ELECTROMAGNETIC SURVEY METHOD APPLICABLE TO UNDERGROUND QUARRIES

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Abstract

We present an electromagnetic method taken from the well known radiogoniometer that allows us to locate at the surface of the ground the vertical axis of a magnetic antenna transmitter buried at a depth h in the earth.

The method and the equipment achieved are called R. E. P. E. (Relevé Electromagnétique de Points Enterrés). They are daily used to accurately survey old quarries by using triangulation instruments at the surface of the earth rather than in galeries where the setting difficulties considerably reduce their accuracy and increase the work length.

The results of several surveys allow us to give the optimum working conditions of the instruments and show that, when the transmitter is at a 20 meters depth, its position is known at the surface with an error lower than 1 centimeter. The power transmitter is of about 8 watts and we can find its location with an error smaller than 1 meter when buried at a depth of about 100 meters.

This equipment may be successfully used for location of subsurface miners. The space surrounding the transmitter must then be free from ferromagnetic bodies.

Principle of the Method

The principle of the method is illustrated in Fig. 1. We put on the ground (for example, in a mine galery) a small emitter; this emitter has an antenna that we consider as a vertical magnetic dipole. If the signal frequency is low enough, the discontinuities of the mine galeries and the surface of the ground do not deform the magnetic field [1], [2] produced by the emitter. Under these conditions the magnetic field is symmetrically distributed around the vertical axis of the antenna.

For determining the position of the vertical axis of the antenna, it is sufficient, on two different stations at the surface of the ground, to practice - with a magnetic antenna receiver - two sightings in the direction of the horizontal component of the magnetic field. The

position of the vertical axis of the emitter antenna is then at the intersection of the two sightings.

Description of the Equipment

The equipment consists of:
- an emitter set in the mine galeries
- a magnetic receiver operating at the surface of the ground
- and a pair of radiophones allowing to the workers to communicate through the earth.

