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Transient Electromagnetic Response With a Ramp Current Excitation Using Conical Source

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ABSTRACT In this paper, transient electromagnetic response excited by ramp-shaped current using a conical source is studied for the sensing of underground environments. The transient time responses from the conical source with either multi-turn coils or a single loop coil are investigated and compared. Although with the same magnetic moment, the turn-off time for conical source is longer than that of the single loop–this is due to the fact that the time of entering different testing stages using a multi-turn coil system is often earlier than that for a single loop system. To correct turn-off error, the conical source type transmitter is used and the one-dimensional modeling of a layered media, in which the calculation of the turn-off response is carried over the entire time range by solving directly an upper limit-variable integral. The turn-off correction method matched the resistivity and the layer thickness, which is critical for the detection of shallow depth problems. Finally, a field example is presented to illustrate the effect of turn-off time on the interpretation of transient sounding data for a conical source system.

INDEX TERMS Transient electromagnetic method, conical source, turn-off time, simulation, ramp current.

I. INTRODUCTION

For deep exploration of geological structures and ore bodies, time domain electromagnetic method (TDEM) using large ungrounded wire loops or long grounded wires as sources has been applied successfully [1]–[4]. However, for the investigations in shallow depth environments such as roadway, pavement and tunnels, the large excitation sources are limited. Krivochieva presented several in-loop and offset-loop excitation configurations for mining applications: Depending on the available access around mine pillars, the transmitter (Tx) loops are configured with different sizes and shapes and the receivers (Rx) are of small or multi-axial coils [5]. For incomplete mine access roads, deploying a closed wire loop between the pillars is impossible and the Tx loops cannot be used to detect the anomalies surrounding the roadway. Therefore, small scale transmitter devices with multi-turn coils are commonly adopted for limited subspace applications [6]–[8]. Finally, those multi coils have strong mutual inductance coupling and with the limited size, often resulted in lengthy turn-off time and created a deeper ''blind zone'' [9].

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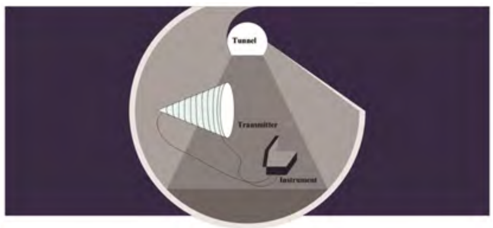

FIGURE 1. **A conical source in mine.**

For the reasons above, we proposed a new transmitter device with a conical source that is evenly bound by dozens of non-overlapping coils (Figure 1) [9]. The conical-shaped excitation has a lower mutual inductance coefficient and can adapt in confined environments. The research further indicated that the behaviors of the primary and secondary fields for the conical source are similar to those for the multi-coil, and for the same transient moment parameter, the mutual inductance for a conical source is only 1/9 times of that for multi-coil.

Transient electromagnetic theories are traditionally derived based on a step function waveform. However, the non-zero loop inductance and transmitter characteristics requires a finite amount of time to turn the current off, and some transient systems are designed to turn off the current in unspecified ways which can be approximated by linear, parabolic, or exponential functions. Considering a homogeneous half space, the transient response excited by ramp and sawtooth current waveforms were studied by Bhattacharya [10]. Based on the work of Knight and Raiche [11], used Laplace transform to investigate the transient responses of a ramp waveform-based turn-off function [12]. Finally, Fitterman presented a new procedure which can be used with any turn-off waveform and any existing transient calculation scheme [13]. A caveat in their scheme is that it does not consider the effect of a finite length transmitter waveform.

For a transmitter of conical source with a finite size, we use Fitterman's method to solve the turn-off problem A: Although we still divide the transient time terms into two parts (early stage and late stage), but the focus is on the late-stage transient behavior and the response calculation is carried out over the whole time range by solving directly an upper limit-variable integral. This paper presents an one-dimensional (1D) TDEM modeling for layered media with a conical source and with forward calculation. A field example is also presented to illustrate the effect of turn-off time on the interpretation of transient sounding data for a conical source.

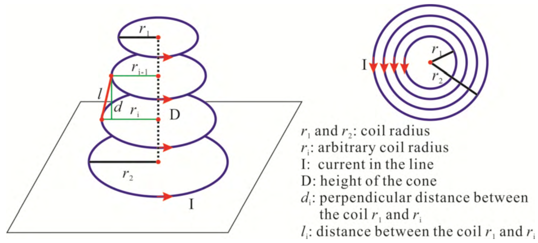

FIGURE 2. Theoretical model of a conical source.

