GEOPHYSICAL TRANSACTIONS 1983
Vol. 29. No. 4. pp. 331—344

# POSSIBILITIES OF THE FOCUSED-FIELD SURFACE GEOELECTRIC METHOD

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The paper investigates the possible applications of the focused-field method. It is shown that, with some restrictions, the method can be used for the detection of tectonic disturbances from the surface, for a more accurate determination of the specific resistivity of the basement and for obtaining almost distortion-free sounding curves in geologically disturbed areas. In mines the focused-field method should be utilized with appropriate modifications.

**d: geoelectric methods, mining geophysics, resistivity measurements**

## 1. Introduction

In 1962 the Geophysical Department of the Technical University of Heavy Industry and the Hungarian Oil and Gas Trust filed a patent on the application of the focused current well logging technique on the surface and in mines. The theoretical foundations of the method were reported by Csókás [1963], the possible fields of application by the present author [1965, 1967, 1980, 1982]. This article, based on the results of the investigations to date, gives a summarized evaluation of the application of the method on the surface and in mines.

## 2. Focused-current sounding

The focused-field method is based on the principle of the Laterolog 7® of borehole geophysics; that is, it applies a focusing electric circuit besides the measuring circuit to ensure that the measuring current should propagate perpendicularly to the surface down to a depth depending on the electrode spread. The penetration depth of the geoelectric method is thus increased. In the focusing circuit the current strength is adjusted by means of the "guard" electrodes $M$ and $M'$, placed in the close vicinity of the current electrode $A_0$ in the centre of the spread. The strength of the focusing current should be changed until the potential difference between electrodes $M$, $M'$ becomes zero. The focusing current is introduced symmetrically with respect to electrode $A_0$ at two or more sides. As an example, *Fig. 1* shows an arrangement with four focusing electrodes.

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Manuscript received: June 6, 1983

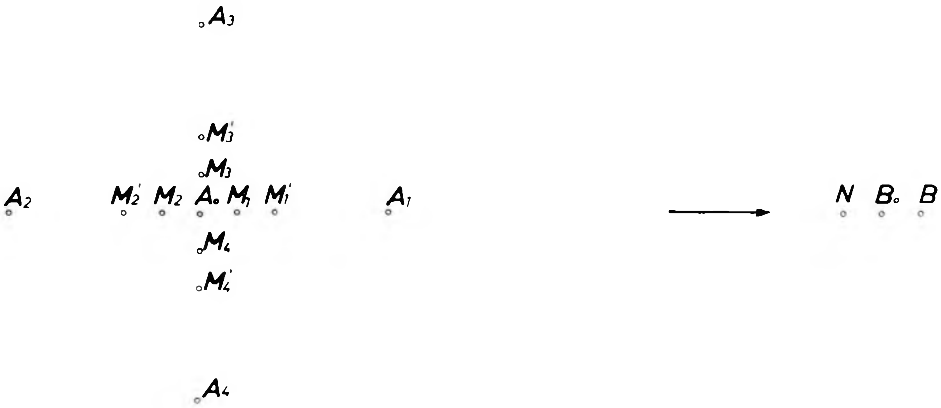

*Fig. 1.* Electrode arrangement with four focusing electrodes ($A_1$, $A_2$, $A_3$, $A_4$)

*1. ábra.* Négyterelős elektróda-elrendezés

*Рис. 1.* Установка электродов с четырьмя фокусирующими электродами

The execution of the measurement requires special instrumentation. The focusing- and measuring currents, which have identical signal form, frequency and phase, are provided by two low-frequency current generators.

The measuring unit contains, besides the measuring amplifiers, a control amplifier which can reduce to practically nil the voltage difference across the electrode pair $MM'$ by adjusting the focusing current.

During measurements the symmetry should always be ensured, that is, the contact resistances of the 2 or 4 electrodes should be equal. This can be achieved by the proper driving in of the electrodes and by changing a resistance connected in series.

Either the measurements are performed with short-circuited guard electrodes $M$, $M'$ when we determine a single specific resistivity with a given adjustment of the focusing current, or we separately set in four directions the zero potential difference between the guard electrodes $M$, $M'$ and obtain four values for the focusing current and four corresponding values for the specific resistivity. In the latter case, the determination of the proper values of the focusing current and of the specific resistivity should be carried out as described in Section 4.

