Development of McOHM-Ⅱ as Renovative Electrical Prospecting Instrument

Koichi TAGO and Takeichiro OHHASHI

Abstract

While the electrical sounding resistivity method has been utilized widely for various purposes, in recent years the necessity has become urged for the instrument functionally further sophisticated. For example, One of the instruments desired with keen interest has been the one hopefully capable of not only conducting the measurement on the field accurately and speedily, but also obtaining the analyses results on the spot over there. McOHM-II is the electrical sounding instrument developed by authers, as the one to meet such requirement.

To supplement, McOHM-II is the instrument to conduct automatic measurement as well as automatic analysis, related to vertical sounding. Its automatic performance covers the changeover with electrode, the check with measurement error, the re-measurement through the change with measurement conditions, and so forth. The methods employed for the analysis are the forward calculation according to linear filter method, and the method of least squares of non-linear type according to the modified Marquardt method. The result of the analysis conducted with the model data has been verified to be the one with the aptitude of accuracy high enough for the practical application.

The vertical sounding conducted by us through the use of this instrument has clarified that the process from the commencement of measurement till the obtainment of analysis result could by covered within 30 minutes.

1 Introduction

While having been widely utilized for a long time as the method for various resources exploration and civil engineering exploration, the resistivity method has admittedly been the one apt to be easily affected by stray current, electromagnetic coupling, etc, and further it has entailed the problem of being susceptible to the local anomaly, to the extent not neglibible, resulting from the soil structure variation with the shallow subsurface formation, the topographic variation, etc.

However, owing to the improvements made in recent years with such respects as the measurement method, the exploration instrument, the analysis approach and so forth to cope with the above pending issues, the resistivity method has been turned to the method utilized in comprehensive fields with considerably practical significance recognized.

With the consequential expansion of the application scope of the resistivity method, the necessity for the instrument equipped with further higher technological function has been urged. For example, the development of the instrument capable of conducting the measurement on the field quickly with high accuracy and of obtaining the analyses results on the spot at the job site.

On the other hand, the progress achieved in the electronics along with the computer technology has made it possible to introduce the system that meets such requirements while being housed in its entirety in a compact case. McOHM-II is the electrical prospecting instrument developed by us according to the above concept, as the one satisfying the requirements in the new era from such angles.

2 Guiding Principles for the Development

The fundamental concept consistently borne in our mind for the development of McOHM-II has been to aim at the accomplishment of the instrument that would meet the requirements and demands from the users in many fields to facilitate their application of the resistivity method satisfactorily for the practical purpose. In other words, our invariable target earmarked was the development of the instrument compact and portable, yet capable of clarifying the analyses results immediately on the spot at job site while offering easy access to any operator, not to mention its feasivility with the quick and highly accurate measurement of resistivity.

For the achievement of the above target, the guiding principles established by us for its designing were the following conditions to be complied with.

1) Vertical electrical sounding as the means utilized in many cases for resistivity method to be easily accessible.
   In respect of this particular condition, the following requirements are to be met specifically.
   ① Electrode configuration to be extendable with ease.
   ② Automatic changeover with electrode to be feasible.
   ③ Function to be retained for checking the connection status with electrodes.
   ④ Automatic checking with measurement error, automatic setting with measurement conditions etc to be feasible, while monitoring the measurement values.
   ⑤ Function to be retained for automatic analysis and automatic output for immediate clarification of the analysis result after the completion of measurement.
2) The structure of the instrument should be of compact all-in-one type that does not require the joint use of personal computer nor scanner for its perfect functioning.
3) Through the modification with the software for measurement control and with the analysis software, the structure of the instrument should be the one able to realize version upgrade to a certain extent even without changing the hardware.

3 Constitution of McOHM-II

In brief, McOHM-II is constituted by resistivity measurement unit, electrode switching unit for conducting the offset Wenner resistivity soundings, analysis unit and the unit to control those units. As indicated in Fig. 1, the system is composed of the following 5 parts when classified according to the circuit blocks.

① Transmitter (Current conduction circuit)
② Receiver (Circuit for measurement of electric potential and current value)
③ Scanner (Electrode switching circuit)
④ System controller (Circuit to control the entire system and to conduct data analysis)
⑤ Power supply (Circuit to supply power to each section)

3·1 Transmitter

Transmitter generates the high voltage of 200V from 12V battery to conduct current to the ground through the circuit as indicated in Fig. 2. To prevnt the polarization, the current pattern used is the one from alternating DC based on constant-current.