II. THEORY

A. ONE DIMENSIONAL MODEL

Figure 2 shows the a theoretical model of a conical source where the radii of n charged rings are evenly between r_1 and r_2 and I is the current intensity in the cone of height D. Based on the proportional relation between the radius and the distance, the perpendicular distance d between two adjacent coils and the radius ri of the i-th coil are determined as.

$$d = \frac{D}{n-1} \quad \text{and } r_i = r_1 + \frac{i\,(r_2 - r_1)}{n-1} \tag{1}$$

From Equation (1), the distance l between two adjacent coils is obtained as,

$$l = \frac{\sqrt{(r_2 - r_1)^2 + D^2}}{n-1} \tag{2}$$

B. APPARENT RESISTIVITY AND TIME TERMS

A step current I is rapidly switched on and off within the n charged conical ring set up starting at $t = 0$, such that

$$I(t) = \begin{cases} I, \ t < 0 \\ 0, \ t \geq 0 \end{cases} \tag{3}$$

As shown in Figure 2, each ring is considered as a single Tx loop and the transient response excited by this loop can be obtained as follow using transformation method:

To derive a quasi-static response of the Tx loop deployed on a homogeneous earth, the voltage induced in a small receiving i-th loop at the center of the coil can be defined as [14]

$$V(t) = \frac{sI\pi^{3/2}}{\sigma L^3}\left[3\Phi(z) - (3z + 2z^3)\dot{\Phi}(z)\right]u(t) \tag{4}$$

where

$$\dot{\Phi}(z) = \frac{2}{\sqrt{\pi}}e^{-z^2}, \quad z = \sqrt{2\pi}L/\tau, \ \tau = \sqrt{\frac{2\pi + 10^7}{\sigma}}$$

Here L is the Tx loop length, σ is the conductivity of the homogeneous medium. s is the Rx area, and $\Phi(z)$ is the error function.

To obtain the apparent resistivity for the conical source, we consider the induced voltage as the superposition of every single coil:

$$V(t) = \sum_{i=1}^{n} V_i\,(t + \Delta t_i)\,, \tag{5}$$

where Δt_i is the delay due to the distance between the first coil to other turns, (and to the first coil, $i = 1$, $\Delta t_1 = 0$). Considering the diffusion velocity of almost 3×10^8 m/s in air, for a conical source with the height, 1m, the maximum magnitude of Δt_i is about 3.3×10^{-6} ms, which is several orders smaller than the gate time t. After that, the apparent resistivity can be calculated either in late time or for all time [14]–[16].

For a transmitter loop over a conducting half-space, based on an image theory approximation the diffusion velocity of smoke rings blown by which was discussed by Nabighian [28]. Making use of the velocity, apparent resistivity pseudo depth curves and sections can be calculated from apparent resistivity time curves and sections.

The asymptotic behaviors of the transient field divided the field into different time regions, which are the "early stage" and "late stage". For a single loop and multi coils, the early stage and the late stage given by Lee and Lewis [17] and Kaufman and Eaton [18] are τ/r <3 and τ/r >15, respectively, while that given by Fitterman and Anderson [13] are τ/r <2 and τ/r >10. Here τ is the same as in Equation (4) and r is the radius of the Tx loop. The terms "early stage" and "late stage" can be divided by the error limit between apparent resistivity and real resistivity. Xue and Li [19] found the error is less than 5% when τ/r >16, and less than 10% when $\tau/r_0 > 9$.

TABLE 1. The parameters for the three *Tx* loops.

	conical source			multi - coil		single loop	
	radius (m)		turn	radius (m)	turn	radius (m)	turn
	bottom	top					
parameter	0.5	1	21	0.7651	21	3.5062	1
t_E (ms)	8.0572×10^{-6}			8.3849×10^{-6}		1.7609×10^{-4}	
t_L (ms)	8.9525×10^{-5}			9.3166×10^{-5}		1.9566×10^{-3}	

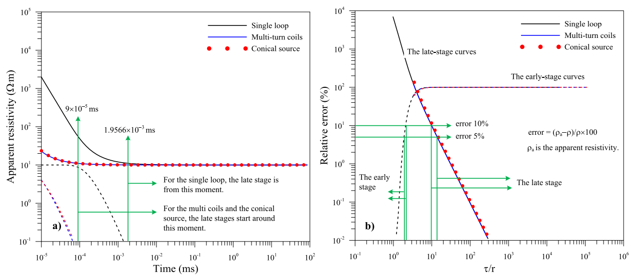

FIGURE 3. Transient responses in the full stage with a dampened current. (a) Apparent resistivity curves. (b) Relative error curves.