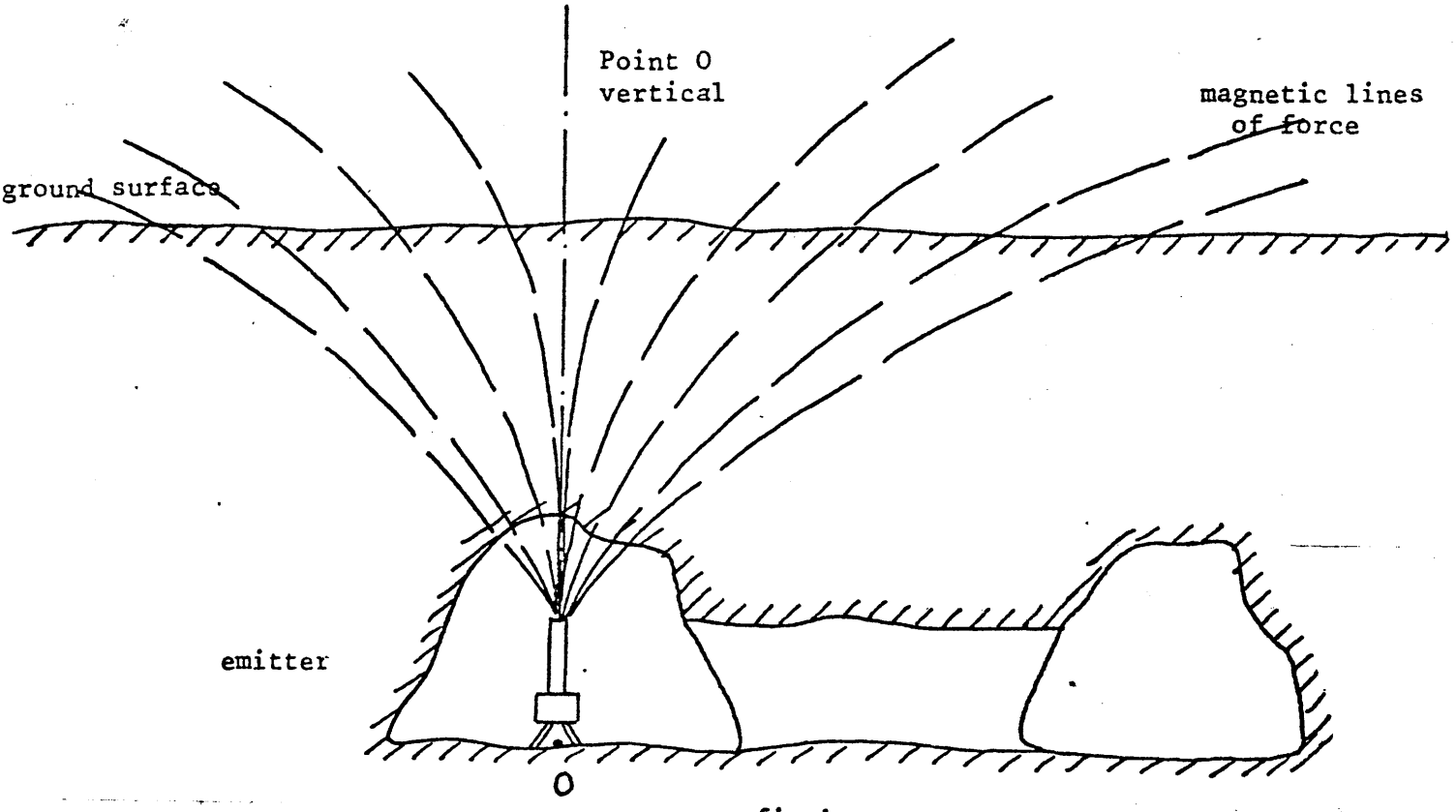

fig.1.

The Emitter

The block diagram of the emitter is presented in Fig. 2. The signal frequency radiated is about 1 kHz and the power produced by the emitter is of about 8 watts.

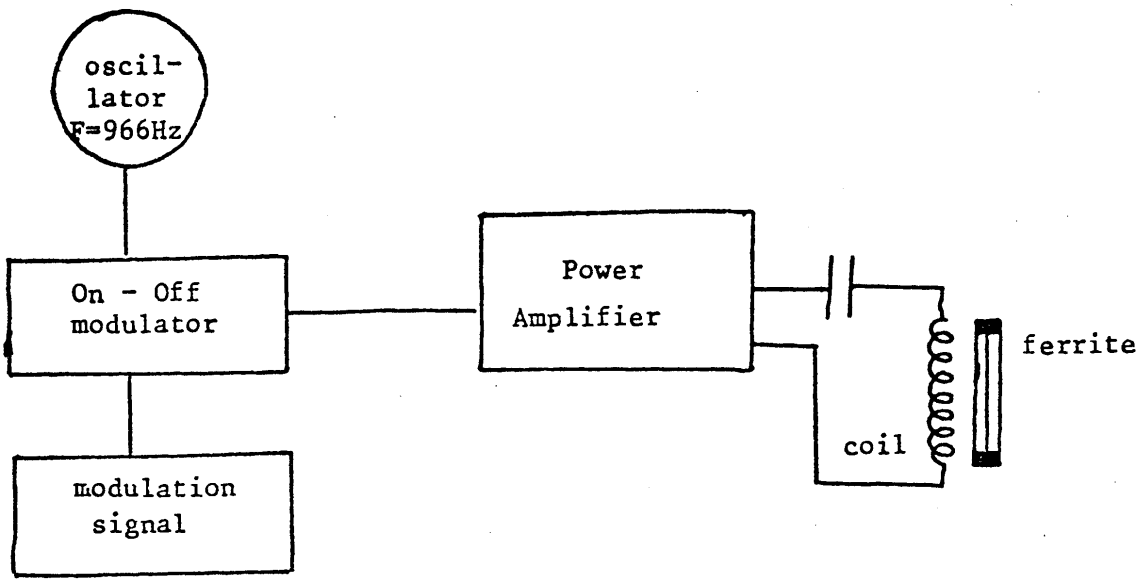

fig.2.

The antenna is constituted by a coil wound around a small bar of ferrite half a meter long. Figure 3 shows the photo of the emitter. The apparatus is mounted on the embase of a theodolite Wild to maintain the verticality of the coil axis.