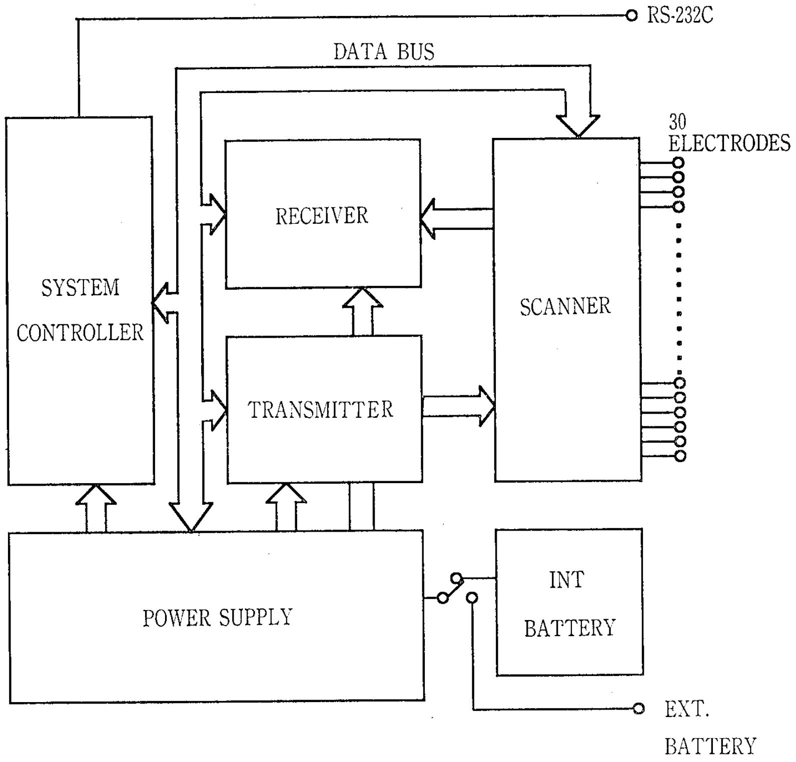


Fig. 1 Constitution of McOHM-II

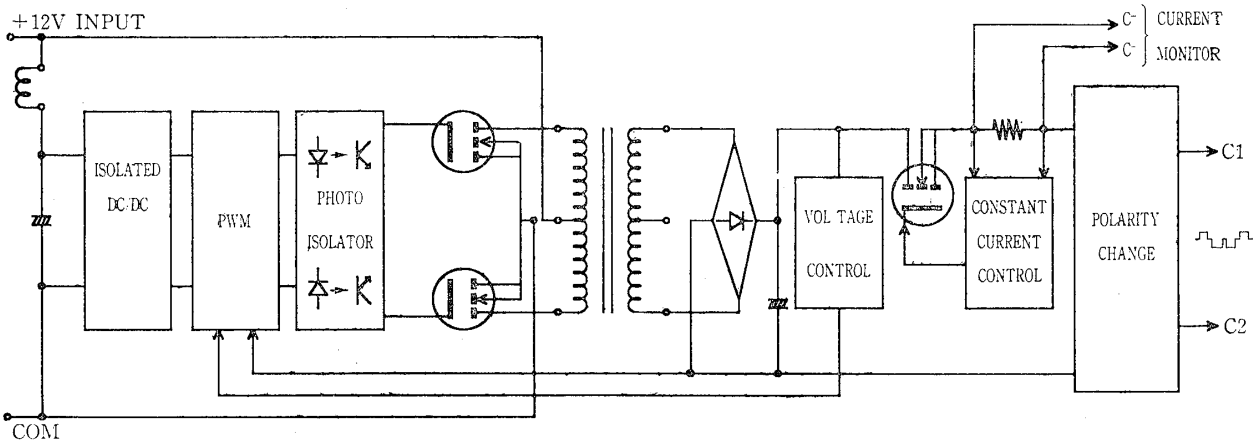


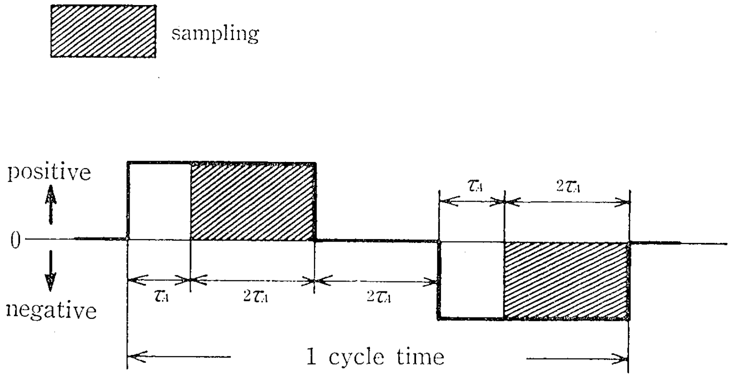
Fig. 2 Transmitter circuit

Most of the conventional electrical prospecting instruments have been those to use the current with the pattern to repeat "positive→negative"like the one indicated in Fig. 3(a).

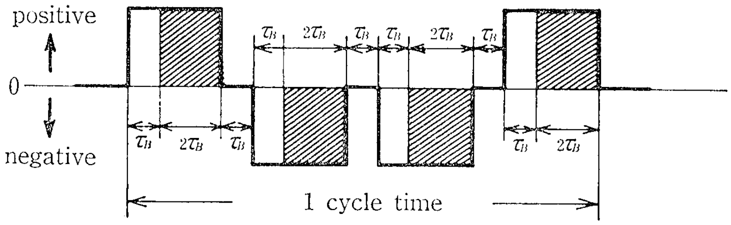
However, the use of such current pattern quite often renders eventual measurement as the one involving the error resulted from spontaneous potential, earth current noise, etc. that are to vary with a long cycle during the measurement of potential.

With the above in mind, to eliminate effectively the noise with a long cycle, the method contrived successfully for McOHM-II in respect of the current pattern is the one to repeat "positive→negative→negative→positive" as a cycle.

As for the elimination effect with the long cycle noise through the change of the current



(a) conventional current pattern



(b) current pattern for McOHM-II

Fig. 3 Current pattern

pattern, reference is made to the next chapter for its details.

3・2 Receiver

As indicated in Fig. 4, the receiver is constituted by the circuit for measuring the potential generated in consequence of current conduction and the circuit for measuring the resultant current on such occasion. While this paper is intended to describe only the potential measurement circuit, the current measurement circuit is identical to the former basically, though lack of the compensating circuit for spontaneous potential with the latter makes the sole difference from the former.

Firstly, the signal as the potential difference between P1 and P2 goes through the over-input protection circuit to be led to the next stage. low-pass filter circuit.

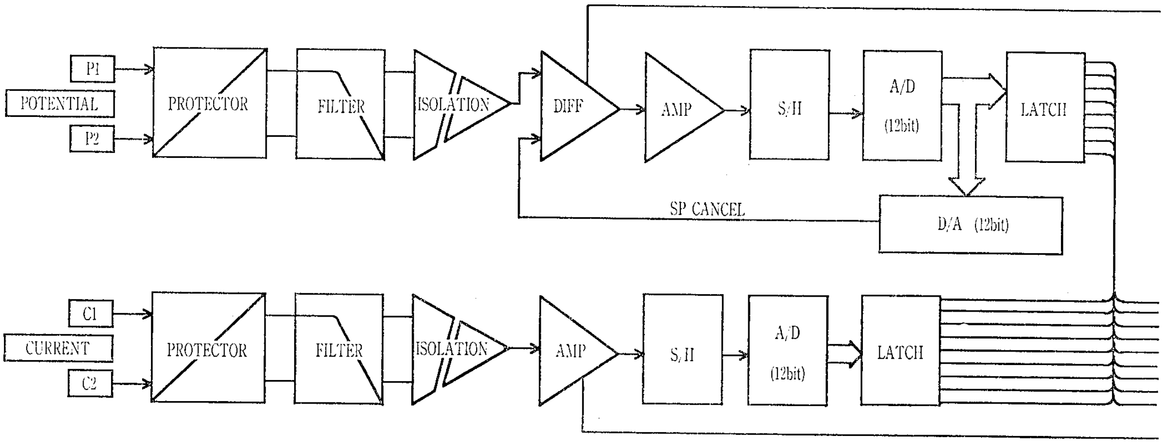


Fig. 4 Receiver circuit

With Butterworth characteristic of 18 dB/oct retained, this filter functions to eliminate the noise component with comparatively short cycle inclusive of commercial frequency. Then, through the isolation amplifier, the noise is transmitted to SP compensating circuit. The isolation amplifier works for the isolation with the input/output circuit. The SP compensating circuit effects the measurement with SP just before the current conduction to the ground and automatically deducts relevant SP component from the potenital at the time of current conduction. Thus, improvement of the measurement accuracy along with the measurement range can be achieved. Then, passing through the amplification circuit equipped with auto-range function, the signal is led to the sample-and-hold circuit. The sampling circuit is of integrating type durable enough against noise. Through such processes as above to realize the cancellation with SP and the elimination with the hum noise, eventual potential signal gets digitized by 12 bit (72 dB) A/D convertor with minimum resolution at 10 μV for its subsequent storage on the memory.

