MEASURING PRECISION OF INDUCED POLARIZATION METHOD①

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ABSTRACT

On the premise that freqency IP and time domain IP are equivalent, the requirement of the measuring precision for electrical potential differences on the condition that the precision of the IP parameters must meet the required precision for field procedure has been studied. Although the requirement of the relative precision of potential differences in time domain IP is not high, the equipment is bulky because its supplying current is very strong. A higher relative precision of the potential differences in variable frequency method is required and it is very difficult to attain the required precision if the IP field value is low. Whereas using the dual frequency IP, much higher relative precision can be obtained since the potential differences of the two frequencies are measured simultaneously; as a result, this kind of instrument is not only portable but also meets the precision requirements satisfactorily.

Key words: measuring precision induced polarization method (IP) dual-frequency IP frequency domain IP time domain IP

1 INTRODUCTION

The induced polarization method (IP) is an effective geophisical technology for prospecting nonferrous metal deposits and ground water. IP method consists of a number of variaties. As far as measurements are concerned, IP can be divided into the time domain and the frequency domain. The former studies the time responses of characteristic IP effect, the latter includes methods of the variable frequency, dual frequency IP, odd harmonic complex resistivity and spectrum IP. These are based on the frequency response. Essentially, they are identical in both physics and chemistry. In other words, the time domain and the frequency domain are equivalent[1]. However, they differ from application since different technologies are adopted.

This paper studies their identities and differences starting from the measuring accuracy.

The measuring content of IP is various. For the purpose of studying IP characteristics in detail, the whole charge and discharge curves can be measured in the time domain, while the IP frequency characteristics including that of the amplitude-frequency, phase-frequency, real component-frequency and imaginary component-frequency, can be measured in the frequency domain. As far as searching for anomolies is concerned, the IP responses can be measured at two points of given time or frequency.

2 HIGHER DEMAND OF RELATIVE PRECISION FOR ELECTRICAL POTENTIAL DIFFERENCES OF FREQUENCY IP

In the frequency domain induced polarization, the amplitude of the potential differences is measured at a higher frequency point (F_H) and a

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lower frequency point, F_L. If $I_L = I_H$, I_L and I_H are the current of F_L and F_H respectively, the percent frequency effect (PFE) can be expressed as:

$$PFE = \frac{V_L - V_H}{V_H} \quad (1)$$

where V_L and V_H are the electrical potenlial differences measured at lower frequency F_L and higher frequency F_H respectively.

According to the error of distribution, the mean square errors of PFE can be obtained from Eqn. (1):

$$\delta_{PFE} = \sqrt{(\frac{1}{V_H})^2(\delta_{V_L})^2 + (\frac{V_L}{V_H})^2(\delta_{V_H})^2} \quad (2)$$

where δ_{PFE}, δ_{V_L} and δ_{V_H} are the mean square errors of PFE, V_L and V_H respectively. Paying attention to $V_L = V_H$ and supposing $\delta_{V_L} \approx \delta_{V_H}$, then Eqn. (2) can be reduced to:

$$\delta_{PFE} = \sqrt{2}\,\frac{\delta_V}{V} \quad (3)$$

where the foot marks of δ_{V_H} and V_V are omitted because $V_L = V_H$. Although Eqn. (3) is very simple it shows an important relation that the mean square error of PFE is directly proportional to the relative mean square error of the potential differences. For the purpose of assuring the PFE precision, the relative error of the potential differences should be required.

Usually, the precision could be evaluated with the mean square error since the values of PFE in the normal field are low and will not vary too much in the field procedure of frequency domain. The upper limit of the relative mean square error of the potential differences is shown in Table 1, in which the normal field of PFE are 2% and 4% respectively, the mean square error of PFE is given by 1/10, 2/10 and 3/10 of the normal field.