The Receiver

The receiver, as shown in Fig. 4, is made of two perpendicular coils and of electronic amplifier and filters. This receiver can operate either as an amplitude detector or as an angle detector.

Amplitude Detector Operation

When the receiver is connected (Fig. 5) as an amplitude detector, we only use the coil A. The signal appearing at the ends of the coil A is amplified and simultaneously heard by a headphone and read on the dial of a voltmeter.

To determine the direction of the horizontal component of the magnetic fields, one turns the axis of the coil A in a horizontal plane until one finds a minimum deviation on the dial. Then the direction of the horizontal field component corresponds to the coil B axis.

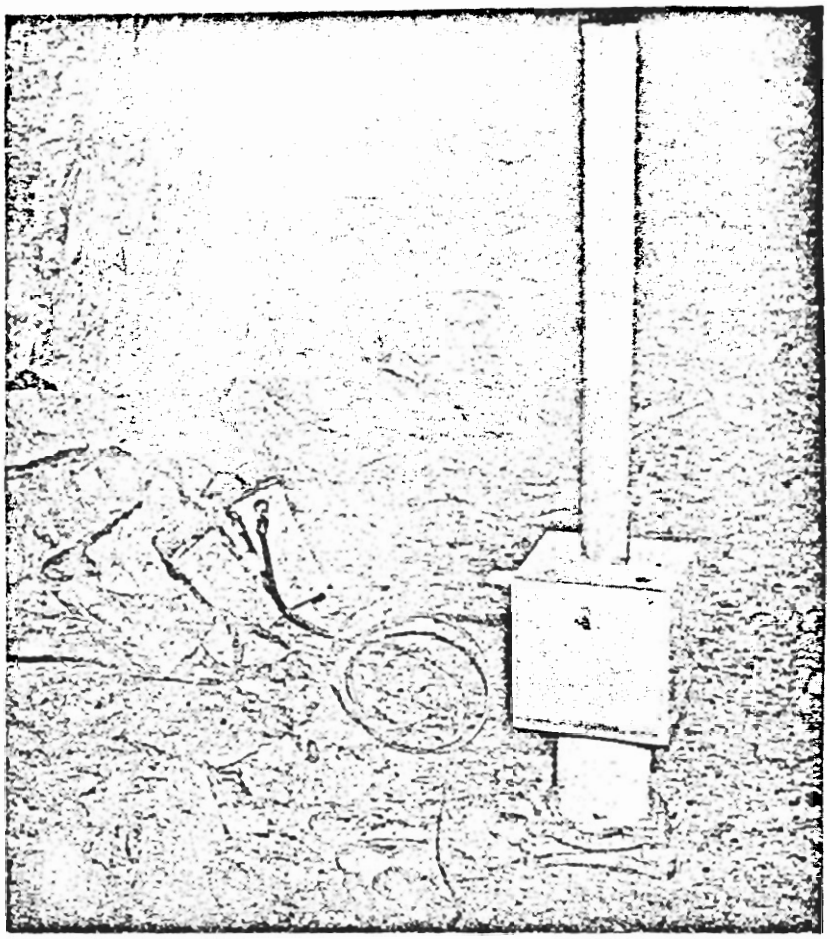

fig.3.