For the elimination of the influence exercised over the potential by the transient phenomenon at time of current conduction, as indicated in Fig. 3, the sampling of the potential is effected with a little delay after the start-up of current conduction. Review is given below on the elimination effect of low frequency noise in case of the sampling effected as above. The output in response to the two varieties of the current pattern can respectively be expressed as follows, where the noise is assumed to be the sine wave with ϕ as the phase at time of start-up with current conduction and with f as relevant frequency, i. e. providing the noise is expressed by

$$y=\sin(2\pi ft+\phi)$$

In case of the conventional current pattern that repeats "positive→negative":

$$N_A=\frac{2}{\pi f}\sin(2\pi f\tau_A)\sin(4\pi f\tau_A)\cos(8\pi\tau_A+\phi) \tag{1}$$

In case of the current pattern utilized for McOHM-II:

$$N_B=\frac{4}{\pi f}\sin(2\pi f\tau_B)\sin(4\pi f\tau_B)\sin(7\pi f\tau_B)\sin(15\pi f\tau_B+\phi) \tag{2}$$

In case of the current pattern for McOHM-II. $\tau_B=0.05$ sec (Cycle$=0.8$ sec), while in case of the conventional current patten with cycle almost equivalent to that for McOHM-II, the same is the current pattern based on $\tau_A=0.1$ sec. The determination of ϕ as the initial phase is dependent on the timing with the start-up of current conduction. However, from the respective contents of the equations (1) and (2), assuming the worst timing case to cause the maximum noise, the component directly dependent on ϕ can be put the value 1 in either case of the two. In this case, the output can respectively be expressed as follows:

$$N_A=\frac{2}{\pi f}\sin(0.2\pi f)\sin(0.4\pi f) \tag{3}$$

$$N_B=\frac{4}{\pi f}\sin(0.1\pi f)\ \sin(0.2\pi f)\sin(0.35\pi f) \tag{4}$$

Plotting, if made, with the absolute values of N_A and N_B expressed respectively by the above equations (3) and (4) through response to frequency, results in what delineated in Fig. 5(a). Additionally, Fig. 5(b) is the delineation with the variation of the absolute values against the initial phase, ϕ on the assumption of $f=0.1$Hz referriog to the equations (1) and (2).

Fig. 5(a) shows that in either case of the two current patterns, providing the noise frequecy is in the vicinity of the frequency (1.25Hz) for current conduction, the noise disturbance is superposed high, that providing the former is with in the range exceeding the latter, eventual

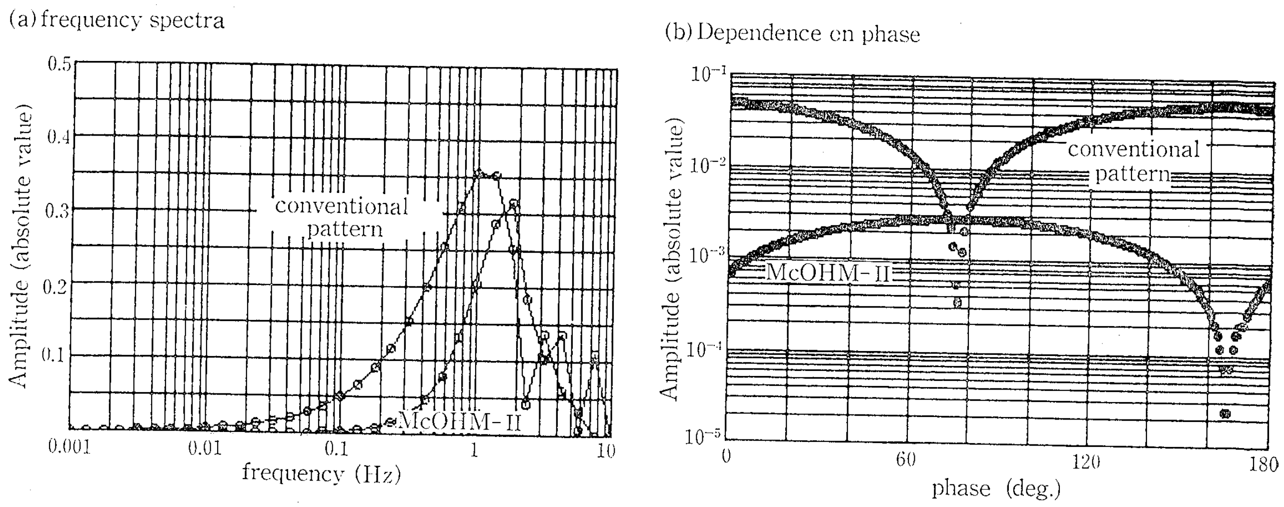


Fig. 5 Comparison of noize reduction for low frequency noize

noises only make symbolic difference from each other and that providing the former is within the range below the latter, evidently the current pattern from McOHM-II causes less noise compared to the conventional current pattern.

From the equations (3) and (4), K as the ratio of N_A to N_B can be expressed by the following equation:

$$K=\frac{N_B}{N_A}=2\sin(0.1\pi f)\sin(0.35\pi f/\sin(0.4\pi f)$$

Accordingly, in case of the frequency lower than 0.5 Hz in an approximate sense, the following equation is satisfied.

$$K \fallingdotseq 0.175\pi f \fallingdotseq \frac{f}{1.8}$$

What deducible from the above quation (5) is that in case of McOHM-II, the noise level at the assumed frequency of 0.1 Hz would approximately be 1/18 while the same at 0.01 Hz would likewise approximately be 1/180, both compared to the conventional respective levels.

3·3 Scanner

The scanner functions to switch the electrodes to be connected to the current terminals C1 and C2, and to the potential measurement terminals P1 and P2 (see Fig. 6). The electrodes within the scope of handing reach 30 pieces in total, while each of C1. C2, P1 and P2 is to be individually and independently connected to a specific independent electrode out of these 30 pieces. Programming has been pre-input so that the electrodes to be connected at the stage may be chosen according to the predetermined sequential electrode configurations.

As indicated in Fig. 6, the scanner circuit consists of the relay blocks for switching the electrodes and the control blocks for driving the former relay blocks. Viewing the necessity to handle the micro potential, the relays used for switching the electrodes are those of highly sensitive type with minor thermoelectromotive force.

Regarding the electrode configuration, offset Wenner array is the basic one through ROM based program. In future, by the modification with the ROM program, it may be feasible as well to flexibly cope with the versatile electrode configuration such as Wenner array, Schlumberger array, iso-spaced four-electrode array (the combination of Wenner, Eltran and Staggered array), pole-pole array and so forth.