If in focused-current sounding the guard electrodes $M$ and $M'$ are short-circuited, the measuring current "beam" perpendicular to the surface will apparently be symmetric. In reality, this "beam" will no longer be symmetric if there occurs any lateral resistivity change within a circle of radius $2\overline{A_0A}$. Indeed, in this case we had to use in each direction focused currents of different strengths in order to provide the zero potential difference between the guard electrodes. Instead of this we apply only an average focusing field strength because of the short-circuited guard electrodes, i.e. the measuring "current beam" is left asymmetric.

Upon inspecting the equation of apparent specific resistivity

$$\frac{R_a}{R_1} = C[U_{A_0M} + \eta_i(U_{A_1M} + U_{A_2M})], \tag{1}$$

where $U$ is the potential at measuring electrode $M$ due to the respective current electrode, $\eta_i$ the focused current ratio in the inhomogeneous half-space (the quotient of the strength of the focusing current and of the measuring current), $R_1$ the specific resistivity of the upper layer and $C$ is a constant, we find that the value of the measured specific resistivity strongly depends on the value of $\eta_i$.

The value $\eta_h$ computed for homogeneous half-space, and the effect of the resistivity contrasts on $\eta_i$, strongly depend on the so-called spread quotient ($n$)

$$n = \frac{A_0A}{A_0O}$$

where $O$ denotes the midpoint between the guard electrodes. With increasing values of $n$, $\eta_h$ increases, and similarly increases the critical depth for which the density of the measuring current becomes negligibly small, i.e. "penetration" increases. At the same time, the change of the measuring current density with depth has a relative extremum, this results in a maximum in the $\eta_i$ function for a focused-current sounding and, consequently, the sounding curve becomes more complex. As an example, we present two sounding curves with two focusing electrodes, fot the two-layer case; for $k = 1.0$ and $k = -0.98$, respectively (*Fig. 2*). (Here $k = \dfrac{R_2 - R_1}{R_2 + R_1}$ where $R_1$, $R_2$ are the resistivities of the upper and lower layers, respectively.)

Processing of the measured data can be done in two ways. In the computation of the apparent specific resistivity

$$R_a = K\frac{U_{A_0M}}{I_0} \tag{2}$$

the value of $K$ is

— either computed from $\eta_h$ referring to the homogeneous half-space; in this case we get a curve ($R_a$) that is highly sensitive to any changes;

— or it is computed from $\eta_i$ corresponding to the inhomogeneous half-space, which results in a nicely smoothed but less sensitive $R_a$ curve; in its interpretation the $\eta_i$ curve should be taken into consideration (*Fig. 3.*).

*Figure 4* shows a field a sounding curve computed by the second method. For the sake of comparison the curve measured by the gradient arrangement is also plotted.