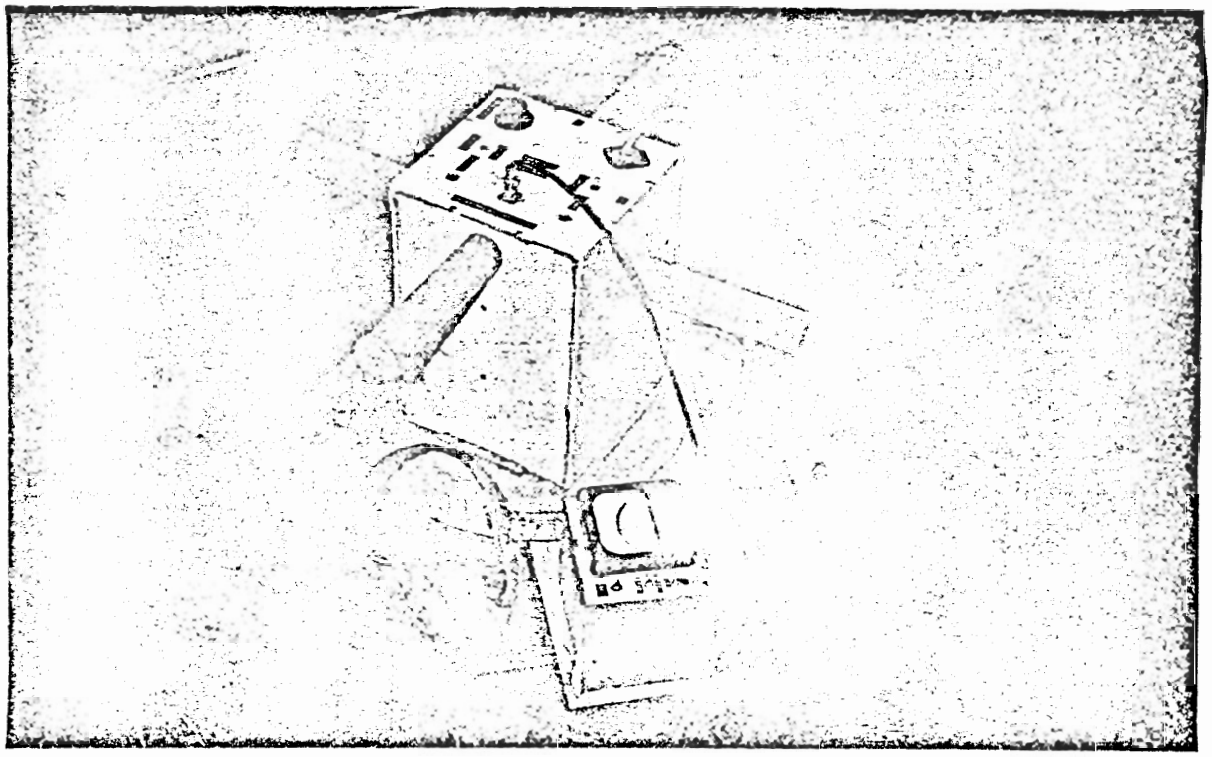

fig.4.

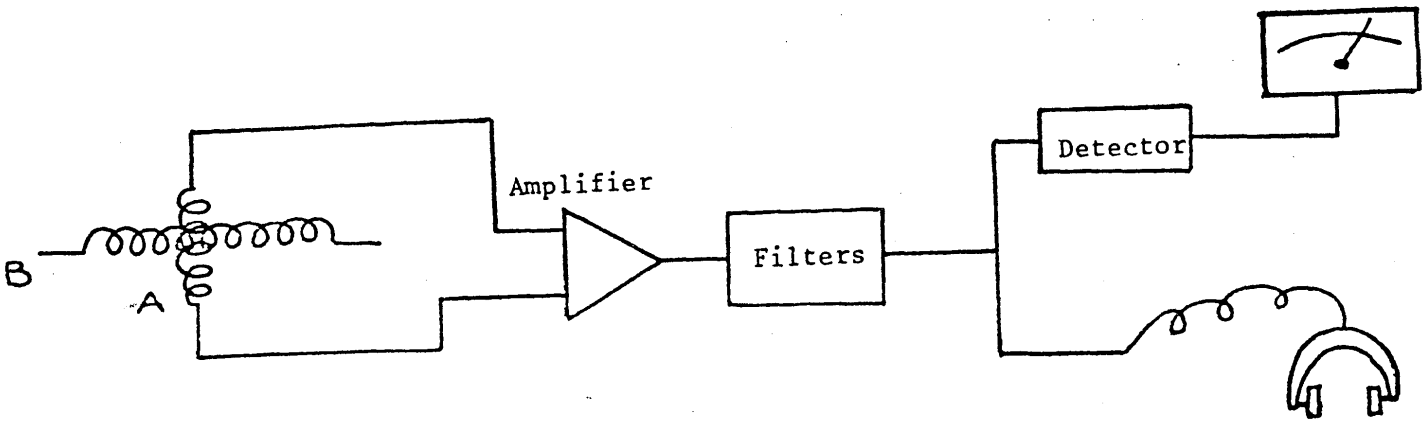

fig.5.