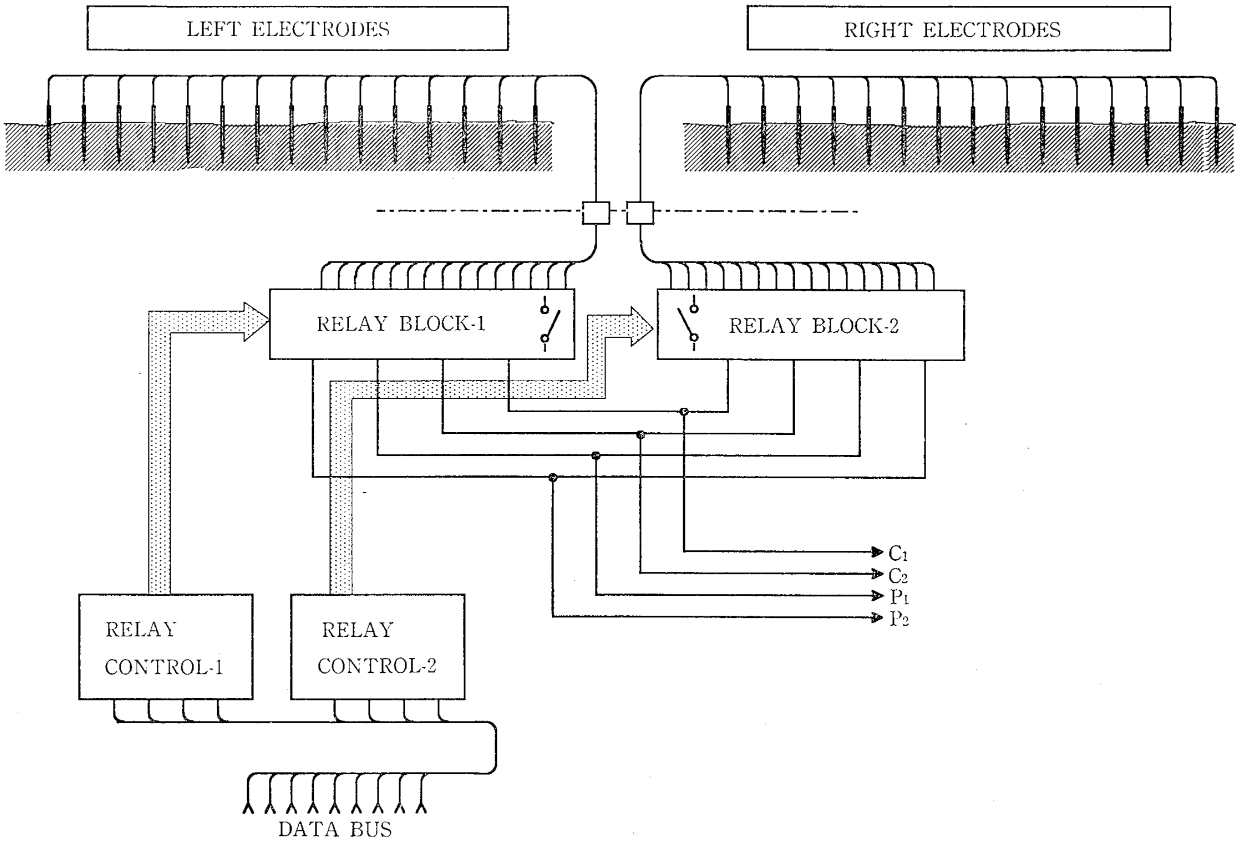


Fig. 6 Scanner circuit

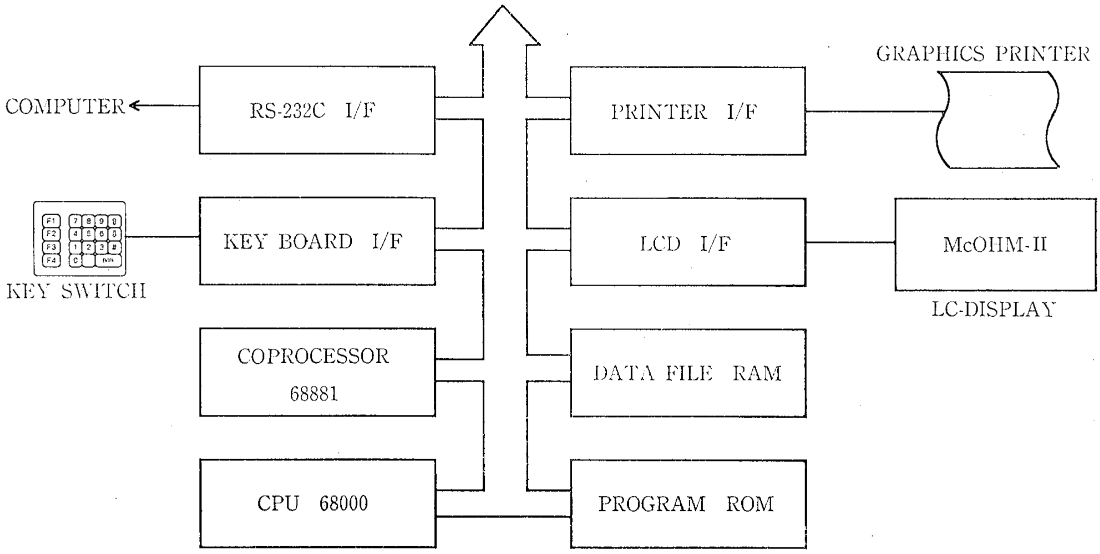


Fig. 7 System controller

3·4 System controller

As indicated in Fig. 7, the system controller is constituted by keyborad I/F, LCD I/F, printer I/F, 16 bit microprocessor (68000), etc. to functionally control each units constituting the system. The measurement data are memorized on RAM for data file and depending on the necessity, can be transferred via RS-232C I/F to the external computer. For data analysis, coprocessor (68881) exclusively for arithmetic operation is used, in addition to 16 bit microprocessor, thereby contriving successfully to shorten the analysis time. In respect of the arithmetic operation, highly accurate processing has been embodied through handling the data by the 64 bit, double precision floating point format according to IEEE standards.

3·5 Power supply

The power supplied to each circuit is converted into the required voltage from DC 12V as follows.

The power supplied to the logic circuit inclusive of CPU is with the capacity of +5V, 3A according to the switching regulator system.

On the other hand, the power supplied to the analog circuit inclusive of operational amplifier is with the capacity of ±15V, 70mA according to DC/DC converter system.

Referring to the power supply for current conduction from transmitter to the ground, the same is the one with high capacity of 200V, 200mA through the use of the circuit in combina tion of DC/DC converter and the switching regulator, as indicated in Fig. 2. Though usually the conversion efficiency with DC/DC converter is approximately 70%, for the enhancement of such conversion efficiency in the case of this particular circuit, on one hand the boosting circuit according to the pulsewidth modulation (PWM) of push-pull type is used and on the other hand, what used for driving the transformer is the Power MOS. FET that entails quite small resistance and that suits the high speed switching. The resultant conversion efficiency obtained was so high as 85%.