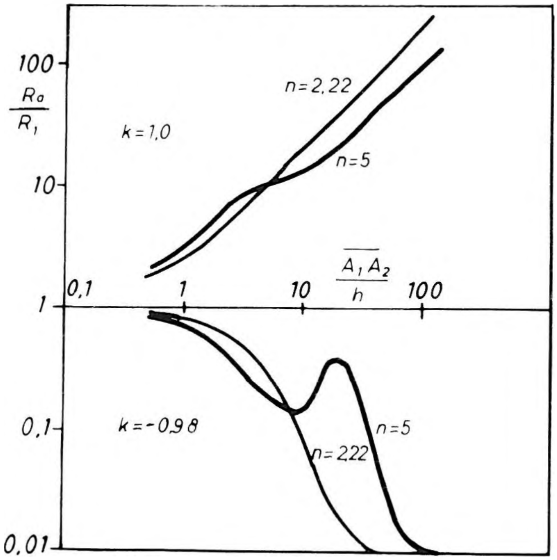

*Fig. 2.* Theoretical sounding curves for two focusing electrodes

*2. ábra.* Kétterelős elméleti szondázási görbék

*Рис. 2.* Теоретические кривые зондирования с двумя фокусирующими електродами

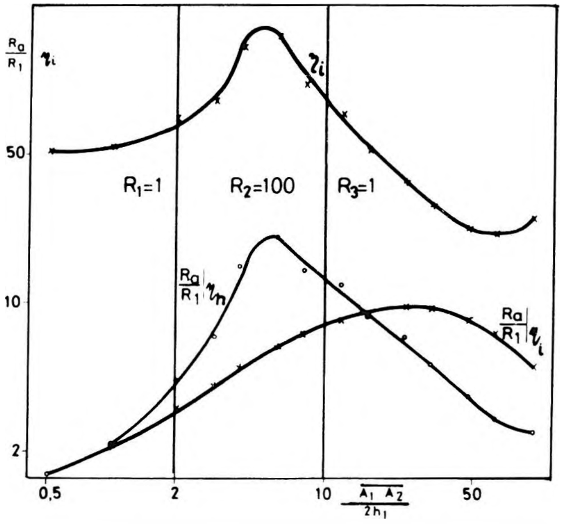

*Fig. 3.* Dependence of focused-field curves on the method of computation of configurational factor *K*. (Research Report of the Geophysical Dept. of the University of Heavy Industries, Miskolc, Hungary)

*3. ábra.* Terelő áramú görbék lefutása a *K* konfigurációs faktor számításától függően (NME Geofizikai Tanszék, Miskolc kutatási jelentése)

*Рис. 3.* Зависимость формы кривых фокусированного поля от способа вычисления фактора конфигурации *K* (По отчету об исследованиях Кафедры геофизики Технического университета по тяжелой промышленности, г. Мишколц, ВНР)

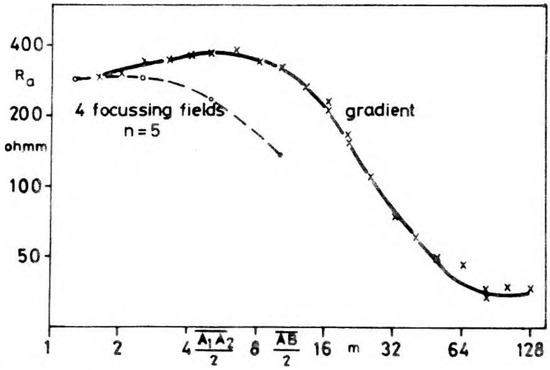

*Fig. 4.* A recorded 4-focusing-electrode sounding curve. (Research Report of the Geophysical Dept. of the University of Heavy Industries, Miskolc, Hungary)

*4. ábra.* Terepen mért 4-terelős szondázási görbe (NME Geofizikai Tanszék, Miskolc kutatási jelentése)

*Рис. 4.* Зарегистрированная в полевых условиях кривая зондирования с четырьмя фокусирующими электродами (По отчету об исследованиях Кафедры геофизики Технического университета по тяжелой промышленности, г. Мишкольц, ВНР)

In the focused-field sounding method three basic points should be kept in mind for the proper selection of the spread quotient and of the number of electrodes:
— "penetration" should be maximum;
— interpretation of the sounding curves should be as simple as possible;
— the effect of the lateral resisitivity changes should be minimized.

## 3. Study of "penetration"

In the study of "penetration" we have made use of the results of Roy and Apparao [1971] and Szaraniec [1971]. Roy and Apparao defined the "depth of penetration" as that particular depth wherefrom a thin horizontal layer exerts a maximal effect on the signal measured at the surface. Szaraniec [1971] introduced the concept of "effective spread length": in the two-layered case with a resistivity contrast $k = +1.0$ or $k \sim -1.0$ this can be expressed as the ratio of the depth of the layer boundary to the spread length, taken at the intersection of the tangent to the steep part of the curve with the straight line $R_a/R_1 = 1$.

For some widely used arrangements *(Fig. 5)* these quantities are compiled in *Table I* and *II*.

From the point of view of penetration, the arrangement with four focusing electrodes of great spread quotient is advantageous. At the same time, if we study the behaviour of the sounding curves, the arrangement with two focusing electrodes and of spread quotient $n = 2.22$ seems to be the most appropriate [Egerszegi 1980]. In this latter arrangement for positive resistivity contrasts the "penetration" is four times as much as for the gradient arrangement, while the shape of the curves is the same as in a gradient arrangement.