To study the time terms of the conical excitation source, we compared three kinds of *Tx* loops including a single loop, multi-turn coils and a conical source with a magnetic moment $M = nIS$ (where I is the current intensity, S is the total area of n charged rings). Given a current, 10 A, the magnetic moment for each device (Table 1) is constant and equal to 386.2 A·m^2. Using equations (4) and (5), we examine the responses of a homogeneous medium with a resistivity of 10 Ω·m for the transmitters (Figure 3). The relative error curves are approximated coincide in Figure 3b, which represents the same time terms for the three *Tx* loops. If the relative error limit for the early and late stages is set to 10%, the time parameter satisfies τ/r <2 at the early stage and τ/r >10 at the late stage. Otherwise, choosing the error limit of 5%, then the factor τ/r at the early term is slightly more than 2, which can be considered as τ/r <3, meanwhile, the late term condition turns to be τ/r >15, which are same in literature [17], [18].

Taking into account the acceptable error range between the calculating resistivity and the real resistivity, we prefer to use the combination of τ/r <3 and τ/r >10 as the time terms of early stage and late stage in this paper, respectively. Hence, the time ranges at the early and late stages can be obtained from the expressions of τ in Equation (4), which are

$$t_E \le 9r^2/2\pi 10^7 \rho_1 \text{ and } t_L \ge 100r^2/2\pi 10^7 \rho_1. \tag{6}$$

where r is the *Tx* loop radius and the subscripts E and L represent the early and late stages, respectively. It is noted that the resistivity ρ of a homogeneous medium is replaced with the first-layer resistivity ρ_1 of a layered medium: According to Fitterman [13], for a layered medium where the loop radius is larger than the first-layer thickness, r in Equation (6) is replaced with the first-later thickness, h_1. However, the loop radius of multi-turn coils and conical source in underground environments is typically smaller than the first-layer thickness. The replacement will not be adopted in current study.

Using the parameters in Table 1, the critical time limits for the early and late stages are calculated using Equation (6), the results are also shown in Table 1. The values of t_E and t_L for both multi-coil and conical source are nearly one order less than that for a single loop, which indicate the time entering the early and late stages for the two small loops is one order-far earlier than that for the single loop. From the apparent resistivity curves in Figure 3a, it can be seen that the transient field begins at about 9.0×10^{-5} ms with the small loops, while it begins at 1.9566×10^{-3} ms with the single loop.

C. TRANSIENT RESPONSE OF A DAMPENED FUNCTION EXCITATION

The dampened current I of the linear attenuation in n charged conical rings can be represented by a piecewise function,

$$I(t) = \begin{cases} I, & t < 0 \\ I\dfrac{t_0 - t}{t_0}, & 0 \le t \le t_0 \\ 0, & t > t_0 \end{cases} \tag{7}$$

where t_0 is the turn off time.

Based on the relationship between step response and turn off current, the transient response excited by a damping current is obtained through Duhamel integral [13]

$$V'(t) = \int_{-\infty}^{t} \frac{-dI(s)}{ds} V(t-s)ds, \quad t > 0 \tag{8}$$

By setting $r = t - s$ in Equation (8), the dampened response is then

$$V'(t) = \frac{1}{t_0}\int_{t}^{t+t_0} V(r)dr, \quad 0 \le t \le t_0. \tag{9}$$

For the treatment of TEM response with a conical source, both the induced voltage in Equation (5) and the turn off time need to be considered. Here we give a brief description of the turn off time, and begin with the inductance: Generally speaking, multi loops can be considered as a number of single coil connected in series. The equivalent inductance of a conical source can be written as [9]

$$L = \sum_{i=1}^{n} L_i + \sum_{i=1}^{n}\sum_{j=1}^{n} M_{ij} \quad (j \ne i), \tag{10}$$

where L_i is the self inductance of the i-th coil, M_{ij} is the mutual inductance between the i-th and j-th coils. The computation can be found in our previous work [9].

To compute the turn off time, we prefer to use the formula in Sirotem system manual, shown as:

$$t_0 = \frac{L}{R}\ln\left(\frac{2U}{U+1.5}\right), \tag{11}$$

where L and R are the inductance and the resistance of the conical source, respectively, and U is the supply voltage.