4 Automatic Measurement and Analysis Algorithm

Automatic measurement and automatic analysis have been arranged feasible in case of the offset Wenner sounding (Barker, 1981).

4·1 Offset Wenner Sounding

At time of conducting the vertical electrical sounding. the influence exercised by the local variation with the resistivity value near the surface cannot be neglected. Compared to the usual Wenner array, this offset Wenner array is the method superior to it in mitigation of the above influence and is the proposal presented by Barker (1981).

As indicated in Fig. 8, through the measurements conducted according to 5 varieties of electrode array through adoption of an indentical electrode spacing the calculaition with the error is feasible.

As shown in the configurations D1 and D2 of Fig. 8, the measurements are to be extended in the case of offset Wenner array through placement of the electrodes differing in location from each other by the distance of *a*, to seek after the respective measurement values and then to adopt the average value from those values thus measured. Meantime, the signal contribution near the surface for the Wenner array is negative in the region between C and P as well as between P and C, and is positive in other intervals (for instance, between P and P as well as outside C), that is to say, the contribution thus alternates in it's sign with every intervals between two electrodes. Such sensitivity distribution are the background for motivation to proceed from Wenner array to offset Wenner array. In other words, offset Wenner array is the method intended to make the measurement result less susceptible to the influence exercised by the local anomaly, by such means as averaging the measured values through slided placement of electrodes by the interval of *a* to make the effective sensitivity smaller.

Fig. 9 indicates the sensitivity distribution in an extreme case where the fully conducting

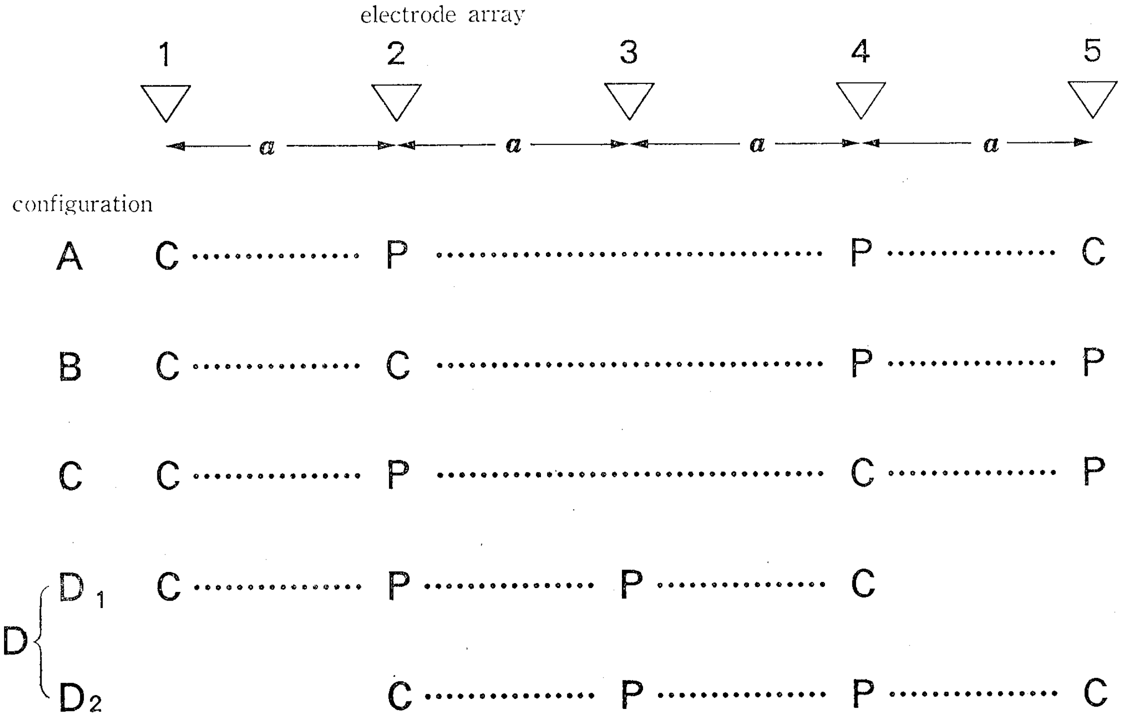


Fig. 8 Electrode configuration in offset Wenner method
(C: current electrode, P: potential electrode)

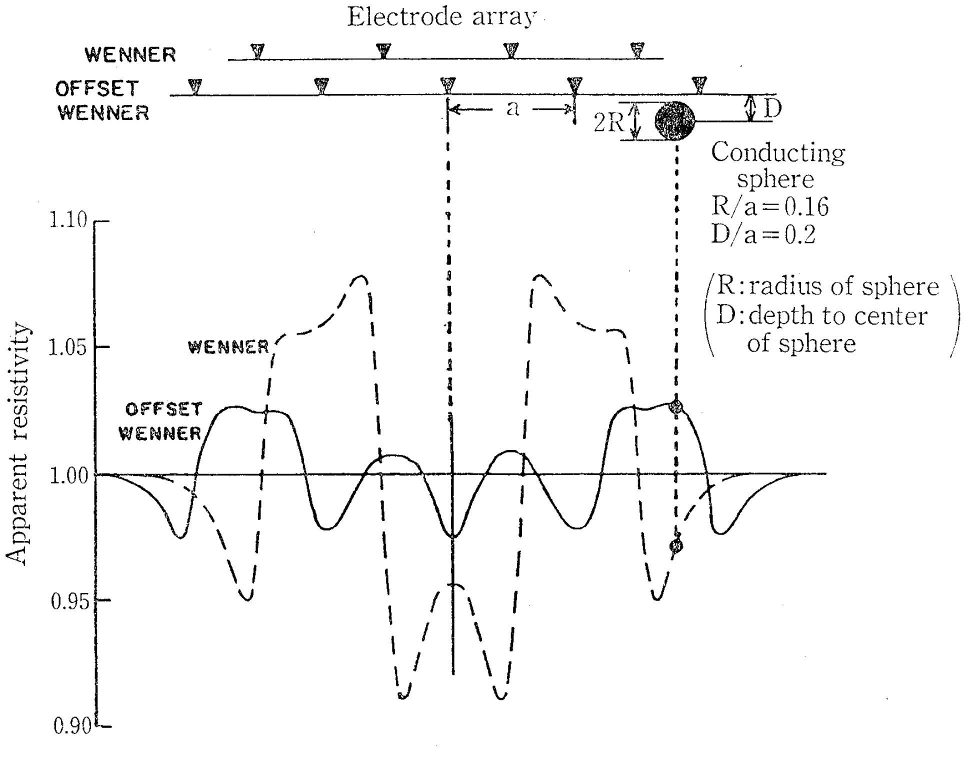


Fig. 9 Horizontal profiles across fully conducting sphere
(after Barker, 1981)

sphere is embedded, from which it can be understood that the sensitivity through application of offset Wenner array is smaller than that through application of Wenner array.