Table I.

| Arrangement | Wenner | Gradient | Potential | Modified unipole | 2-focusing-electrode $n=5$ |
|---|---|---|---|---|---|
| Penetration depth | $0.11AB$ | $0.125AB$ | $0.35AM$ | $0.175A_1A_2$ | $0.135A_1A_2$ |

Table II.

| Arrangement | | Wenner | Gradient | Potential | Modified unipole | 2-focusing-electrode | | 4-focusing-electrode | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $n=2.22$ | $n=5$ | $n=2.22$ | $n=5$ |
| Effective spread length | $k=1$ | $0.47AB$ | $0.5AB$ | $5.7AM$ | $2.85A_1A_2$ | left $2.1A_1A_2$ | $2.8A_1A_2$ | left $2.1A_1A_2$ | $2.8A_1A_2$ |
| | | | | | | right $2.1A_1A_2$ | $1.1A_1A_2$ | right $5.7A_1A_2$ | $8.5A_1A_2$ |
| | $k=-0.98$ | $0.25AB$ | $0.3AB$ | $1.0AM$ | $0.5A_1A_2$ | left $\sim 0.3A_1A_2$ | $\sim 0.43A_1A_2$ | left $\sim 0.42A_1A_2$ | $\sim 0.56A_1A_2$ |
| | | | | | | right $\sim 0.3A_1A_2$ | $\sim 0.06A_1A_2$ | right $\sim 0.42A_1A_2$ | $\sim 0.06A_1A_2$ |

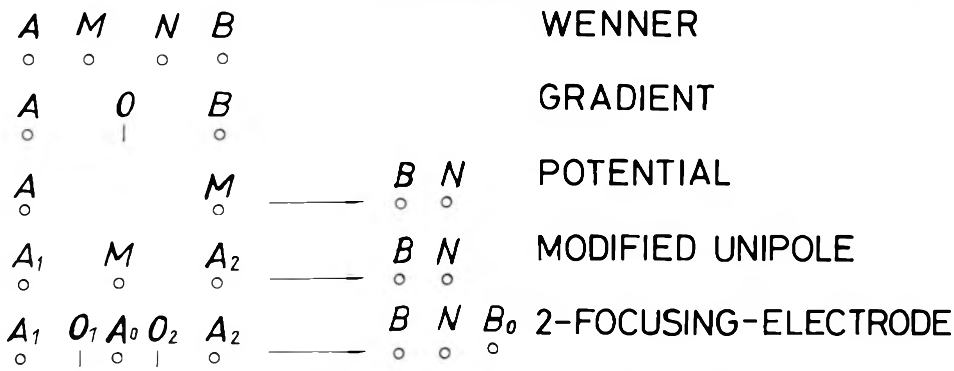

*Fig. 5.* Electrode arrangements *5. ábra.* Elektróda-elrendezések *Рис. 5.* Установки электродов

In the case of a positive resistivity contrast the focused-current sounding has a further advantage over the gradient arrangement: it yields a fair resolution even for contrasts as high as $R_2/R_1 > 100$; that is, it differentiates between the different high resistivity basement formations [Egerszegi 1980].

All the advantages listed in favour of the focused-current sounding also apply to the potential arrangement: it has a great "penetration" and a high resolution power for large positive resistivity contrasts.

## 4. Study of the "lateral effect"

As already mentioned, the focused-field sounding method is very sensitive to the lateral resistivity changes within a circle of radius $2\,\overline{AA_0}$ [Egerszegi 1965]. This effect can most easily be demonstrated by a 4-focusing-electrode arrangement if we do not short-circuit the guard electrodes and separately satisfy the condition $\Delta U = 0$ in the different directions. In the case of a lateral effect, the condition $\Delta U = 0$ is satisfied for different $\eta_i$ values in different directions, as illustrated in *Fig. 6* for the arrangement shown in *Fig. 7*.

During the computations we changed the value of the spread quotient $n$, the distance $d$ of the centre of the spread from the boundary of contrast $k = 0.9$, and the value of $\varphi$; that is, the angle made by the direction through the guard electrodes and the normal of the contrast boundary (Fig. 7).

