup using sharp pointed pincers,

. insert the cup in the body of the apparatus,

. let the cup fall, it will fit in of itself.

To remove the cup :

. seize the lip of the cup using sharp pointed pincers,

. pull.

- Figure 8 shows the closing (or opening) of the apparatus before or after use.

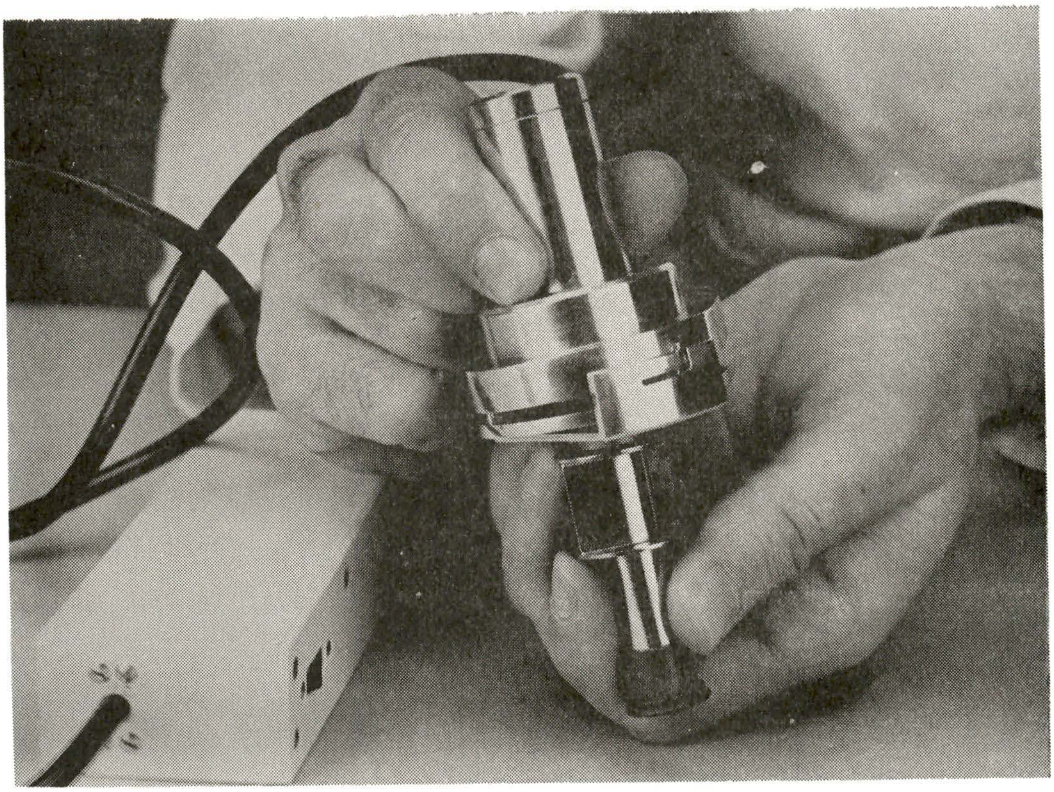

Figure 8 - Closing or opening of the apparatus

To close the apparatus :

. engage the guide slot of the clamp plate with the outer lock pins on the body of the apparatus,

. turn the clamp plate till locked.

To open the apparatus :

. unlock by turning the clamp plate,

. take the two parts apart.

When opening the apparatus after sampling, it is necessary to hold the cyclone vertically downwards so that the dust collected by the cyclone remains at the bottom and does not fall in the cup through the outlet tube.

- Figure 9 shows the placing in position of the lid.