For a copper wire with a diameter of 0.1 mm and a resistivity of 1.85×10^{-8} Ω·m at 30 °C temperature, the inductance (L) and the turn off time (t_0) for the conical source and the multi-coil in Table 1 can be calculated by combining Equation (10) and (11) as shown in Table 2. It can be seen

TABLE 2. The parameters for the three *Tx* loops.

	conical source	multi - coil
L (H)	6×10^{-4}	3.2×10^{-3}
Calculated t_0 (ms)	1.524×10^{-1}	8.374×10^{-1}

that L and t_0 for multi-coil are five times more than that for the conical source representing a lowered mutual-inductance effect and a shorter turn off time for the conical source than that for the multi-coil.

The turn off times in Table 2 match the values measured in the field at an order of magnitude measured using a TerraTEM system, which are 2.068×10^{-1} ms for the conical source and 3.283×10^{-1} ms for the multi-turn coils. In the field study, we first made a conical transmitter with a top radius of 0.5 m; bottom radius of 1 m; height of 1 m and with 63 turns, the wire length was 300 m. The current measured by the system was about 7.1 A. The coil is then rewind into a multi-coil with side length of 2 m and with 37 turns. The current measured was the same as in the conical source. It should be noted that the turns for the conical source is almost twice as that for the multi-coil with a same wire length – a probable reason that the turn off times measured are close.

D. TRANSIENT RESPONSE IN A LAYERED MEDIUM

Compare with the late stage start times in Table 1, the turn off times for the two loops in Table 2 seem much longer. This implies that the late TEM response is influenced in time domain by the ramp effect, which arises starting at the late stage entry to the moment that the ramp current winding down to zero. To reduce the impact resulting from the ramp effect, method from Fitterman and Anderson [13] where the voltage in the late stage described by Kaufman and Eaton [18], is used. By integrating Equation (9), the voltage for the turn-off ramp can be obtained without the integral item as

$$V'(t) = \frac{1}{t_0}\int_t^{t+t_0} V(r)dr = V(t)\cdot\frac{2t}{3t_0}\left[1-(1+t_0/t)^{-3/2}\right]. \tag{12}$$

The voltage excited by a step current in the late stage can be written as

$$V(t) = \frac{V'(t)}{F(t,t_0)}, \tag{13}$$

where

$$F(t,t_0) = \frac{2t}{3t_0}\left[1-(1+t_0/t)^{-3/2}\right], \tag{14}$$

And $F(t, t_0)$ does not depend on the geoelectrical parameters, which indicates that the effect of the turn-off time is becoming less important as t increases or t_0 decreases. Equation (13) describes that the effect of the turn-off ramp on late stage response, thus we can use this calculation to reduce the ramp effect on the measured voltage in the data process.

Equation (13) can be used to correct the response excited by a linear ramp function. Figure 4 shows the responses as a

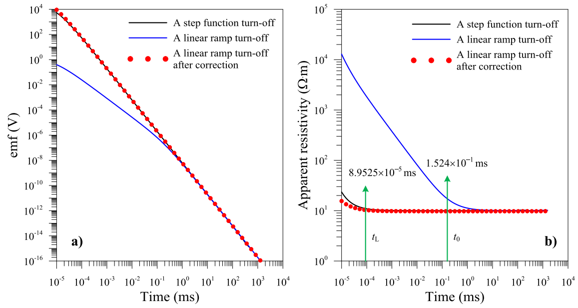

FIGURE 4. Transient responses in the full stage with a ramp current. (a) Induced voltage curves. (b) Apparent resistivity curves.

result of ramp effect: Due to the turn-off excitation, the start time of the late stage is far behind that excited by a step excitation. However, through the correction using Equation (13), the late -stage response with ramp shows the same behavior as with the step excitation. Note that there are only two time parameters t and t_0 existing in Equation (14), so the correction is well adapted for any application.