The general relationship reads as

$$\eta(\varphi) = \frac{f_1(n, n') + kpf_2(n, n', p, \varphi)}{f_3(n, n') + kpf_4(n, n', p, \varphi)} \tag{3}$$

where $p = \overline{A_0A}/d$, the functions $f_1$ and $f_3$ refer to the homogeneous half-space,

$$\eta_h = \frac{f_1(n, n')}{f_3(n, n')} \tag{4}$$

while the functions $f_2$ and $f_4$ are the changes due to the inhomogeneity. Functions $f_2$ and $f_4$ assume both positive and negative values with changing $\varphi$. The equation implies that this change has the greater amplitude, the greater the value of *k*. The curves of Fig. 6 however, imply that the amplitude also increases with increasing values of *p* and *n*. These considerations show, similarly to above, that in order to reduce the lateral effect one should use an arrangement of small spread quotient ($n = 2.22$) in the case of focused-current measurements. Distortions due to the lateral effect cannot be checked unless an arrangement of four focusing electrodes is used.

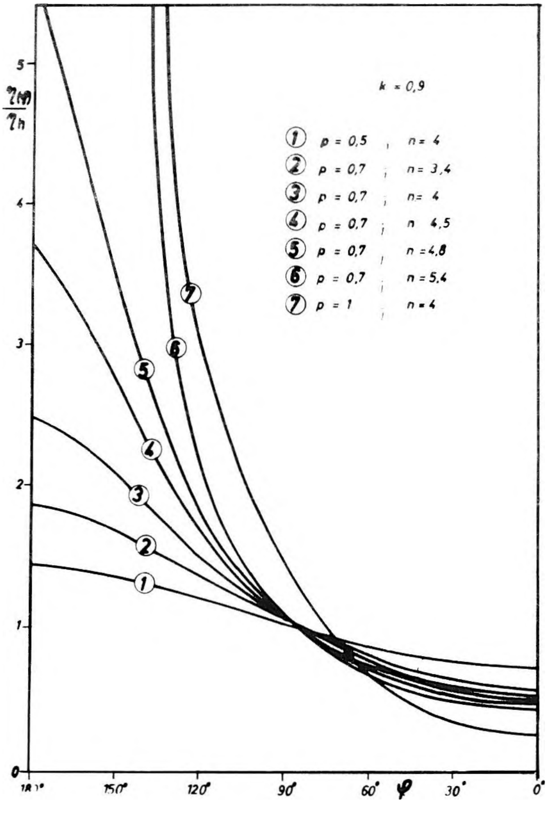

*Fig. 6.* Variation of $\eta_i$ as function of the vertical layer boundary and of the relative position of the guard electrode pair ($p = \overline{A_0A}/d$)

*6. ábra.* $\eta_i$ változása a vertikális réteghatár és a figyelőelektróda-pár egymáshoz képesti helyzetének függvényében ($p = \overline{A_0A}/d$)

*Рис. 6.* Изменение $\eta_i$ в зависимости от вертикального раздела и взаимного положения пары наблюдательных электродов ($p = \overline{A_0A}/d$)

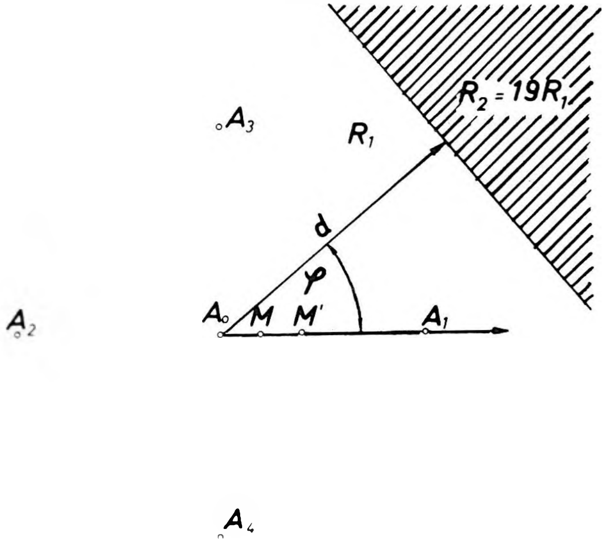

*Fig. 7.* Relative position of vertical layer boundary with respect to the 4-focusing-electrode spread

*7. ábra.* Vertikális réteghatár helyzete a négyterelős terítéshez viszonyítva

*Рис. 7.* Положение вертикального раздела по отношению к установке с четырьмя фокусирующими электродами

*Figure 8* presents a field example for the determination of $\eta_i$ and $R_a$ for the separate setting of the zero potential difference between the guard electrodes in the four directions. The determination is based on an observation drawn from Fig. 6, *viz.* the $\eta$ value free from lateral effects should be read off around the midpoint between the maximum and the minimum.