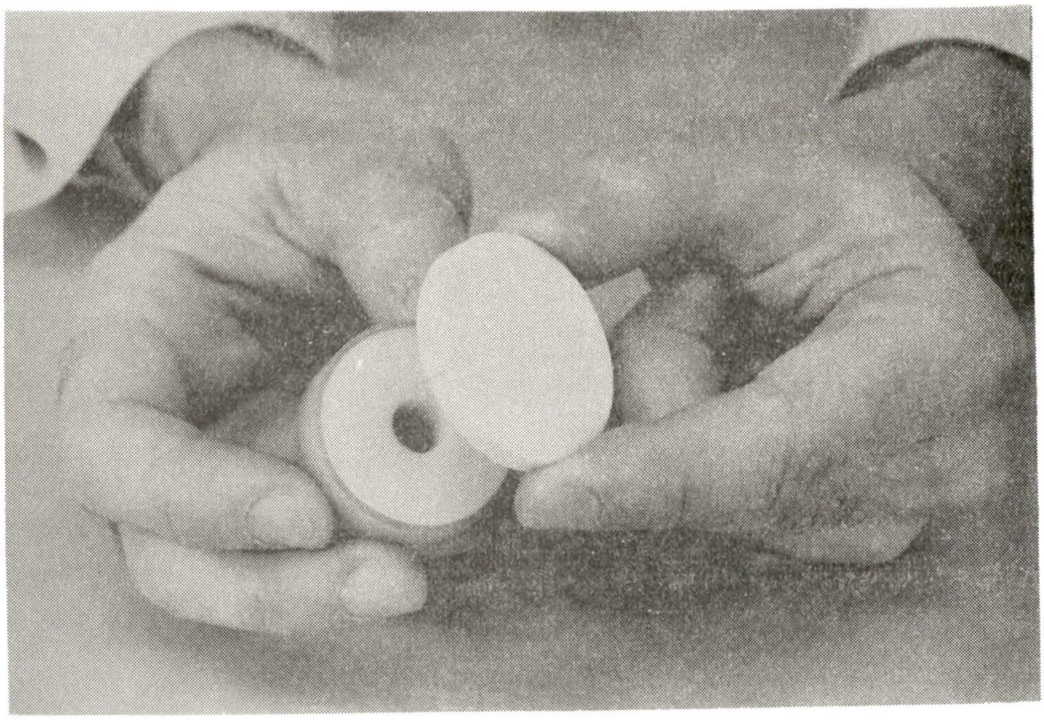

Figure 9 - Placing or removal of the lid

This operation should be performed only in the case of transportation for example to an analytical laboratory far from the sampling point. When the laboratory is near by, it is convenient to bring the samplers each time back to the laboratory. The lids are then of no use.

- Figure 10 shows the instrument and the battery being recharged on the charging apparatus.

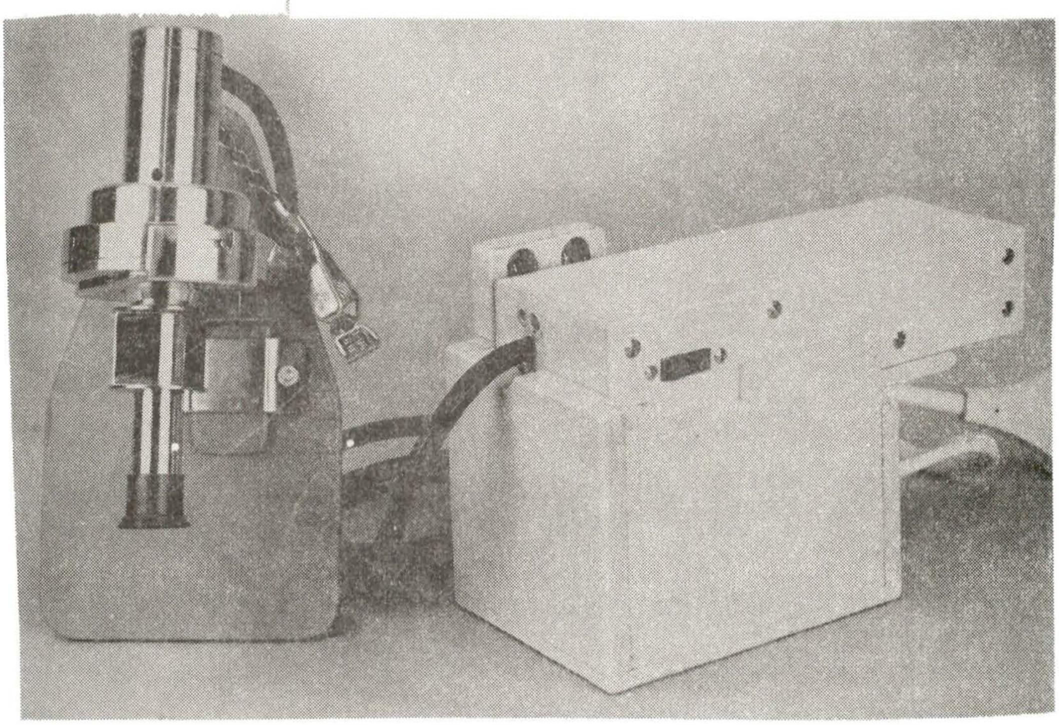

Figure 10 - Sampler and battery box on charging apparatus

.../...

