Application of Computer Methods for Planning, Checking and Controlling Mine Ventilation

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SYNOPSIS

Mine ventilation in the German coal mining industry is concerned mainly with problems of thermal environment arising from greater depths and with increasing emission of methane gas. The development of computer techniques over the past ten years for solving these and ancillary problems is reviewed. The emphasis from a planning and control point of view falls mainly on ventilation network calculations, temperature predictions and advance estimates of methane emission.

INTRODUCTION

Most of the mineral production of the world, in terms of both quantity and value, comes from drillholes and opencast mines. Nevertheless, underground mining still plays an important role. For example, in the Federal Republic of Germany all the hard coal and practically all salt are mined in workings which are situated more than 500 m below the surface. Compared with other methods of extraction, deep mining is handicapped by the necessity to maintain a suitable environment for the workmen. As long as it is not possible for the miners to be insulated from the surrounding atmosphere, like space travellers, a ventilation current has to be passed through the whole mine in order to create appropriate climatic conditions and to dilute and remove toxic gases.

At present, working faces in the West German coal mines have reached lengths of up to 250 m, and the average depth has increased to almost 800 m. At such depths the natural temperature of the rock ranges from 40 to 55°C. With increasing output from a single face, say up to 6 000 tons per day of run-of-mine coal, considerable quantities of heat are released from machinery and from the surrounding strata. Machines installed in the face and gateways may have a total power rating of up to 1 000 kW per productive unit. Another problem is caused by the emission of methane from the coal at a rate up to 60 m^3 of CH_4 per ton of output. This gas must be diluted as quickly as possible to below the maximum permissible concentration, which in Germany is 1.5 per cent.

The air flow supplied to the working faces varies from 15 to 25 m^3/s. The main fans installed on the surface can create a pressure of up to 500 mm water gauge and an air flow of up to 250 m^3/s. As a rule, only 50 per cent of the intake air current will pass through the faces; the rest is used to ventilate other workings, or it is lost through short circuits.

With increasing depth and output, ventilation has become more and more important, so that now digital computers are used in most cases for the solution of ventilation problems in German coal mines. In the middle fifties, efforts were made to develop analogue systems to simulate ventilation networks. This approach did not become popular in Germany. The application of computers is, however, widespread. At the end of 1970, approximately 30 computers were installed in the mining industry and most of them are used, apart from other tasks, for the calculation of ventilation networks.

Ventilation problems which are so important and complex that they call for the use of computers can be subdivided into three categories:

(i) routine calculations, for example, computation of pressure measurements,

(ii) planning, for example, the prediction of gas emission at coal faces, and

(iii) simulation, for instance, the investigation of the stability of ventilation networks.

The place of a digital computer in the main ventilation system of a mine can be represented schematically, as shown in Fig. 1.

The basic data for the planning of the ventilation system are determined in conjunction with the planning of the mining operations. They are based on the experience available, which may be documented or stored in a data bank. If, for technical or safety reasons, the measures required for the ventilation of the mine cannot be put into practice, the ventilation plan has to be revised. In certain conditions it may even be necessary to modify the general plans for the mining operations, for instance, the layout or the cross-sectional area of the workings.

As mining operations progress according to plan, results of control measurements are compared with the data of the plan (comparison between effective and the target values). If differences exceed permissible values, the ventilation plan has to be adapted to the changed conditions.

It is intended to give here a review of the state of development which has been reached ten years or so after the first application of computer programs for the solution of ventilation problems in the German coal mining industry. In the different branches of ventilation, several programs have been developed. Most of them differ only in input and output, the methods of calculation being more or less the same. This review deals with three aspects, namely:

(i) calculation of ventilation networks,

(ii) calculation of thermal conditions, and

(iii) pre-calculation of methane emissions.

CALCULATION OF VENTILATION NETWORKS

Measured quantities have to be compared with one another or correlated with other relevant quantities in order to convey an idea. It would be impossible, for instance, to estimate the quality of a ventilation system only from the distribution of the different air currents without taking into account the pressure to which this distribution is due. The simulation of a certain ventilation network by a mathematical model is not based on measured values of the air flow or of the difference in pressure, but on the *resistance* to flow, which is determined approximately as the quotient of pressure loss and the squared quantity of air.