Angle Detector Operation

In this case the coils A and B are both used and the receiver acts as shown in Fig. 6. It detects the phase difference between the signals issued from the coils A and B.

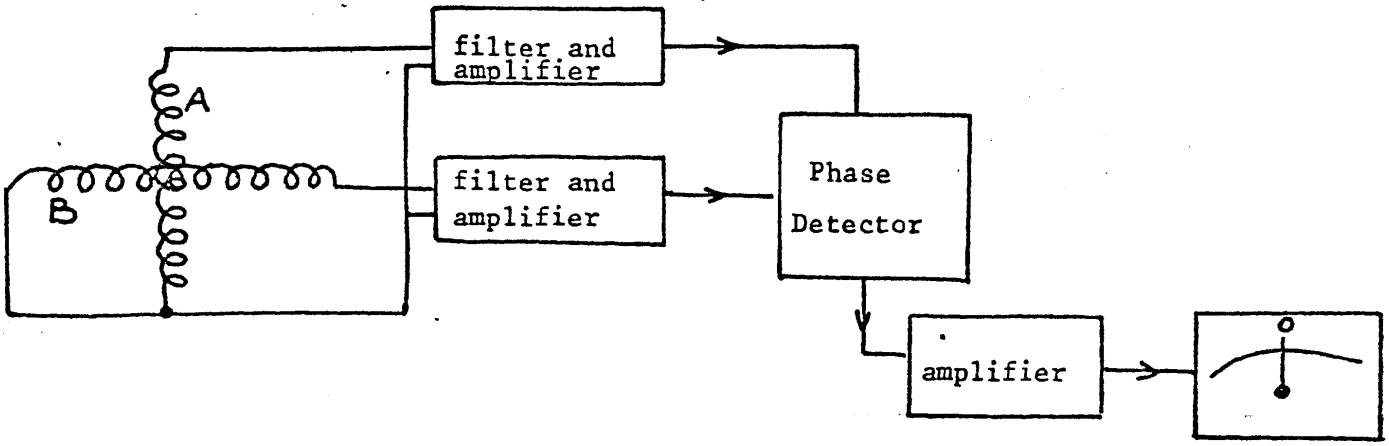

fig.6.

As is shown in Fig. 7, when the phase difference is $\pi/2$, the coil A or the coil B are in the emitter direction. When one of them is in the emitter direction a system of control allows us to verify the coil A is found in the right direction. The use of the receiver as an angle detector permits good accuracy when the signal/noise ratio is high.