Table 1 Upper limit of relative mean square error of potential differenees

PFE (%)	2.0			4.0		
$\frac{\delta_{PFE}}{PFE}$, (%)	±0.2	±0.4	±0.6	±0.4	±0.8	±1.2
δ_V/V, (%)	±0.14	±0.28	±0.42	±0.28	±0.57	±0.85

2/10 of the normal field could be regarded as the mid-level of accuracy. The relative accuracy of the potential difference could be lowered if the limit of PFE's mean square error is increased. The experiences show that the normal field of PFE is usually around 2%. The anomaly could be as high as 10% or more. Such high anomalies are usually caused by carbonized rocks or pyrite mineralization not being buried deep enough under the ground. Or, they are sometimes caused by shadow sulphite ore bodies. The anomaly of PFE caused by deeper sulphite under the ground is usually around several percentage (e. g. 4%). The most important thing is to lower anomaly to around several percentage with required precision. As a result, the relative mean square error should be less than ±0.14% ~±0.28% in the normal field.

Since the PFE values are large in the anomaly field, the relative mean square error could be used in evaluating the precision. The Eqn. (3) can be divided by PFE and then we have

$$\frac{\delta_{PFE}}{PFE} = \frac{\sqrt{2}\,\delta_V}{PFE \cdot V} \quad (4)$$

This is the relative mean square error of PFE, which is directly proportional to that of potential differences and inversely proportional to PFE.

The upper limit of the relative mean square error of the potential differences are shown in Table 2, when the anomaly values are 4% and 10%, the relative square error of PFE are ±2.5%, ±5.0%, ±7.5% and ±10%. From this table we can see that when the lower values of anomaly are something around 4%, the relative mean square error of the potential difference should be less than 0.21% which is a mid-level measuring precision (e. g. δ_{PFE}/PFE lies ±7.5%). If the relative precision of PFE is raised to ±2.5%, the relative accuracy of potential difference should be reached to ±0.07%.

The discussion above is on the assumption that $I_L = I_H$. In fact, they may not be the same. When $I_L \neq I_H$, the PFE can be expressed as

$$PFE = (\frac{V_L}{I_L} - \frac{V_H}{I_H})/(\frac{V_H}{I_H}) \quad (1)'$$

and its mean square error δ_{PFE} is

$$\delta_{PFE} = [(\frac{I_H}{V_H I_L})^2(\delta_{V_L})^2 + (\frac{V_L I_H}{V_H^2 I_L})^2(\delta_{V_H})^2 + (\frac{V_L I_H}{V_H I_L^2})^2(\delta_{I_L})^2 + (\frac{V_L}{V_H I_L})^2(\delta_{I_H})^2]^{1/2} \quad (2)'$$

Similarly we can reduce Eqn. (2)′ into

$$\delta_{PFE} = \sqrt{2}\sqrt{(\frac{\delta_V}{V})^2 + (\frac{\delta_I}{I})^2} \qquad (3)'$$

and $$\frac{\delta_{PFE}}{PFE} = \frac{\sqrt{2}}{PFE}\sqrt{(\frac{\delta_V}{V})^2 + (\frac{\delta_I}{I})^2} \qquad (4)'$$

While variable frequency methods are employed, the current of lower frequency I_L is regulated first and V_L is to be measured. Then, the frequency is changed into higher F_H , supply I_H and V_H is measured. It is usually considered that the current has remained unchanged when the frequency is changed from F_L to F_H due to the steady current unit inside the transmiter.

In this case, the Eqn. (1) can be still used to calculate PFE. What the steady current unit does is to make the change a little in stead of unchanged. For example, some IP transmiters indicate their specifications that the current change is less than ± 0. 3% if the change voltage of power supplier or resistance of the current circle is less than ±10%.

As is known, a change of supplying current causes a change of potential difference by same percentage. So, part of the random error of the potential difference is caused by the random change of current which is shown on the second item under the radical sign in Eqn. (3)′. The first item in Eqn. (3)′ is due to other causes.