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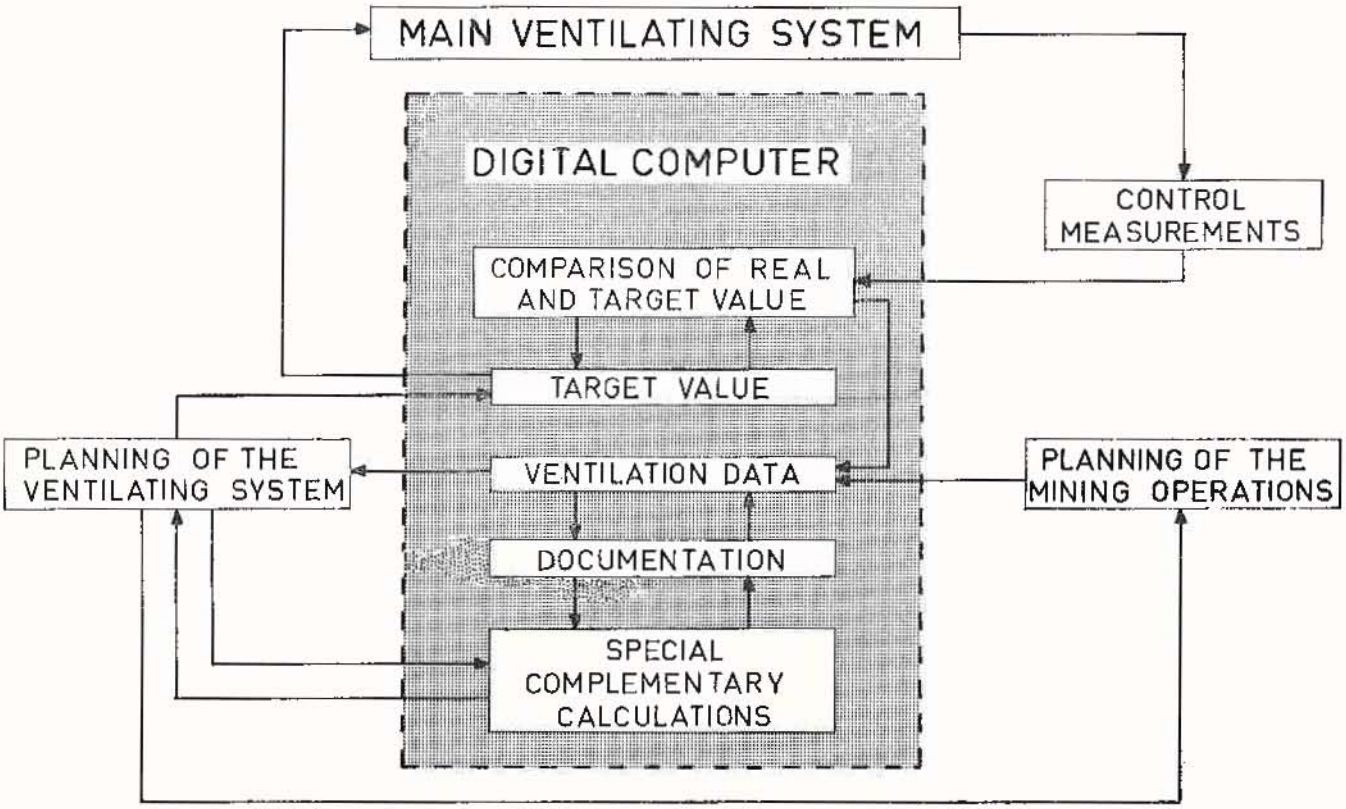

Fig. 1. The place of a digital computer in the planning and control of a mine ventilating system.

It is now general practice to use a program in order to determine the resistance to flow through airways. As the program makes use of pressure and air flow measurements underground, it checks the plausibility of the measured values and makes the corrections necessitated by measuring errors, by a change in atmospheric pressure and by the different elevations of the measuring points. Useful yardsticks for checking the accuracy of measurements are the calculated value of the cross-section and the resistance to flow over a length of 100m. Both of these values could reveal possible measuring errors.