To supplement, the measurement error is determined in the following way. Assuming the resistance values sought after according to the Configuration A, B and C as indicated in Fig. 8 to be respectively represented by RA, RB and RC, theoretically RA=RB+RC must always be satisfied. Accordingly, for the definition and calculation of e_{obs} as measurement error, the following equation can be applied.

$$e_{obs}=\frac{\mathrm{RA}-(\mathrm{RB}+\mathrm{RC})}{\mathrm{RA}}\times 100(\%)$$

In case of McoHM-II, the automatic control function is equipped with it to modify the measurement conditions such as the current value for conduction, the stacking time, etc. for extending re-measurement in case e_{obs} as the measurement error exceeds 5%. Of course, RD1 and RD2 and acquired and stored as the measurement values, in addition to RA. RB and RC, and can be output by the built-in printer. Through the use of these velues, the calculation of e_{of} as offset error and of e_{lt} as lateral error is feasible according to the following equations. Meantime, these values make the indexes to represent the extent of the deviation of the underground structure from horizontal stratification.

$$e_{of}=\frac{\mathrm{RD1}-\mathrm{RD2}}{\mathrm{RD}}\times 100(\%)$$

$$e_{lt}=\frac{\mathrm{RD}(2a)-2[\mathrm{RC}(a)-\mathrm{RD}(a)]}{\mathrm{RD}(2a)}\times 100(\%)$$

Anyhow, $\mathrm{RD}=\frac{\mathrm{RD1}+\mathrm{RD2}}{2}$ should rule the above and a and $2a$ in respective parentheses express the measurement values in case of the electrode spacings are a and $2a$ raspectively. In an approximate sense, suppose these errors exceed several ten %, sounding curve is influenced by lateral resistivity effects.

Furthermore, in case of the application of offset Wenner array for McOHM-II, for the purpose of obtaining the data as much as possible with the electrodes limited in number, the intermediate values and the exterior value at twice maximum measured spacing are determined according to the following way. Meantime, as for the extrapolation value, general practice is to calulate the same only in case e_{obs} is less than 5% and further in case both e_{of} and e_{lt} are less than 50%.

Suppose the resistance value obtained through Wenner array with a as the electrode spacing is represented by RW (a), the following two equations can be deduced.

$$\mathrm{RW}(3a)=\frac{1}{2}\mathrm{RW}(2a)+\mathrm{RB}(2a)-\mathrm{RB}(a)+\frac{1}{2}\mathrm{RW}(4a)$$

$$\mathrm{RW}(2a)=2[\mathrm{RC}(a)-\mathrm{RW}(a)]$$

When consideration is given to the above equations while substituting RD for RW, it leads to such conclusions as that form the former equation, the intermediate values are obtained from the measurement value based on $3a$ as electrode spacing from those measurement values on the bases of a, $2a$ and $4a$ as electrode spacings and that from the latter equation, the measurement value based on $2a$ as electrode spacing is obtained from the measurement value on the basis of a as electrode spacing.

4·2 Automatic Measurement

Fig. 10 indicates the flow chart related to the automatic measurement.

Ahead of the measurement, the placement of the electrodes through the use of the multicore cable for the exclusive purpose is required.

Simultaneously with the commencemet of measurement, self-diagnosis is extended with the system, inclusive of the checking with the connection status of the electrodes, etc. Subsequent performance proceeds to the initialization of the scanner and the switching of the electrode configuration to enter into the measurement. Through monitoring the potential obtained during the measurement, by modifying the current value to be conducted to the earth depending on the potential value and by adjusting to increase or decrease the stacking times, the data acquisition along with its storage are extended under optimal conditions.

In addition, as referred to before, the calculation with the measurement error is arranged to be made while the measurement is in progress and in this particular respect, if the measurement error exceeds 5%, automatically the measurement conditions are modified and the system enters into re-measurement. To be prepared for the case where after all the measurement error cannot be rendered less than 5% despite re-measurement practically done following the