The author has done many experiments on sites. The results show that the contact resistances of electrodes vary distinctly because of the change on the surface condition of electrodes caused by the current. The change of the contact resistance could be around several percentage or even more than 10%. The voltage of the power supplier often changes due to the variation of the working condition of the generator. Therefore, the requirement for current stability mentioned above is not enough. For instance, if PFE=4. 0% and the variation of current as well as the potential difference are ± 0. 3%, the relative mean square error caused by other sources is only ± 0. 1% (Table 2).

Table 2 upper limit of relative mean square of potential difference

PFE(%)	4. 0				10. 0			
$\frac{\delta_{PFE}}{PFE}$, (%)	±2. 5	±5. 0	±7. 5	±10. 0	±2. 5	±5. 0	±7. 5	±10. 0
δ_V/V, (%)	±0. 07	±0. 14	±0. 21	±0. 28	±0. 17	±0. 35	±0. 53	±0. 71

In this case, the relative accuracy of the potential differences should be less than ±0. 1% in order to meet the requirement of the application. It is difficult to measure the signals because the frequencies used in frequency domain IP are within the ultra-low frequency range especially in the field. The lower the frequencies, the higher the geological noise(MT noise and so on) and the $1/f$ noise of the instrument become. Plus the effects from other noises, it is very difficult to meet this kind of precision satisfactorily. Consequently, It is very difficult to obtain the required precision in the variable frequency method even a well-designed equipment is used. To meet the required precision, some special technology, such as a long period accumulation or superposition, have to be adopted. However, this would decrease the working efficiency and increase the field cost.

3 DIRECT MEASUREMENT OF SECONDARY POTENTIAL DIFFERENCES IN TIME DOMAIN IP

In time domain IP, the apparent polarization ratio (η_s) and chargeability (M) are used to indicate the IP response. They can be expressed as follows, respectively.

$$\eta_s = \frac{V_2}{V} \qquad (5)$$

$$M = \frac{\int_t^{t+\Delta t} V_2(t)dt}{V} \qquad (6)$$

where $V_2(t)$ is the secondary potential difference, which fades with the passing of the time; V_2 is the secondary potential difference at a certain time; V is the potential difference at the end of the charging time. Because the value of the secondary potential difference is very small and faded, it is difficult to measure it. In order to raise the accuracy, the secondary potential difference is integrated in the chargeability. If the integral quantity is divided by the integration time (Δt), it would be the average of the secondary potential difference. Therefore, both the substances of η_s and M are identical.

The following is only the analysis of η_s, which can be obtained in this way of

$$\delta_{\eta_S} = \sqrt{\left(\frac{1}{V}\right)^2(\delta_{V_2})^2 + \left(\frac{\eta_S}{V}\right)^2(\delta_V)^2} \qquad (7)$$

where δ_{η_S}, δ_{V_2} and δ_V are the mean square errors of η_S, V_2 and V.

Because $1/V \gg \eta_S/V$ and the value of V_2 is much larger than that of V_2 and $\delta_V < \delta_{V_2}$, consequently, the second item under the radical sign could be omitted, Thus

$$\delta_{\eta_S} = \frac{1}{V}\delta_{V_2} \qquad (8)$$

Eqn. (8) indicates that the mean square error of η_S is mainly caused by the mean square error of V_2. Usually the relative square error is used to measure the accuracy of η_S. From Eqn. (8) the relative square error can be expressed as