When complex ventilation networks have to be analyzed, there are, in principle, two different methods which permit the calculation of the distribution of air currents and pressure from the given values of resistance to flow and fan pressure. In the first method, arbitrary values of pressure at junctions or nodes are assumed and the resulting pressure distribution is gradually corrected until it satisfies Kirchhoff's first law. The second method is used in Germany to analyze not only ventilation but also gas and water distribution networks. Here, the calculation starts from an estimate of the quantities and the direction of flow in the branches of the network. Subsequently gradual corrections are made to eliminate pressure differences around the meshes so as to satisfy Kirchhoff's second law.

The first step in finding the meshes of a network is the selection of a basic system. This means that a sequence of branches must be designed which connect all junctions of the network without forming a mesh in itself. There remain a number of 'independent' branches, each of them closing a mesh. The given direction of flow in the independent branches determines the direction of flow around the mesh, Fig. 2.

The values of the air flow which satisfy both of Kirchhoff's laws are found by iteration. Starting from an arbitrary quantity of air flowing through each of the independent branches, an adjustment is determined for each mesh which is added to the currents flowing through the branches of the mesh in question. This iteration is continued until both of Kirchhoff's laws are satisfied.

Apart from the fans, natural ventilation also generates a certain pressure which must not be ignored in precise ventilation calculations for deep and hot mines. A correction, corresponding to this effect, is calculated from the difference in elevations and the mean density of the air within one mesh. This correction is taken into account in the course of the iteration.

Where there are several fans in a ventilation network, the calculation must not rely on fixed-duty points on the characteristic curves of the fans, but the mutual interference of the fans has to be considered. This is achieved by further iterations for the meshes which include a branch with a fan. The pressure and air quantity are altered repeatedly until the point of intersection between the mine curve and the fan characteristic is reached.

In Fig. 3 the flow chart of a program used for the analysis of a ventilation network typical of German coal mines is shown. This program is designed to meet normal industrial requirements at minimum cost. The program, after some modifications, can be used to study unusual or even emergency situations; for instance, the problems arising from a mine fire or from the breakdown of a fan may be studied by simulation. A disadvantage of the program is that, in case of larger networks, the automatic finding of meshes calls for a relatively great memory capacity of the computer. However, the computers used by the German mining industry have

proved to be of sufficient size to cope with all practical problems which have arisen so far.

CALCULATION OF THERMAL CONDITIONS

In the planning of deep mines, a knowledge of climatic conditions is essential. In particular, the temperatures to be expected at the working faces and other characteristics of ventilation must be known with reasonable accuracy.

The application of digital computers has made it possible to calculate, with the required accuracy and at reasonable costs, the data which are needed to pre-determine the air conditions in a mine. The programs known so far are used to predict air conditions not only in through-ventilated faces and roadways, but also those in workings and headings with independent air supply. As there are no essential differences in the fundamentals, it will suffice to discuss only broadly the program for the pre-calculation of the air conditions at coal faces.

This program requires as input data, among others, the depth, natural rock temperature, nature of the country rock, the method of roof control, quantity of air, output from the face and the installed electric power. The first step in the calculation is to determine the rise in temperature of the ventilation air at the entrance to the face due to the emission of heat from the electric driveheads or, conversely, the drop in temperature caused by refrigeration (Fig. 4).

The face is then subdivided into sections, each of them about 5 m in length. Using a subroutine, the surface temperature of the surrounding strata and the increase in the temperature of the ventilating air, due partly to the release of heat from the strata and partly to the oxidation of the coal, are calculated. Next, the effects of the auto-compression of the air and of the frictional heat, generated by the coal-getting machines and the haulage equipment, are taken into consideration. The dry- and wet-bulb temperatures at the end of the first section of 5m, calculated in this way, are the input values for the next section of the same length. This calculation is repeated until the end of the face is reached, where, once again, the heat emitted from the driveheads is added.

In principle, the calculation of the changes in air conditions in roadways follows the same lines, but there are certain differences in the details. For example, the age of the roadway is not constant along its length. This and other differences must be taken into account when dealing with roadways.