E. EQUATIONS

By introducing an input impedance, frequency domain EM expressions in a layered earth were presented by Morrison *et al.* [20]. Applying inverse Fourier transform, the frequency response can be transformed into time domain. For a coil with a step current expressed in equation (3), the transient responses at the center of the i-th loop in a layered earth are [21], [22]

$$H_{z,i}(t)=\frac{2}{\pi}\int_0^\infty \mathrm{Im}\left[Ir_i\int_0^\infty \frac{\lambda Z^{(1)}}{Z^{(1)}+Z_0}J_1(\lambda r_i)\,d\lambda\right]\frac{\cos\varpi t}{\varpi}d\varpi, \tag{15}$$

and

$$\frac{\partial B_{z,i}(t)}{\partial t}=\frac{2}{\pi}\int_0^\infty \mathrm{Re}\left[Ir_i\int_0^\infty \frac{\lambda Z^{(1)}}{Z^{(1)}+Z_0}J_1(\lambda r_i)\,d\lambda\right]\cos\varpi t\,d\varpi \tag{16}$$

where I is the transmitter current, ri is the radius of the coil, λ is the wave number in space domain, Z_0 and $Z^{(1)}$ are wave impedance, and J_1 is the 1st Bessel function.

Note that solving the Bessel function and transforming the results into time domain in equations (15) and (16) are essential: For the former, a Hankel transform and numerical filtering algorithm originally proposed by Anderson [23] can deal with the Bessel function; furthermore, a 140 points fast Hankel transform developed by Guptasarma and Singh [24] showed high precision and efficiency. For the latter, there were several ways such as G-S transform [11], [25], improved cosine and sine transform numerical filtering algorithm [26], [27] that can be used to transform from frequency domain to time domain.

Considering a cone with a top radius, 0.5 m; bottom radius, 1 m; height, 1 m; current of 10 A; and with 21 turns, acting on a homogeneous half-space with a resistivity of 10 Ω·m. Using the three transformations, the induced

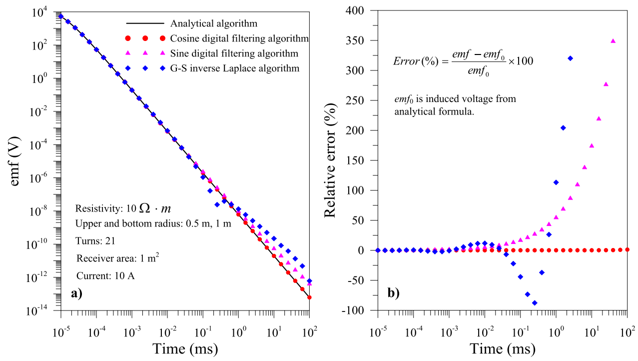

FIGURE 5. Curves for three transform methods. (a) Induced Voltage. (b) Relative error.

TABLE 3. Relative errors for the transform methods.

	Cosine digital filtering	Sine digital filtering	G-S inverse Laplace
Average error	0.1%	71.1%	411.5%
Maximum error	1.2%	558.3%	4351.7%

voltage is calculated, and the relative error of the voltage to the analytical solution from Equation (7) is determined for each method. The resulting curves of the induced voltage and the relative error over time are shown graphically in Figure 5. The results indicate that the induced voltage calculated by the cosine digital filtering algorithm agrees with the analytical solution with the lowest relative error (average error 0.1% and maximum error 1.2% from Table 3). Additionally, the error curve of the cosine filtering method shows a great stability in time domain, while the others are increasing or oscillating over time (Figure 5b). Hence, the cosine filtering method is used in the following calculations.

III. SIMULATION

In order to analyze the behavior of turn-off responses, we will focus on the apparent resistivity curves and the "smoking ring" results. The "smoking ring" inversion, proposed by Nabighian and Macnae [29], is an approximate method that can quickly describe the variation of resistivity with depth without an initial model.

Considering the effect of turn-off time, two models of a three-layer medium were constructed and the above calculation is used to simulate their transient responses. In the two models, the thickness in the first layer changes in model 1, while the resistivity in the first layer was modified in model 2. The results of apparent resistivity and "smoking ring" inversion before and after turn-off correction for the two models are shown in Figure 6 to Figure 9, respectively.

It can be seen from the apparent resistivity figures, the curves in the early stage for all models are disturbed heavily by the turn-off time with serious inclination at the beginning. The influence by the late apparent resistivity conversion is not significant because the curves become consistent and match the models at the early range after correction using the late-stage formula, i.e. Equation (14). At the

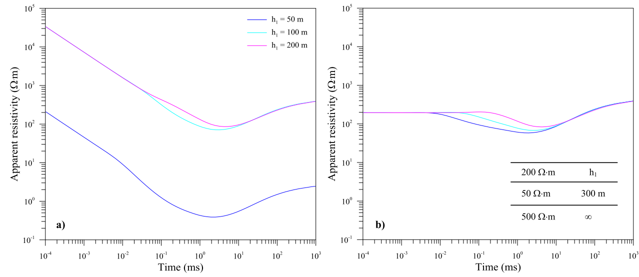

FIGURE 6. Apparent resistivity curves for model 1. (a) Without turn-off correction. (b) With turn-off correction.