To place the battery box in the charging apparatus :

. position the box so that it fits in the compartment provided on the charging apparatus, as indicated in Figure 10,

. press,

. connect to the mains,

. check that the lamp burns.

To perform this operation, first switch the instrument off. There is no recharging when it is on.

- Figure 11 shows the instrument worn by man.

Figure 11 - Sampler worn by man

To fit oneself with an apparatus :

. take the sampler in the left hand and the box in the right hand,

.../...

. pass the cable above the head over the left shoulder,

. slip the holder plate into the small breast-pocket of the jacket and the box into the opposite side-pocket,

. clasp the sampler to one's collar,

To take the sampler off after sampling, reverse the process, taking care that the instrument is not held upside down.

VI - EVALUATION

Measurement of the respirable dust is carried out by weighing the rotating assembly (cup with filter) before and after taking the sample.

Since the polyurethane foam is sensitive to moisture, the following precautions should be taken ;

Two cases are to be considered :

- There is available a balance room with controlled humidity and temperature or a room which although not air-conditioned has a low degree of humidity (less than 25 %). In this case, it is enough that the cups are stored in the room overnight for instance to attain equilibrium with the room atmosphere ; then they are weighed. The equilibrium can be attained more rapidly by circulating a small quantity of air through the foam to increase transfer phenomena. This is carried out by blowing a small quantity of clean air at the centre of the cup or by rotating the cup in clean air.

The dust concentration is given by the formula :

$$C \text{ mg/m}^3 = \frac{\text{Weight of dust collected in mg}}{\text{Filtered volume in m}^3}$$

- A balance room as above is not available. A reference filter must be used. It is weighed at the same time as the dust loaded filter and the reading is corrected to allow for the change in weight of the reference filter between the two weighings.

If W_1 is the weight of the reference filter weighed before sampling and W_2 the weight of the same filter weighed after sampling, the dust concentration is given by the formula :

$$C\ mg/m^3 = \frac{\text{Weight of dust collected} - (W_1 - W_2)\ \text{in mg}}{\text{Filtered volume in } m^3}$$

The respirable dust collected can be recovered in a liquid bath, a wetting agent being added to the liquid. The suspension obtained can be examined under the microscope for dust counts or collected on a filter membrane for further analysis (ash content or quartz determination). For that purpose, the foam filter used must have been handled in a liquid bath to remove preexisting particles and dried before the first weighing.

The larger particles collected in the cyclone can also be recovered, weighed and analysed, if desirable.

VII - CHECKS, ADJUSTMENT, MAINTENANCE, REPAIRING

The nominal flow rate of the instrument is 9 l/mn (540 l/hr).

The flow rate is sensitive to any additional pressure loss, so that it should be checked by using a device (Figure 12) to balance the pressure upstream and downstream from the instrument. The procedure is a follows :

. pull the cyclone out of the sampler,

. take an air-tight, closed chamber (tin box for instance) comprising an air inlet tube and a pressure gauge connection,

. place the cyclone at the bottom of the box under tight conditions with the cyclone outlet tube emerging from the box,

. connect the outlet tube of the cyclone to the sampler,

. connect a flowmeter (for example rotameter) to the air inlet tube of the box and a sensitive manometer to the pressure gauge connecting tube,

. switch the instrument on and blow air through the air inlet tube of the flowmeter, till the sensitive manometer gives a zero reading,

. check that the manometer reading is 9 l/mn (540 l/hr),

.../...