CALCULATION OF METHANE EMISSIONS

As the final example of the application of digital computers in the field of mine ventilation, a compound program, consisting of three independent parts, will now be introduced. This has been developed to predict methane emissions and to aid in the interpretation of experimental data on gas emissions from strata.

Although the physical laws governing the release of gas from the carboniferous strata are relatively well known, the exact mathematical formulation of these laws is extremely difficult on account of the great number of parameters involved. These parameters differ widely in nature and some of them are not even quantifiable. Nevertheless, as mining operations are adapted to the gas emissions as predicted by the program, increased safety and improved economics result.

The program for the prediction of methane emissions is based on the assumption that the zones of gas release from the roof and floor strata of a seam can be represented by two triangles having the length of the face as their bases. The overlying and underlying seams are disregarded, unless their thickness exceeds a certain value. The gas content of each seam is assumed to be equal to the mean of all available empirical values for the seam in question. If necessary, the gas content of another seam, comparable in respect of gas emissions, is used in the calculation. Gas emission from the rock is neglected, because of the low gas content.

Using a second program, the actual gas emission during the working of the seam is calculated from measurements in boreholes, from the results of methane drainage, and from gas analyses of the ventilation air. The combined result of both programs is used as input for a third program which stores all the essential data in a data bank and which is used as a basis for further predictions.

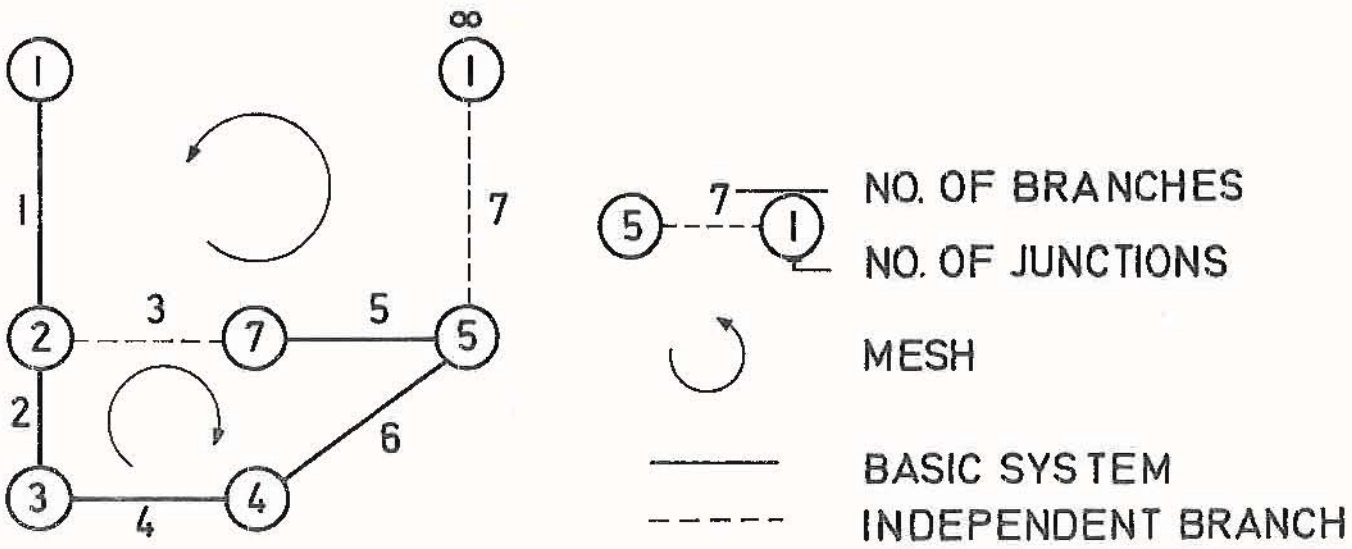

Fig. 2. Schematical representation of junctions, branches and meshes in a ventilating system.