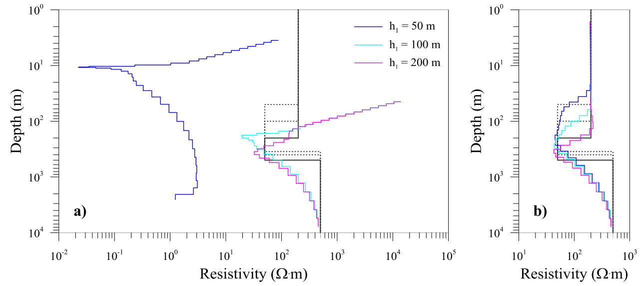

FIGURE 7. "Smoking ring" curves for model 1. (a) Without turn-off correction. (b) With turn-off correction.

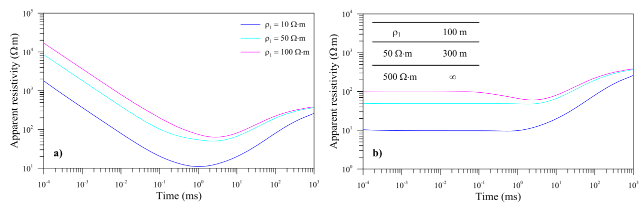

FIGURE 8. Apparent resistivity curves for model 2. (a) Without turn-off correction. (b) With turn-off correction.

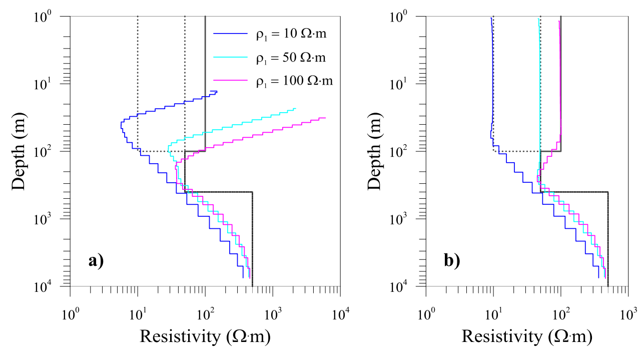

FIGURE 9. "Smoking ring" curves for model 2. (a) Without turn-off correction. (b) With turn-off correction.

same time, the turn-off responses calculated by Equation (9) showed the full-range responses. The influence of turn-off time on each model depends more on the thickness and resistivity of the first layer than of the subsequent layers. The first layer can be interpreted as the overburden: The thinner layers (such as the thickness $h_1 = 50$ m in Figure 6) made the apparent resistivity deviate from real world and the lower resistivity in the first layer affects the apparent resistivity of the whole medium and even reveals the "skin effect" that is well known in electromagnetic theory. The apparent resistivity curves after turn-off correction show the

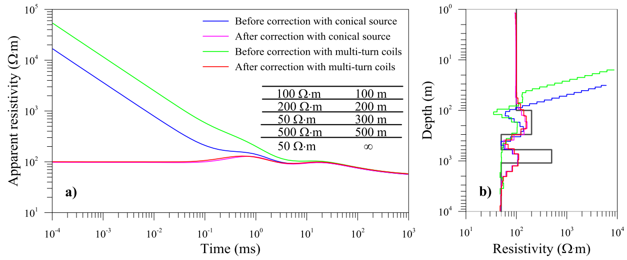

FIGURE 10. Simulation for a 5-layer model with multi-coil and conical source. (a) Apparent resistivity curves. (b) "Smoking ring" curves.

characteristics of a three-layer model, which can simplify into a two-layer model since the resistivity of the first layer is the same as the second layer, as shown in the second curve in Figure 8.

The turn-off time effect leads to influence on the aforementioned "smoking ring" results: the shallow thickness and low resistivity of the first layer resulted in deviation in the apparent resistivity curves (Figure 7 and Figure 9). The turn-off correction makes the "smoking ring" curves smoother and the resistivity and thickness curves match the models well.