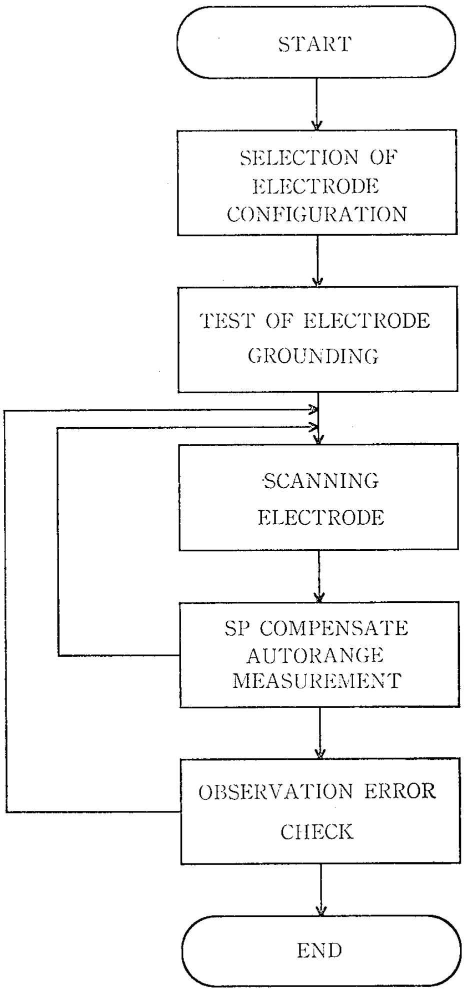


Fig. 10 Flow chart of automatic measuring system of McOHM-II

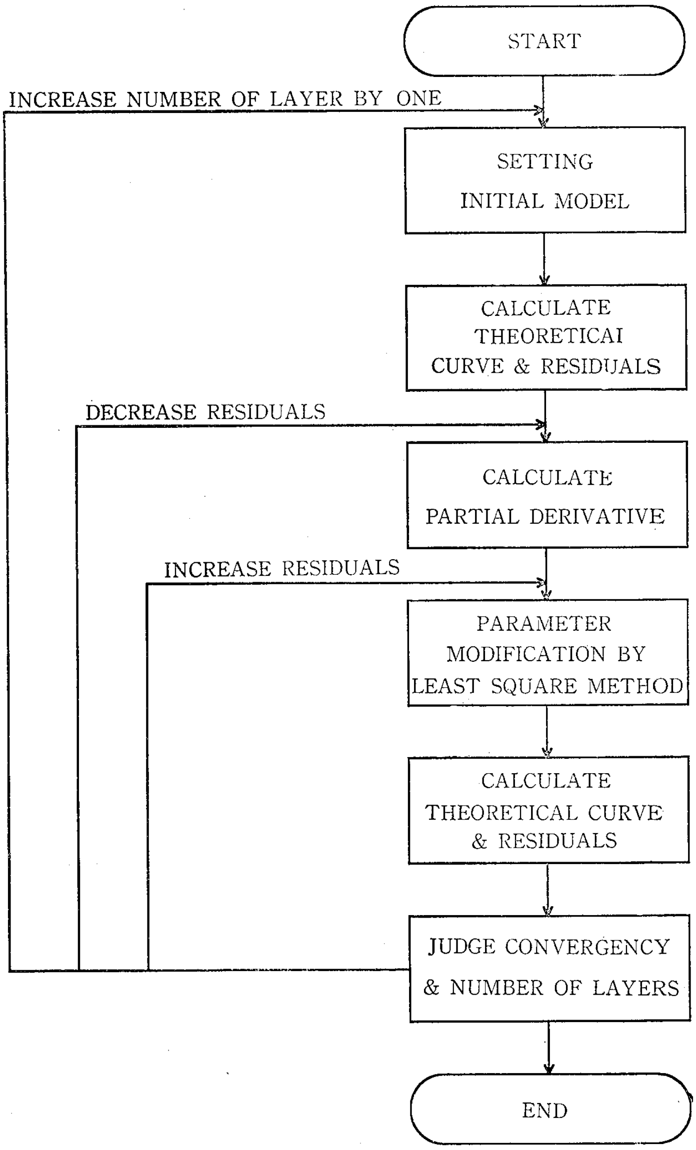


Fig. 11 Flow of analysis

modification with the measurement conditions, the program has been incorporated into the system, thereby such steps being automatically taken as printing out of the value of relevant measuremet error, checking the quality aptitude of the measurement data, and proceeding to the next measurement.

4·3 Automatic analysis

The methods applied for the analysis are the forward calculation by linear filter method and the nonlinear method of least squares by modified Marquardt method. Linear filter method is the method to calculate the potential measured on the surface as the product through multiplying "the transform function determind from the resistivity structure" by "the filter coefficient", and accordingly once the filter coefficient is worked out, the theoretical value of the surface potential can simply be determined. The filter coefficient applied by us is the one based on 4 Points/decade by Koefoed (1979), and its application to the two layered structure model with resistivity ratio at 1/100 has been confirmed capable of obtaining the stable solution. The automatic analysis is the method to start with determination of the initial model in simple manner, to calculate the apparent resistivity by linear filter method related to the resistivity structure of such model for the comparison with the measured value, and then to proceed to modify the model, one after another, by the nonlinear method of least squares.

Fig. 11 illustrates the analysis flow. First step is to seek for the logarithmic relation between the electrode spacings and the measured values, and then through application of spline interpolation to convert the same into the data based on 4 points/decade. With this data, the determination is sought after on the layers number, the layers thickness and the resistivity values of the layers with the tentative initial model, of which the relevant apparent resistivity then is calculated by linear filter method, based on which eventual residuals are to be determined.

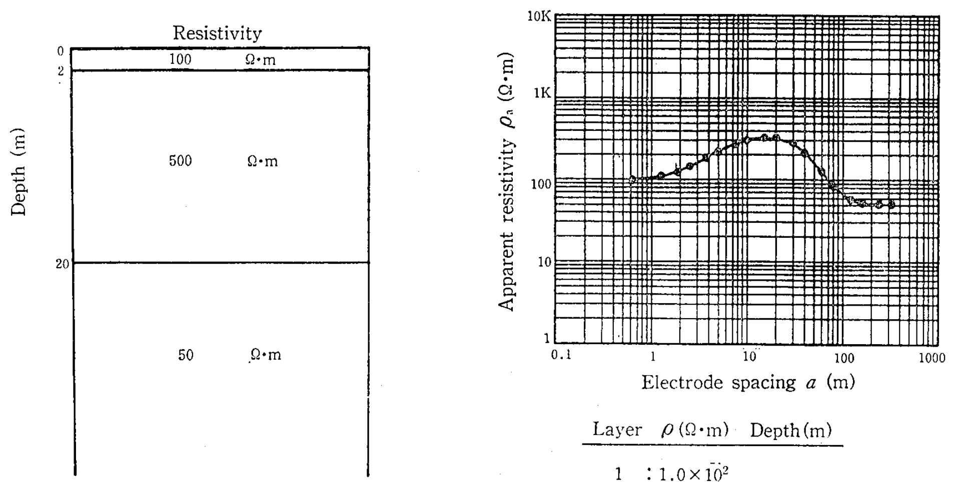
Then, after determination on $\frac{\partial \rho_a}{\partial P_m}$ as the partial derivative with the measured apparent resistivity ρ_a against the analysis parameter P_m (in which ρ_m as resistivity and d_m as thickness of each layer of the model are involved), the formulation of the relevant normal equation is dealt with.

The normal equation thus formulated is solved by modified Cholesky method, thereafter to proceed to the modification with the thickness of each layer along with its resistivity value. Then, with the modified model, recalculation is extended with the relevant residuals for the comparison with those of the initial model. In case the former residuals are smaller than the latter ones, the formulation of the normal equation is again sought after, followed by the repetition of the steps as described above. On the other hand, in case the residuals with the modified model are larger than those of the initial model, the calculation should be repeated with the identical model by rendering larger the parameter referred to as Marquardt factor, for the convergence with the solution.

In case the eventual residuals are rendered smaller than those at the preset levels, or in case the calculations have gone througe the slated times (layers number+5 times), the step is over in this regard.

In view of the analysis result sometimes significantly affected by the measurement value deemed anomalous which is involved in the measurement data, the countermeasure for avoiding such undesireable influence is to apply firstly Biweight estimation method by which the significance of the data seemingly affected can be rendered less when the relevant residuals become large and then to proceed to the application of method of least squares.

With regard to the layers number for analysis, providing the electrode spacing is within 100m, the same are arranged to be up to 4 layers, while if the electrode spacing exceeds 100m, the same of an optimal number within the scope of 5 layers is arranged to be selected.