$$\frac{\delta_{\eta_S}}{\eta_S} = \frac{\delta_{V_2}}{V_2} \qquad (9)$$

That is, the relative mean square errors of η_S and V_2 are identical. For this reason, η_S could reach the required precision so long as the V_2 measuring accuracy could be guaranteed in the time domain. For instance, if the relative mean square error of V_2 is $\pm 3.5\%$, the relative mean square error of η_S will be the same value. In comparison with what discussed in the frequency domain, the mean square error of potential differences would be $\pm 0.1\%$ when the relative mean square error of PFE is also $\pm 3.5\%$. That is, the relative accuracy of the measuring potential difference could be far more less than that in the frequency domain. This may be regarded as the advantage of the time domain. Meanwhile, it has some disadvantages yet. The value of the secondary potential difference is around 1/50 of the total field or primary field in normal field. In the frequency domain, the secondary field is measured indirectly. Both the V_L and V_H are measured directly. Their values are similar to the total field. If the lower limits of the potential difference for accurate measurement in the time domain and frequency domain are equal, the time domain supplied current would be 50 times larger than that of the frequency domain in order to guarantee the carrying out of the field work. In this way, not only are the generator, current transmiter and other equipment bulky, but the current wires are also very thick and the number of electrodes would be increased up to 50 times. Consequently, the entire equipment of the time domain IP would be much more bulky and heavy than that in frequency domain.

4 WHY COULD THE DUAL FREQUENCY IP BE EFFICIENT AND FLEXIBLE

The main goal of the dual frequency IP is to supply the current of two frequencies into the ground simultaneously while the dual frequency electrical potential differences are measured concurrently. The dual frequency current is formed by two square wave currents, the frequencies of which are F_L and F_H, and their amplitudes are the same (I_0). Therefore, the dual frequency current (I) can be expressed as:

$$I = \frac{4I_0}{\pi}\sum_{n=1}^{\infty}\frac{1}{2n-1}[\sin(n\omega_L t) + \sin(ns\omega_L t - \varphi)] \qquad (10)$$

where ω_L and ω_H are the lower and higher angle frequencies respectively, $s = \omega_H / \omega_L$, and n is the order of harmonic. The starting time difference of the two square waves of F_H and F_L could be conversed into F_H phase difference. The dual frequency current would have different wave formes when φ are of different values. The dual frequency wave form of $s=13$ and $\varphi = \pi$ are shown in Fig. 1.

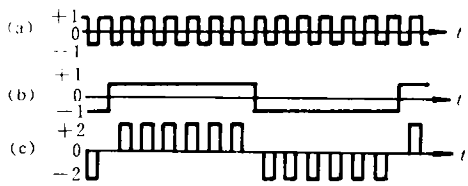

Fig. 1 Example of the composition of dual frequency current

(a)—High frequency current.
F_L is the frequency, I_0 is the amplitude;
(b) Low frequency current.
F_H is the frequency, I_0 is the amplitude;
(c)—Dual frequency current formed by superposition of (a) and (b): The amplitude is $2I_0$.

Reaching high relative precision in measuring the potential differences is the key to the portability of the frequency domain IP. Otherwise, it could not be used pragmatically nor considered as portable. Multiple parameters could be measured by dual frequency IP simultaneously[2]. For the purpose of comparing dual frequency methods with variable frequency methods and time domain IP, only the dual frequency amplitude-frequency measurement is discussed in this paper.

The measuring precision requirement of potential differences shown in Eqn. (4) is based on that V_L and V_H are measured at different times. It means that the measuring precisions of V_L and V_H are different. What we are more concerned with is that whether PFE could reach a certain degree of precision or not. Eqn(4) can also be rewritten in the following way:

$$\frac{\delta_{PFE}}{PFE} = \frac{\delta(V_L - V_H)}{V_L - V_H} \tag{11}$$

Thus, we can see that the key point of reducing δ_{PFE} /PFE is to raise the precision of the difference between V_L and V_H, namely ($V_L - V_H$). Owing to the fact that the random error could be either positive or negative, when the real error signs of V_L and V_H are opposite, the error of these differences is increased. For instance, when the measuring error of V_L is positive and that of V_H is negative, the value ($V_L - V_H$) is increased while the sign of δ_{PFE} / PFE is positive, the value of PEE is increased. On the contrary, when the error of V_L and V_H are negative and positive respectively, the value of δ_{PFE} / PFE is increased as well. But its sign is negative. When the error signs of V_L and V_H are made identical and the error ($V_L - V_H$) is quite small, the higher precision could be obtained with small δ_{PFE} / PFE. V_L and V_H are measured at different time when the variable frequency method is employed. Under such circumstances, the error signs of V_L and V_H may not be always identical due to the alteration of the current supply, state of the receivers and the noises.