As a last simulation, a 5-layer model was built using the proposed approach to explain the turn-off effect and correction on the simulated data from multi-turn coils and conical source, and the results are shown in Figure 10. It can be seen that the turn-off time affects predominantly the response of the shallow layers including the first and second layers and that the curves before and after correction coincide. However, it is worth noting that the apparent resistivity of multi-coil is more seriously affected than that of conical source (Figure 10a), the influence shown in "smoking ring" figure appears not only in the shallow layer, but also in the deep layer (the fourth layer) (Figure 10b). In Figure 10b, the high resistivity in the fourth layer cannot be identified for multi-coil while it seems normal for conical source. This model illustrates that it is not necessary to correct the turn-off effect for deep sounding for conical source, but it is necessary for multi-coil. In reality, for the small size transmitter equipment, the target detected is usually buried in a small depth. Therefore, we can conclude that the turn-off correction is critical for the small depth detection.

IV. FIELD EXAMPLE

We conducted a field experiment in an ore zone combining a Terra TEM system and a conical source (Figure 11), the top and bottom radii of the field source device are 0.5 m and 1 m, respectively, on which 50 coils are wound, and the emission current is about 7 A, the distance between the top ring and the bottom ring is 1 m. The receiver is a loop with 64 wound coils, and the radius of each coil is 1 m. The central points of transmitter and receiver coincide.

Considering the complex terrain in the measurement, we designed a survey line with a length, 1.6 km, and measured point interval, 5 m (Figure 12). However, there were a number of points located down the gully, we had to abandon them.

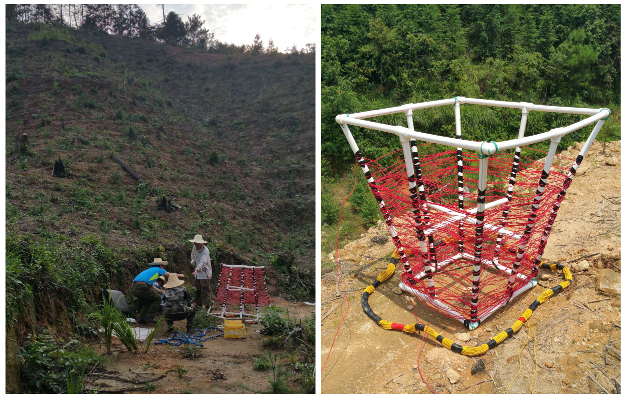

FIGURE 11. Field experiment with a conical source.

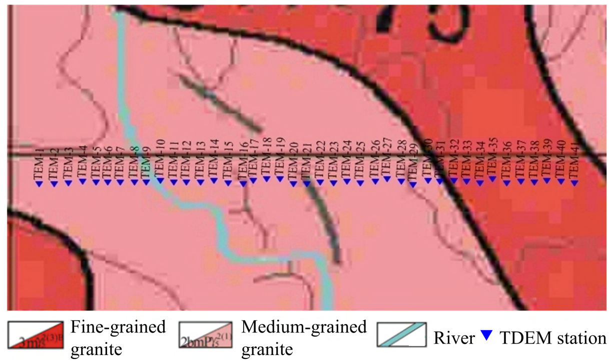

FIGURE 12. Geological map and station layout.

In the following data processing and explanation, we prefer a cross section with 41 measured points, because they were continuous and none were abandoned.

The exposed rocks around the survey line, which are shown in Figure 12, mainly include fine and medium grained granites. Between the station TEM-9 and TEM-11, there is a river running through, according to geological information, which was caused by a fault below the bottom of river. By measuring the resistivity of rock samples, we had average values of 7159 Ω·m and 5490 Ω·m for fine and medium grained granites, respectively, and common values of 5953 Ω·m and 5581 Ω·m for them, respectively.

For the raw data, data preprocessing, including bad channel delete and filtering, are performed to make sure the decay of voltage data by time matching the transient field characteristics. Then, the data were corrected using the method described above. The curves before and after correction at one measured point are shown in Figure 13. Compared with Figure 4, it can be seen that the voltage response after correction tends to be a step response at the early time with the apparent resistivity corrected to drop at the same moment, which shows the same correction effect as in the theoretical homogeneous medium example shown in Figure 4.

Figure 14 shows the section maps of apparent resistivity before and after turn-off correction, where the distance between the measured points is 5 m. Comparing pictures in Figure 14, we can see two anomaly zones with low resistivity around the regions at 40 - 60 m and 180 - 200 m, respectively.