In conclusion, it can be stated that for the focused-field surface sounding a 2-focusing arrangement of spread quotient $n = 2.22$ should be used, with occasional measurements with a 4-focusing arrangement for checking purposes.

## 5. Focused-field profiling

It is quite another situation if we are concerned with the detection of the lateral step-like resistivity change (due to a fault). In this case, the condition $\Delta U = 0$ should be set in at least 4 directions, or we could also use two 4-focusing arrangements rotated by 45° with respect to each other. The spread quotient should also be increased, an optimal choice being $n = 5$. In this case we can also obtain a negative $\eta$ value for $\varphi = 180°$ which makes the localization of the maximum and minimum more reliable. $\eta(\varphi)$ increases from $+0$ to $+\infty$, then further, from $-\infty$ to $-0$; that is, the negative $\eta$ of small absolute modulus will yield the maximum. The exact tracing of the maximum and minimum is very important since this provides the direction of the normal erected to the vertical layer boundary of positive resistivity contrast.

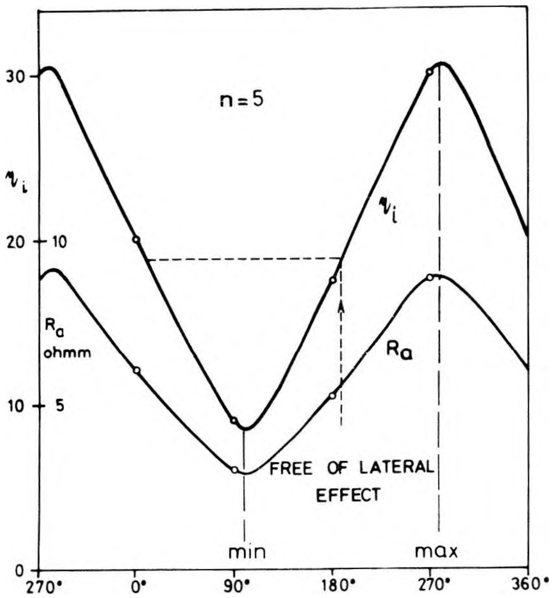

*Fig. 8.* Variation of $\eta_i$ and $R_a$ as functions of the position of the guard electrodes (field example)

*8. ábra.* $\eta_i$ és $R_a$ változása a figyelőelektródák helyzetének függvényében (terepi példa)

*Рис. 8.* Изменения $\eta_i$ и $R_i$ в зависимости от положения наблюдательных электродов (пример полевой работы)

The sensitivity to asymmetry of the focused-current arrangement can be utilized by separately setting the condition $\Delta U = 0$ in each direction [Egerszegi 1982], as is usually done in focused-current profiling. This accentuates the effect of lateral resistivity changes. In the case of a 2-focusing-electrode arrangement, if the spread direction is perpendicular to the vertical layer boundary, two values should be distinguished. $\eta_\pi$ refers to the case where, approaching the resistivity contrast the straight line normal to the boundary and the line across the guard electrodes form an angle of 180°, $\eta_0$ to the case when this angle is $0^o$.

The variation of $\eta_\pi$ in the case of focused-current profiling is shown in *Fig. 9.* The curves were computed for different spread quotients and spread lengths. The left-hand-side of the figure is linearly scaled in order to plot the negative values, the right-hand-side is logarithmic so that values less than one can more clearly be seen.

Figure 9 illustrates that in certain cases, due to the large asymmetry, the value of $\eta$ can also be negative and it tends to zero from the negative side.