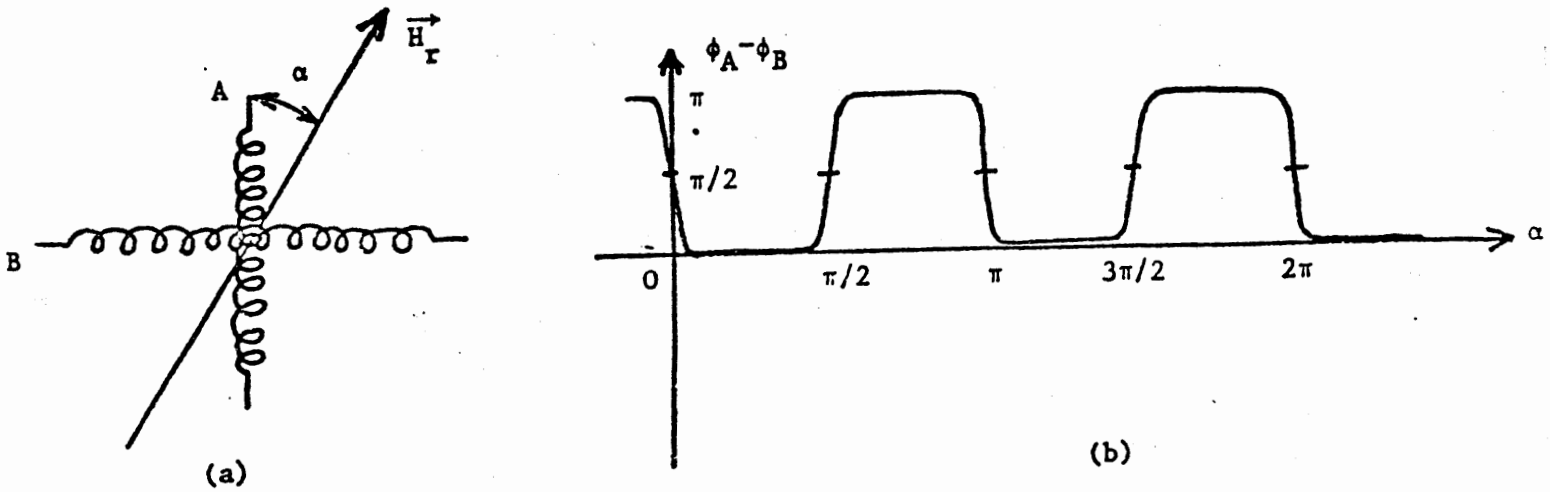

fig.7.

Radiophones

The radiophones were built to establish radio communications between the team at the surface of the earth and the team in the mine gallery. The main data are the following:
- the power supply is a 7 volt and 10 amp-hour battery
- the consumption of each radiophone is about 8 watts
- the transmission is made with a single-sideband system.

These radiophones allow communication between the surface of the ground and a station buried at a depth of about 25 meters. Figure 8 shows a radiophone set on the ground.

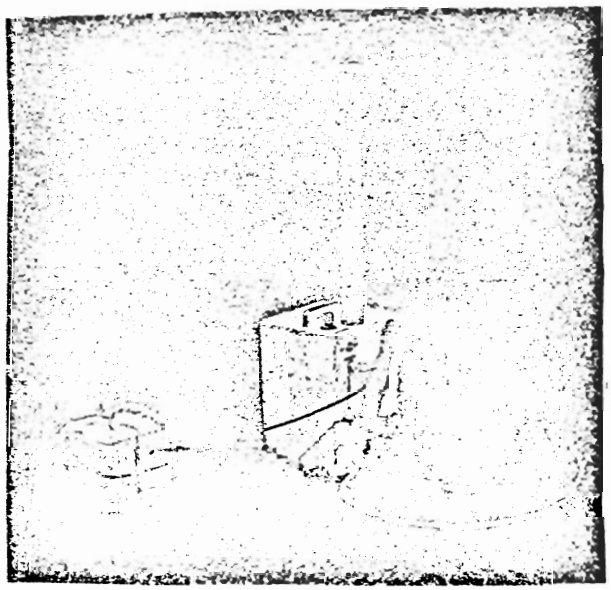

Fig. 8.

Performances of R.E.P.E.

This system has been used for three years to survey old quarries near Lille in the North of France. The experience acquired with this apparatus allows us to study the different kinds of errors made during the survey and the average of errors taking account of the working conditions.

We can distinguish four sorts of errors:
- the error due to anomalies of conductivity included in the surrounding ground of the emitter
- the error due to the verticality of the antenna emitter axis
- the error due to the horizontality of the receiver coil axis
- the error due to the noise signal acting near the receiver.

We have particularly studied the first three of them.

Anomalies of Conductivity

The magnetic lines of force are theoretically distorted by conductivity and magnetic permeability anomalies. We have chosen the signal frequency of the emitter in order to verify the relation:

$$(\sigma_a \omega \mu_o)^{\frac{1}{2}} \ell < 0.2$$

where σ_a = conductivity of the anomaly
ℓ = dimension of the anomaly

In these conditions we can deduce from[2] that the magnetic lines of force are not modified by the finite conductivity and the geometry of possible anomalies.

In our case where the main anomalies are cavities, the experiment shows that the magnetic field is not disturbed when the frequency is about 1 kHz and when the depth of the emitter is about 12 meters. For larger depths it could be necessary to reduce the frequency until we verify the above equation where ℓ represents the emitter depth. However, the magnetic lines of force are distorted by ferromagnetic bodies whatever frequency is used and, in general, it is impossible to survey near iron pipes or metallic buildings. We can consider the survey must be made according to the R.E.P.E. method for distances greater than 16 meters from iron pipes and 8 meters from metallic buildings.