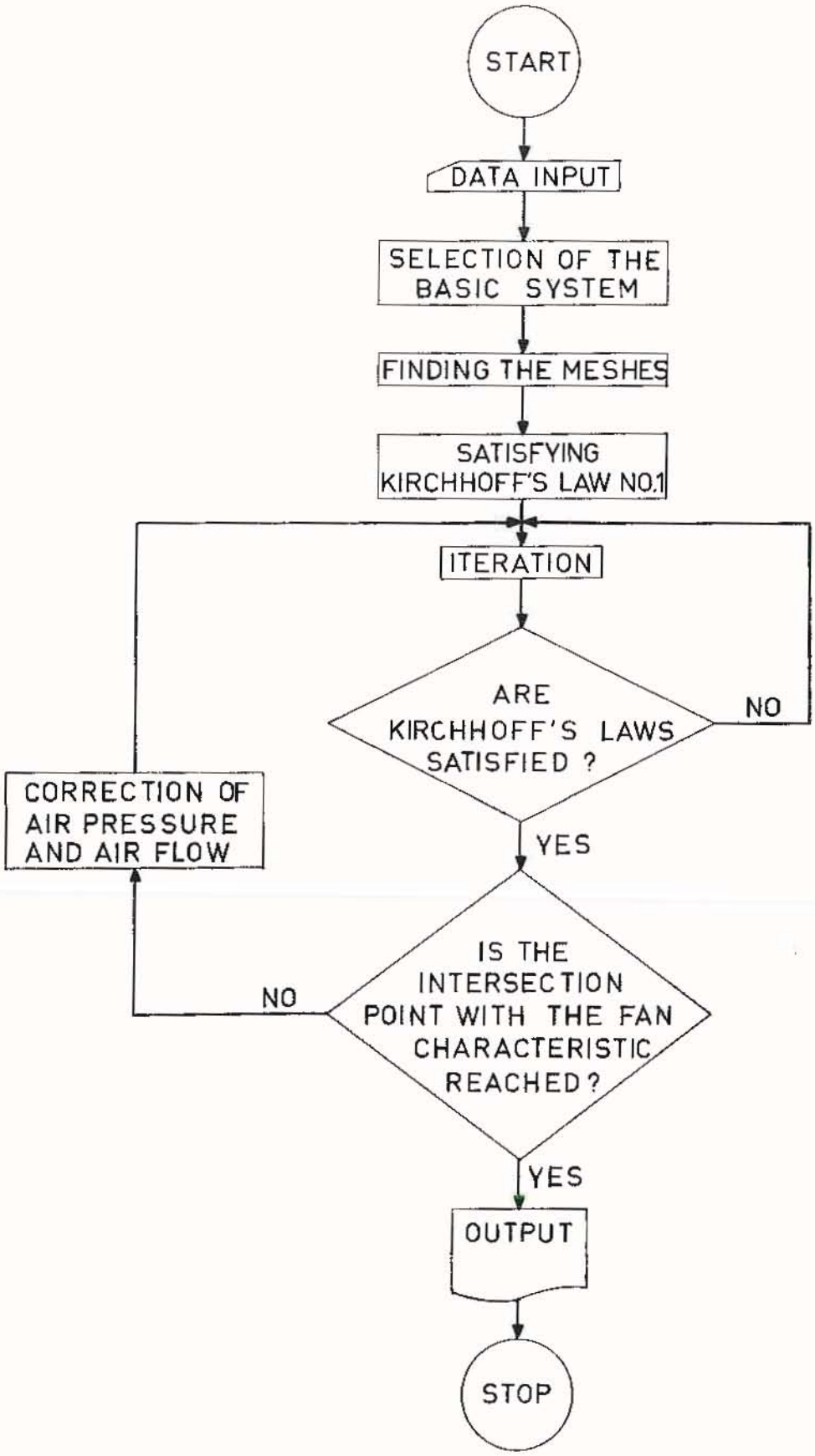

Fig. 3. Flow chart of a program for calculating a ventilation system.