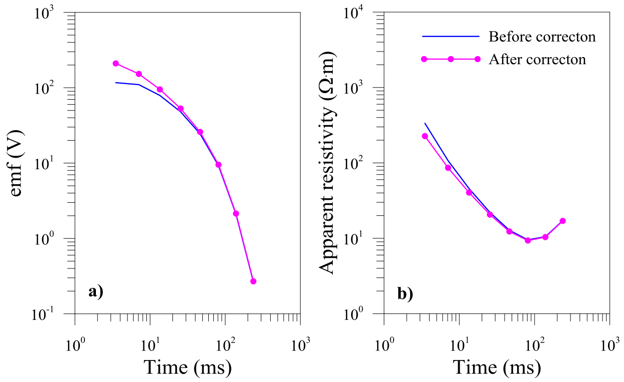

FIGURE 13. Comparison before and after correction. (a) Induced voltage curves. (b) Apparent resistivity curves.

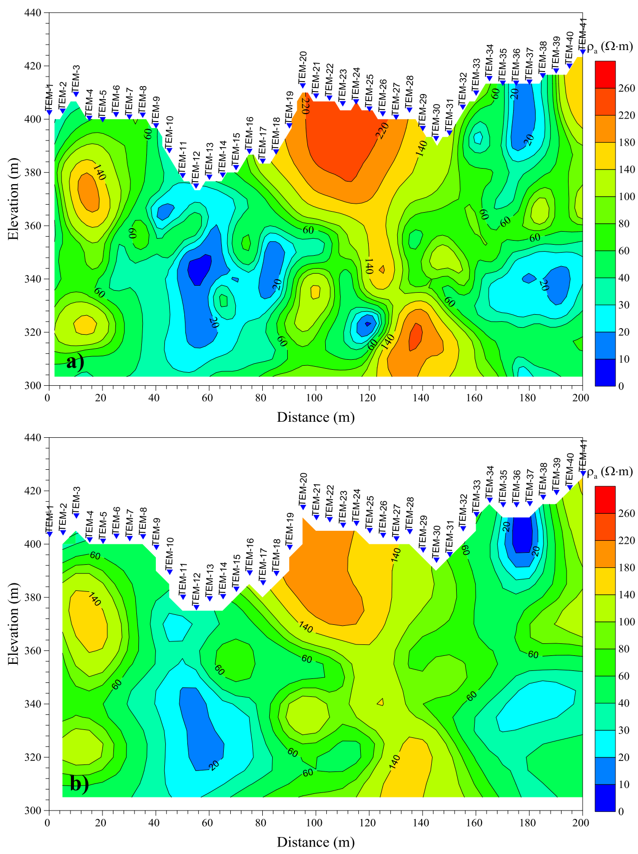

FIGURE 14. Section map of apparent resistivity. (a) Before correction. (b) After correction.

According to the geological data, the former one is related to a known fault inclined from upper left to lower right below the bottom of river. The subaerial position and inclination of the anomaly zone match the fault well. For the latter one, without any known geological information it is speculated at first the low resistivity response is a result of possible underground water reservoir. However, from the view of Dr. Yanguo Wang, a researcher at the East China University of Technology, who has studied geological structure in this area for several years, this anomaly zone is more likely to be an inclined fault since the low resistivity belt extends from shallow to deep.

Because of the turn-off correction, there are some differences in the apparent resistivity values. The section map in Figure 14b is preferred because the two low resistivity areas are more obvious and identifiable than in Figure 14a.

V. CONCLUSIONS AND DISCUSSIONS

In our previous study [9], [30], we found the mutual inductance for a conical source is only 1/9 times of that for multi coils with the same transient moment parameters. For the proposed conical source in this paper, we conclude that the conical source has advantage over a single loop system in that a much earlier time entering the early and late stages can be achieved. However, the effect of the overburden (the first-layer medium) still cannot be avoided. For the multi-turn coiled conical source, it is necessary to correct the turn-off effect because turn-off time for these sources is much longer than that for single loop.

Our field experiment provides the proof that the data after turn-off time correction are more useful for detection of anomalies. However, the calculated apparent resistivity is significantly less than the measured rock resistivity, many researchers have an agreement that this difference originates from the transmitter type with small and multi-turn coils, currently, which is still an unsolved problem. Therefore, in the data interpretation on our experiment, we mainly focused on the resistivity contrast in the horizontal and vertical directions. Besides, the effect on the measured data before and after correction needs to be studied further.

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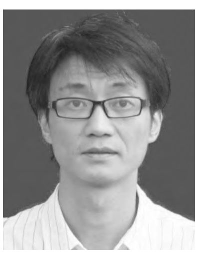

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