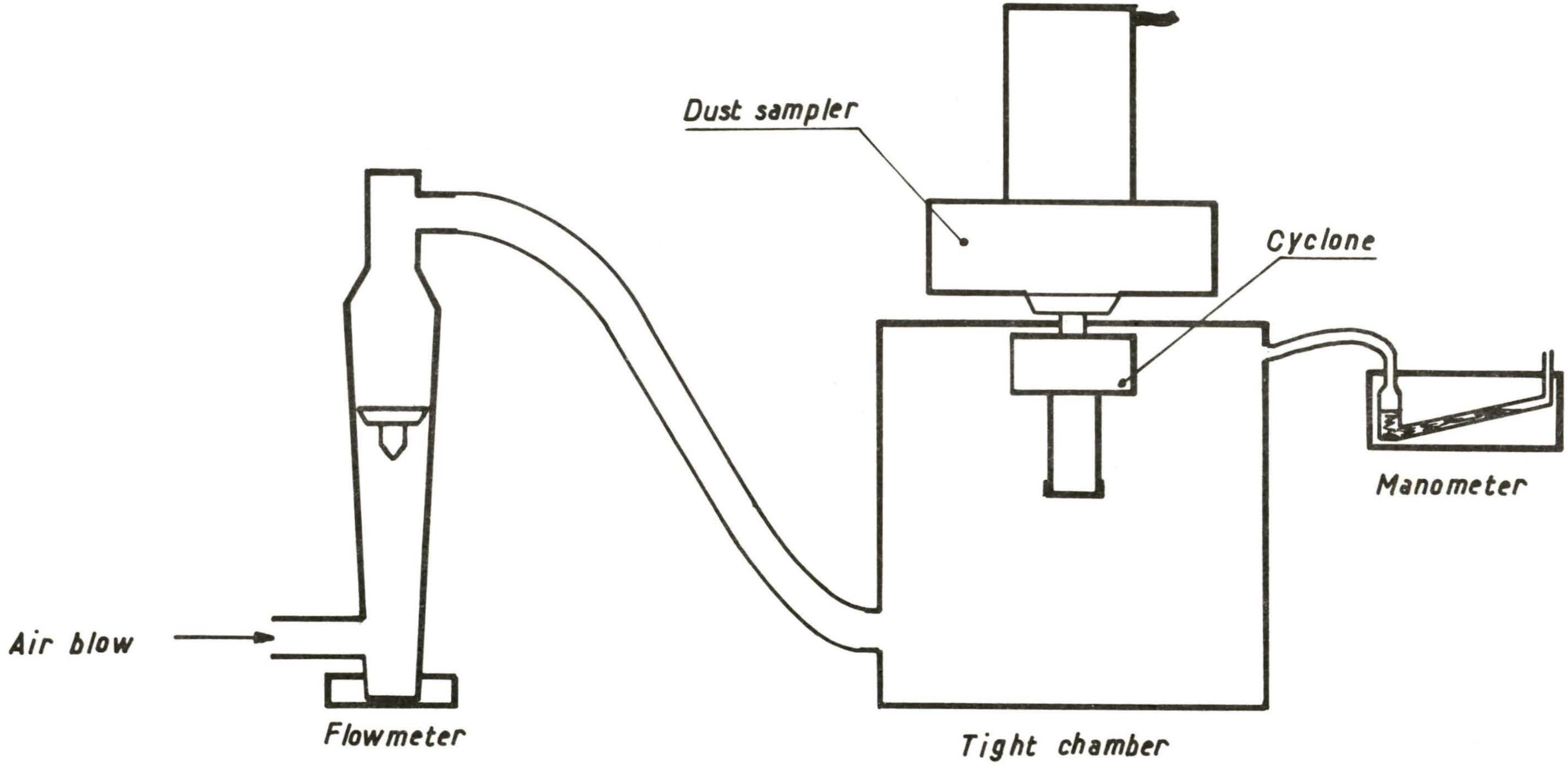

Fig.-12- DEVICE FOR CHECKING FLOWRATE

. should the flowmeter give another reading, adjust the control potentiometer mounted on the voltage regulation printed circuit of the battery box, until a correct reading is obtained.

In addition,

. measure the overpressure of the instrument at zero flow rate. To this end, connect (under tight conditions) a manometer to the air outlet and check the reading. The overpressure at zero flow rate for the instrument n° .... is ....

. measure the speed of rotation of the rotating assembly, the instrument being open, with the help of a stroboscope. For the instrument n° .... the speed of rotation is ....

For further quick indirect checking it is sufficient to verify

. either the overpressure of the instrument at zero flow

. or the speed of rotation of the rotating assembly, the instrument being open.

The instrument requires no maintenance with the exception of periodical cleaning.

The risks of failure are small and only with regard to the electronic components (fuse for example) and the motor. In particular, when the motor presents signs of wear, it should be replaced. In principle, the lifetime of the motor is 2 000 hours.