The great advantage of the dual frequency induced polarization is to be kept the identification be tween the error signs of V_L and V_H as well as the simi larity of the value. The current of the two frequencies are combined into the dual frequency wave which is injected into the ground in the filed procedure of dual frequency IP. If the amplitude of dual frequency current is varied with the variation of voltage of power source, the current would effect the high and low frequency current at the same degree. For this reason, the relative relation of the two currents remains almost unchanged. In other words, the variation of I_L and I_H are changed with the same proportion so that the variation of the dual frequency current almost will not effect PFE[3].

V_L and V_H are amplified simultaneously with one set of amplifier in dual frequency IP receiver. Therefore, the effect of the variation of the gain on V_L and V_H are the same.

The effects from the random noise on V_L and V_H are quite similar due to the measurement of V_L and V_H are done at the same time. The relative relation of V_L and V_H thus remain unchanged or to be changed very a little.

A great deal of applications in different areas and working conditions have showed that the current supply of this dual frequency IP equipment is much smaller and more portable than that used in the time domain IP and is similar to the resistivity methods[4].

Fig. 2 shows a comparative example made in Hengshan, Hunan Province. The time domain IP was measured by M-3 IP instrument. The current supply was 1 ampere using an generator as the power source. Each working group consisted of 12 people. The dual frequency IP instrument was used in working, the current supply was only 25 milliampere using battery as the power source. Each of such working group needed only 5 people. Both dual frequency IP and time domain IP showed their anomalies with the same phase on the same

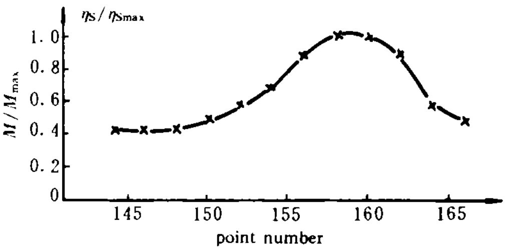

Fig. 2 Comparision of dual frequency IP with time domain IP on line 135 in Hengshan, Hunan

The dimension scale: 1:2 000; the mid-gradient AB = 620 m, MN = 40 m; the dot dash line is measured by time domain IP instrument, the symbol—x is measured by dual freguency IP instrument; the M and PFE of point № 158 are 8.6%, 7.1% respectively;

measuring profile. The sychronization of M-3 was sometimes interfered by the noise so that it costed more time and the repeated accuracy was not very high.

4 CONCLUSION

In dual frequency IP, Supplying dual frequency current and measuring its potential differences make the difference between lower and higher potential differences keeping high precision. Both the advantages of portability and the required precision of PFE have been obtained by this method. Since most nonferrous ore bodies are located in mountainous districts where transportation is quite inconvenient, portability and high precision for the dual frequency IP instrument have great significance in raising the beneficial results of the geophysical exploration.

Although the relative accuracy of the potential difference required by the time domain IP is lower than that of the frequency domain, the whole instrument of the former is quite bulky since its required supplying current is large.

When using variable frequency methods, more attention should be paid to precision. These methods could also be applied in the district where normal field is higher and anomaly field is greater. Care must be taken when using it in the district where field value is lower. The dual frequency IP and the time domain IP are identical in essence, but have their own characteristics. The application of these two methods should suit local conditions, avoiding to emphasize one method at the expense of another.

Generally speaking, the dual freqency IP is more effective than the time domain IP, whereas a higher precision can be assured by the time domain IP if it is used in districts where both values of normal and anomaly fields are very low.

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