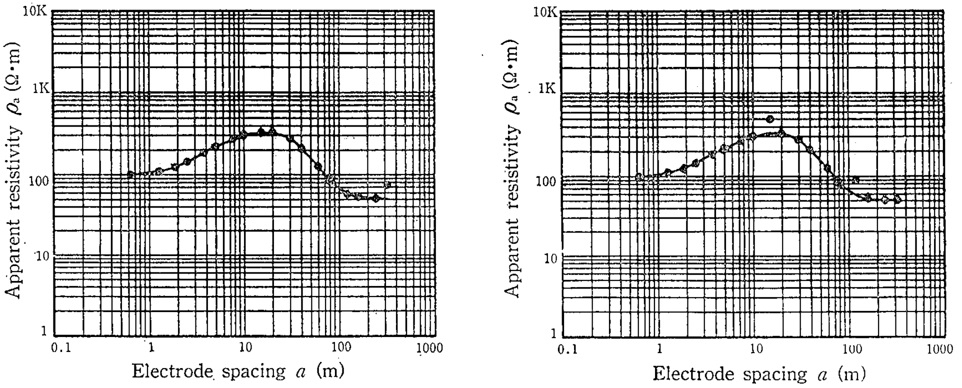
(a) Resistivity model

(b) Result of VES analysis from the resistivity model

Layer	ρ (Ω·m)	Depth (m)
1	: 1.0×10^2	1.9
2	: 4.8×10^2	20.8
3	: 0.5×10^2	

(c) Result of VES analysis obtained from the different value at a=320m

(d) Result of VES analysis obtained from the different values at a=15m and 120m



Layer	ρ (Ω·m)	Depth (m)
1	: 1.0×10^2	2.0
2	: 4.9×10^2	20.1
3	: 0.5×10^2	

Layer	ρ (Ω·m)	Depth (m)
1	: 1.0×10^2	1.9
2	: 4.9×10^2	20.6
3	: 0.5×10^2	

Fig. 12 Examples of the error check for VES analysis

Concerning the test method to ascertaion to what extent the automatic analysis is keeping its quality appropriateness, the recommendable method would be that to effect calculation beforehand with the theoretical data obtainable in case of conducting the vertical electrical sounding with the model of which the resistivity structure is known in advance to the involved crew, and then to judge to what extent the analysis results from such data coincides in contents with those from the initial model. Fig. 12 shows an example of the test conducted in such manner. To supplement, Fig. 12(a) shows the resistivity model of which the data calculation was conducted. Fig. 12(b) delineates the analysis result of such data, evidencing the particular model repeated with error within the range not entailing practical inconvenience. While Fig. 12(c) and (d) are the examples through the review given to the data involving the anomalous values, the former shows the analysis of the data based on $a=320$m and calculated being multiplied by 1.5 times and the latter shows the analysis of the data based on $a=15$m and on $a=120$m and respectively calculated being multiplied by 1.5 times. What can be learnt from these (c) and (d) is the analyses conducted with almost appropriate quality aptitude achieved, not affected by those anomalous values in any serious sense.

5 Conclusion

As above, the development has successfully been made by us with the resistivity measurement instrument capable of conducting in single package the automatic measurement and the automatic analysis with the vertical electrical sounding. The result from the vertical electrucal sounding conducted by authors through the use of this instrument has revealed that the time required from the comemncement of the measurement till the obtainment of the analysis result spanned approximately 30 minutes in the case that the maximum electrode spacing is 200 m.

As almost satisfying the target performance aptitude aimed at prior to entering into its development, this instrument can reasonably be considered as the one to have achieved the practical applicability superior to the level retained by the conventional instruments. Nevertheless, what we have in our mind is to further enhance the performance aptitude of this instrument to the one that could cover the automatic measurement along with the automatic analysis in the exploration on higher technological level inclusive of two dimensional survey.

References

Barker, R. D. (1981) : The offset system of electrical resistivity sounding and its use with a multicore cable, Geophysical Prospecting, Vol. 29, No. 1, pp, 128～143.

Koefoed, O. (1979) : Geo-sounding principles-1, Resistivity sounding measurements, Elsevier, Amsterdam, pp. 92～102.

新しい電気探査装置 McOHM-II の開発

田子公一・大橋武一郎

概　要

電気探査比抵抗法は，古くから各種の資源探査や土木調査に広く利用されてきた手法であるが，最近ではその利用範囲が拡大するにしたがってより高度な機能を持った装置の必要性が高まってきた。たとえば，野外において精度よく，迅速に測定でき，しかもその場で直ちに解析結果が得られるような装置の開発が望まれている。

このような要望に応えるシステムの一つとして新しい電気探査装置 McOHM-II を開発した。

この装置の開発に当たっては，つぎの条件を満たすことを設計方針とした。

1) 比抵抗法で多く利用されている垂直探査が容易に実施できること。そのために，つぎの機能を備えることを具体的条件として設定した。
    ① 電極設置が容易に行えること。
    ② 電極の切換が自動的に行えること。
    ③ 電極の接続状態をチェックする機能を有すること。
    ④ 測定値を監視しながら誤差のチェックや測定条件の設定が自動的に行えること。
    ⑤ 測定終了後直ちに解析結果が判るように、自動解析・出力する機能を有すること。
2) コンパクトな一体型の装置とし，パソコンやスキャナなどを併用する必要がないこと。
3) 測定をコントロールするソフトウェアや解析ソフトウェアの変更によって，ハードウェアを変えなくてもある程度のバージョンアップが可能な構造となっていること。

McOHM-II は，大きく分けて，比抵抗測定部とオフセットウェンナ法による垂直探査を行なう場合の電極切換部，解析部およびそれらをコントロールする部分で構成されている。このシステムを回路ブロックに分けるとつぎの5つになる(図—1参照)。

① トランスミッタ部（通電回路）
② レシーバ部（電位測定および電流値測定回路）
③ スキャナ部（電極切換回路）
④ システムコントローラ部（システム全体のコントロールとデータ解析を行なう回路）
⑤ 電源部（各部へ電源を供給する回路）

上記のような構成で垂直探査の自動測定および自動解析が行えるようにするとともに，探査方法としてはオフセットウェンナ法 (Barker, 1981) を採用した。

この装置では，測定中に測定誤差 (e_{obs}) が5％を越えた場合，通電する電流値やスタック回数などの測定条件を変えて再測定するように自動的に制御される。

測定には，専用の多芯ケーブルを用いる。測定が開始されると，システムの自己診断が行われ，電極の接続状況がチェックされる。続いてスキャナを駆動し，電極の切換を行ない測定に入る。測定中に得られた電位を監視し，その値の大きさによって大地に流す電流値を変更するほかに，スタッキング回数を増減して最適条件においてデータを収録する。一方で，測定中に測定誤差を計算して，それが5％を越えた場合には，自動的に測定条件を変更して再度測定を行う(図—10参照)。

解析は，リニアフィルタ法によるフォワード計算と修正マルカート法による非線形最小二乗法を用いている。

自動解析においては、得られた VES 曲線から初期モデルを設定し、このモデルの比抵抗構造についてリニアフィルタ法によって見掛け比抵抗を計算し，これと実値とを比較しながら，非線形最小二乗法によって順次モデルを修正する方法を採用している(図—11参照)。

解析層数は，電極間隔が100m より小さい場合は4層まで，100m を超える場合は5層までの範囲で，最適な数を選択するようになっている。

モデルデータを用いて解析した結果によれば，実用上十分な精度をもって元のモデルを再現することが確かめられた(図—12参照)。

本装置を用いて最大電極間隔200m の垂直探査を実施した結果によれば，測定を開始してから解析結果が得られるまでの所用時間は約30分であった。