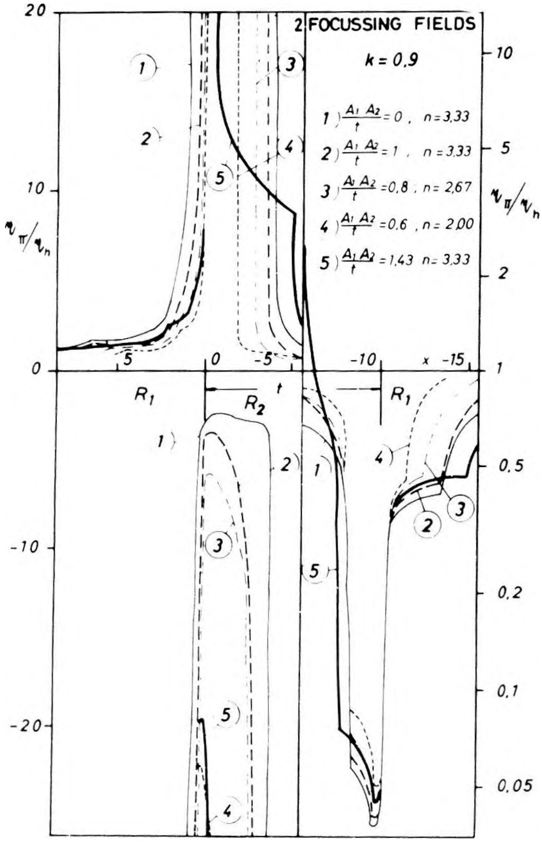

*Fig. 9.* Variation of $\eta_\pi$ along the profile ($k = 0.9$)

9. *ábra.* $\eta_\pi$ szelvénymenti változása ($k = 0,9$)

*Рис.* 9. Изменение $\eta_\pi$ по профилю ($k = 0.9$)

## 6. Application of "compensating circuit method" in mines

In the focused-current arrangement — for positive resistivity contrasts and if we do not take into account the distant electrodes — we get a relatively large "penetration" as compared with spread length. This seems ideal for in-mine applications where there is a quite small surface available for measurements but the electrodes $B$, $B_0$ and $N$ can be placed far apart along the drifts. With a 2-focusing-electrode arrangement there is no obstacle to planting the electrodes in the drifts — the only problem is that a bidirectional focusing is not sufficient for measuring the whole field. On the other hand, a 4-focusing arrangement can be realized only in a restricted manner which is certainly not satisfactory in spite of the relatively large "penetration".

In mines it is advisable to substitute the focused-current arrangement by the so-called compensating circuit technique [Egerszegi 1979]. This is applicable in the first place in coal seams where the effect of the embedding layers can be reduced by focusing the measuring current or by compensating for the potential change due to the surrounding layers in order to get more unambiguous and accurate results. This solution utilizes the favourable properties of the potential and focused-current arrangements by means of variable spread quotients so that the compensating current strength cannot be adjusted by means of guard electrodes but some other procedure should be applied. The electrode arrangement is shown in *Fig. 10.* During sounding the compensating electrodes $A$ and the measuring electrode $M$ are moving such a way that the ratio $l/A_0M$ is kept constant.

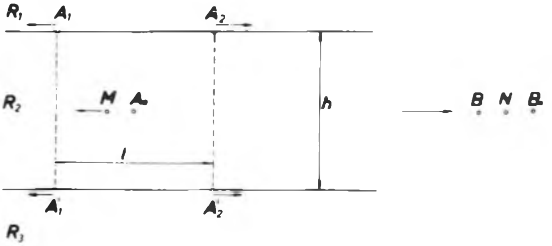

*Fig. 10.* Electrode arrangement with compensating circuit

*10. ábra.* Kompenzáló áramkörös elektróda-elrendezés

*Рис. 10.* Расположение электродов с компенсирующей схемой

The measuring current $I_0$ causes a potential

$$U_{M_i} = U_{M_h} + U_{M\Delta}, \tag{5}$$

at electrode $M$, where $U_{M_h}$ is the potential that would be measured over an infinitely thick layer of specific resistivity $R_2$. The task of the compensating circuit is to produce a potential at electrode $M$ having the same magnitude but the opposite sign as that of $U_{M\Delta}$:

$$U_{M_k} = -U_{M\Delta}$$

$$U_{Mk} = \frac{R_2 I_0}{2\pi A_0 M} y f(R_1, R_2, R_3, u), \tag{6}$$

where

$$u = \frac{2A_0M}{h} \quad \text{and} \quad y = \frac{I_1}{I_0}$$

and $h$ is the thickness of the coal seam [Egerszegi 1979]. $I_1$ is the strength of the current introduced from the side of specific resistivity $R$ through current electrodes $A_1$ and $A_2$:

$$I_3 = I_1 \frac{R_1}{R_3}$$

where the indices 1, 2 and 3 refer to the overlying layer, to the coal seam and to the underlying layer, respectively. By means of Eqs. (5) and (6) we can establish a relationship between $k$ and $U_{M_i}$ for known values of the resistivities $R_1$, $R_2$, $R_3$ and for a given value of $u$ (see *Fig. 11* for the case $R_1 = R_3 = 9R_2$, $u = 1/3$). By means of this relationship we can set the compensating current strength to this initial value of $u$. For other $u$ values $y$ can be computed by means of Eq. (6) *(Fig. 12)*, and we have to set this computed value during the measurement. For actual measurements, focused-current instruments have to be developed.

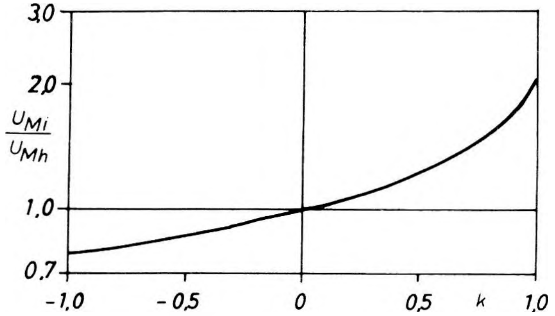

*Fig. 11.* Potential $U_{M_i}$ as function of resistivity contrast ($k$)

*11. ábra.* $U_{M_i}$ potenciál az ellenállás-kontraszt ($k$) függvényében

*Рис. 11.* Потенциал $U_{M_i}$ в зависимости от контраста сопротивлений ($\kappa$)

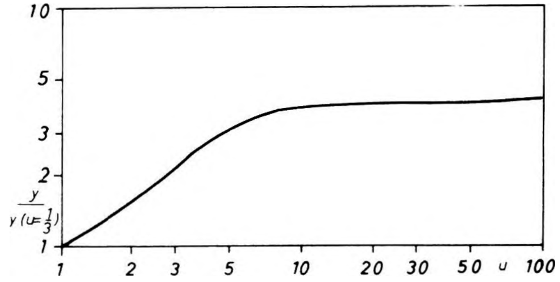

*Fig. 12.* Compensating/measuring current ratio ($y$) as function of spread length ($u$)

*12. ábra.* Kompenzáló- és mérőáram hányados ($y$) a terítési távolság ($u$) függvényében

*Рис. 12.* Отношение компенсирующего и измерительного токов ($y$) в зависимости от расстановки электродов ($u$)

## 7. Conclusions

It can be concluded that the focused-field method should be applied mainly in special cases.

In geoelectric measurements such a case is encountered if, for a positive resistivity contrast, a very large "penetration depth" is necessary compared with spread length or we have to determine the specific resistivity of the high resistivity basement. It is advisable to carry out the geoelectric sounding by a 4-focusing-current arrangement if the sounding curves indicate distortions due to lateral resistivity changes. In such cases the disturbing effects should be determined and eliminated.

In geoelectric profiling the high sensitivity of the method to asymmetry is advantageous for the detection of eventual faults. When measuring in mines the results should be made more accurate and unambiguous by the compensating circuit technique specially tailored to the surfaces available for measurements.

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## A FELSZÍNI TERELŐÁRAMOS MÓDSZER LEHETŐSÉGEI

EGERSZEGI PÁL

A tanulmány a két áramkör alkalmazásának lehetőségeit vizsgálva megállapítja, hogy a módszer korlátozottan alkalmazható tektonikai zavarok felszíni kimutatására, az alaphegység fajlagos ellenállásának pontosabb meghatározására, valamint nagyon zavart területen közel zavarmentes szondázási görbe felvételére. Bányában csak módosított formában alkalmazható a két áramkörös eljárás.

## ВОЗМОЖНОСТИ НАЗЕМНОГО МЕТОДА ФОКУСИРОВАННОГО ПОЛЯ

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В результате рассмотрения возможностей метода фокусированного поля в работе отмечается, что данный метод может в ограниченной мере применяться для выявления тектонических нарушений с дневной поверхности, более точного определения удельного сопротивления фундамента, а также для записи почти свободной от помех кривой в шумных районах. В шахтах метод фокусированного поля может найти применение только в видоизменённой форме.