Verticality of the Emitter Antenna Axis

The error of verticality of the antenna axis is mainly due to the reading of the air-level which equips the emitter. Several measure-

ments showed that this error is about 2.4 mm when the emitter is at a depth of 12 meters.

Horizontality Error of the Receiver

When the receiver is used as an amplitude detector, the principle of the determination of the emitter direction consists of the evaluation of the amplitude of the horizontal magnetic field component produced by the emitter. If the receiver coil axis does not turn in a horizontal plane, the emitter direction does not correspond to the direction of the minimum signal issued from the receiver.

It is shown in another publication[6] that the angle error in the determination of the emitter direction is given by the formula:

$$\operatorname{tg} \delta = \frac{1}{2} \operatorname{tg} V \sin 2\alpha$$

where:
- V = tilt angle of the magnetic field vector with the horizontal plane
- α = accuracy of the air level of the receiver
- δ = horizontal angle error of the emitter direction

The accuracy of the air level of the receiver is about 1'5; consequently, when the emitter is set at a depth of about 12 meters and the receiver at a horizontal distance of 1 meter from the vertical axis emitter, the theoretical error of the vertical position of the emitter is 0.5 cm.

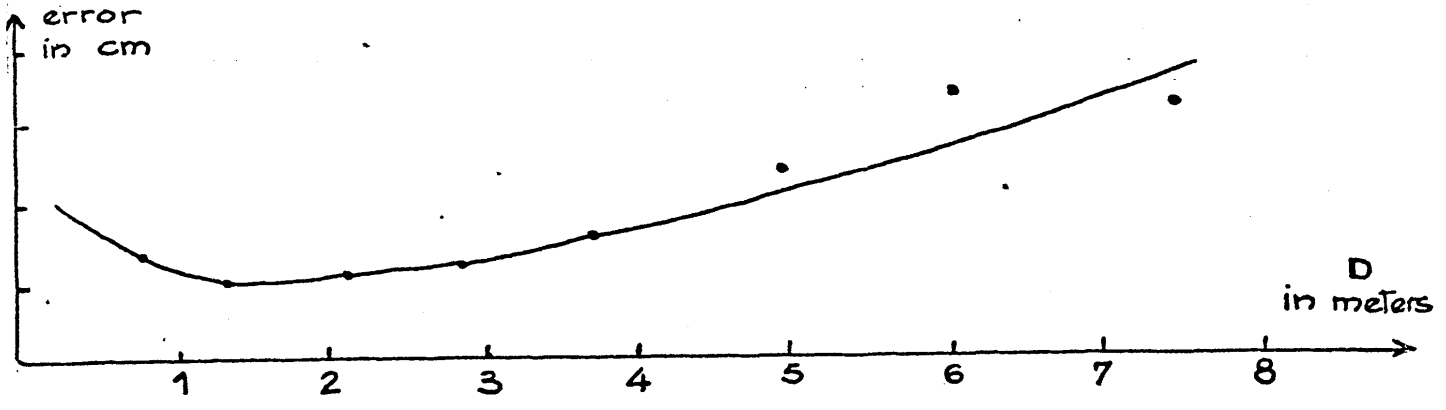

fig.9.

This curve shows that there is an optimum distance D which gives a minimum error. The distance is about 1.5 m.

Conclusions

The experience acquired during these last three years of surveys allows us to say that this method is a fair extension of the traditional survey with a theodolite and permits the reduction in price of the survey by about 20%. But this method is not a substitute for the

traditional survey; in particular, when the ground contains magnetic materials or iron pipes, or when the survey is made under buildings, the theodolite must be used alone. Practically, the survey must be made according to the R. E. P. E. method for distances greater than 16 meters from iron pipes, 8 meters from metallic buildings and 3 meters from any car. However, under certain working conditions, the R. E. P. E. method is the only available, particularly when the galleries are tortuous and their sizes small or when the ceiling is very near the floor.

Acknowledgements

We would like to thank MM. P. Mangez and J. Baudet for their contribution during the realization of these apparatus.

References

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