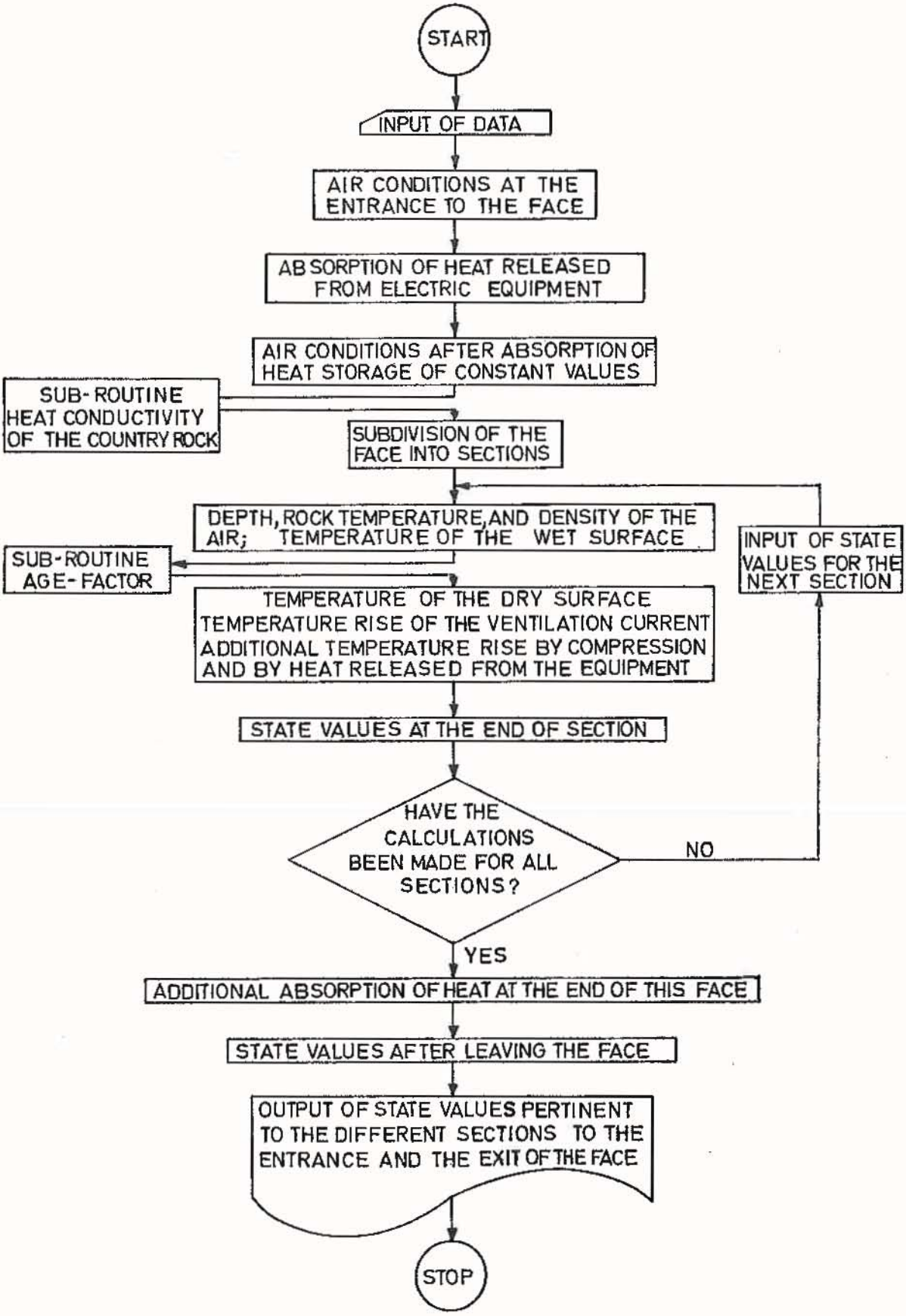

Fig. 4. Flow chart of a program for pre-calculation of the air conditions in faces.

CONCLUSIONS

Some computer programs which are used in the German coal mining industry for the planning, control and the supervision of ventilation systems, are introduced in this paper. In the present state of the art, digital computers play only an indirect part in the solution of ventilation problems. For the time being, the change-over to direct control is still meeting with great difficulties. These are due partly to the permanent local changes in the ventilation systems and their liability to disturbances and partly to the unsuitability of measuring instruments and data transmitters. In spite of these shortcomings, the control of the ventilation systems of mines, also of coal mines, will be entrusted in the near future to computers. One concept, which is currently on trial, visualizes a real-time computer which will be used to compare pre-set target values with the values measured underground and to control, depending on the results, adjustable fans and regulators so as to ensure the correct distribution of air in the mine.