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Fast Turn-off Mine Transient Electromagnetic Transmitter System

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Abstract: For solving problems such as short turn-off time, high linear degree of falling edge, measurement of turn-off time and influence of primary signals for transient electromagnetic transmitter, and restrictions because of the environmental conditions of underground coal mine, this thesis aims at designing a new transient electromagnetic transmitter system suitable for coal mine. Supported by damping absorption circuit, such system applies small volume, sectional transmitting coil, with features of short turn-off time, high linear degree of current falling edge. It uses the transmitter monitoring circuit, which accurately measures turn-off time and simultaneously records the current value changes after turn-off, thus to eliminate the influence of primary field as well as to restore earlier secondary field signals for reference and finally to improve the ability to detect the shallow structure. It turns out that the new system has a shorter turn-off time, a higher linear degree of current falling and more accurate data record of turn-off current. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Transient electromagnetic, Coal mine, Transmitter current, Fast turn-off.

1. Introductions

Transient electromagnetic method (TEM) is a geological structure exploration method widely applied in geophysical sciences, for example, mineral exploration, groundwater detection, engineering monitoring and soil salinization investigation and so on. It firstly injects the bipolar pulse current into the transmitting coil, which will stimulate the primary pulse magnetic field, and then measures the secondary field, thus locates the unknown underground targets [1]. Given the obvious advantages such as small volume, strong directivity, high resolution and sensitivity of low resistance zone of the coal mine transient electromagnetic method, it has become the best way in water disaster detection in the coal mine [2]. Today, we have some representative transient electromagnetic systems both home and abroad, including the TerraTEM of an Australian corporation GeoInstruments, V6 [3, 4] of a Canadian company Phoenix and GDP-32 of an American company Zonge; domestically, we have the distributed TEM system FDK-1 developed by Xi'an Branch of China Coal Research Institute [5], the ATEMII [6] developed by Jilin University (JLU), the CUGTEM200X [7] by China University of Geosciences (CUG), as well as the WTEM-1 [8] jointly developed by Chongqing University (CQU) and Chongqing Benteng Numerical Control Technology Research Institute, etc. As for the mining transient electromagnetic systems, there are PROTEM-47 transient electromagnetic system developed by a Canadian company Geonics, YCS2000 by Xi'an Research Institute, CCTEG (China Coal Technology & Engineering Group), and intrinsically safe mining transient electromagnetic instruments such as YCS40 developed by Chongqing Research Institute, CCTEG, and TEMHZ75 by High-tech Resources Detecting Instrument Research Institute of CUG, Wuhan, and YCS600-I by Shanxi Geosina Geological Instrument Co., Ltd, as well as YCS40(A) of Fujian Huahong Intelligent Technology Co., Ltd. The quality of the current waveform transmitted from TEM has an importance effect on the measurement; therefore, bipolar pulse current waveform with short turn-off latency time, large current and high linear degree of current falling edge has become the key point in TEM transmitter technology research.

The mining transient electromagnetic instrument is quite different from the one which is applied underground in terms of a smaller transmitting power, a smaller circuit volume and a relatively simpler structure and so forth, however, the key technologies are the same. Thus, considering the working restrictions of transient electromagnetic, if a new kind of mining transient electromagnetic transmitter system which is supported by sectional transmitting coil and damping absorption circuit can be developed, the turn-off time will be shortened, and linear degree of current falling edge will increase, meanwhile, the turn-off time and changing process of detection the transmitting current can both be recorded much more accurately, as a result, the exploration accuracy can be largely improved.

2. Design of the Transmitter System

Generally speaking, the mining transient electromagnetic equipment needs a smaller volume, the integration of transmitting and receiving sections, and an integrated multi-turn loop, moreover, the transmitting and receiving must be connected with hardware synchronously in order to share the synchronizing signal without the GPS synchronous controller in the ground equipment. The structure of the transmitter is as Fig. 1, mainly including the master controller, transmitting battery, transmitting controlling circuit, damping absorption circuit, and transmitting observing circuit, together with the transmitting coil. As for the master controller, it uses the 32-bit RSIC Nios II series embedded processor to finish all the order from the whole transmitter system; secondly, the transmitting battery includes two sets of inserted rechargeable NI-MH batteries to charge the transmitting coil and then form a primary magnetic field; thirdly, the transmitting controlling circuit is responsible for controlling the transmitting current forward and reverse in the transmitting coil; fourthly, the damping absorption circuit is for helping the transmitting coil to release energy more quickly, so the transmitting current can drop to zero rapidly and the turn-off time can be shortened; finally, the transmitting observing circuit is for recording the state of transmitting coil, the voltage, the current and the turn-off time so as to provide some primary magnetic field data for later analysis and increase the detection ability. The transmitting coil is a multi-turn square loop with a side length of 2 meters.

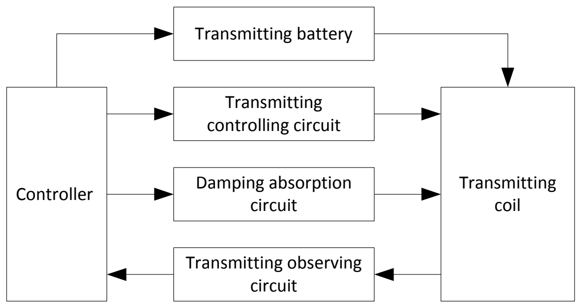

Fig. 1. Structure of the transmitter.

3. Transmitting Circuit

The transmitter adopts the bipolar transmitting method to transmit current forward and reverse. In order to reduce the effect on the secondary field from the primary field, the transmitting current needs to be turned-off ideally with a rectangular wave alternatively from positive to negative. Whereas, given the particularities of TEM, such as the low voltage power supply; the large inductance value transmitting coil with a low loop resistance, it's fairly difficult to realize a longer turn-off time and a steep current pulse with a higher linearity [8]. Although the turn-off time is generally very short (from several μs to hundreds of μs), it has great influence on the secondary transient electromagnetic field. At present, almost all the signals recorded by the TEM transmitters are terminal signals, or only the terminal signals are adopted in data processing (for example, the Canadian GEONICS series and the Australian CIROTEM series), which will, on the one hand, damage the exploration capability of TEM in shallow structure, because the information of which is mainly carried by the early signals; on the other hand, decrease the resolution capability of TEM, for the turn-off current will distort the transient [10]. To get an ideal pulse current, literature [11] proposed a regenerative constant voltage clamp pulse circuit, which accelerated the fall of load current through a constant high voltage clamp. On the basis of literature [11], literature [8] made some improvements; it used a constant voltage clamp transmitting circuit consisting of a direct-current voltage stabilizing circuit as the constant voltage source to realize the fast and linear fall of the load current. Literature [12] further adopted the damping absorption circuit to the constant voltage clamp circuit to achieve the same effect. However, the constant voltage clamp circuit is applied in all these methods, which makes the control of the current more complicated, besides, the resonance with coil because of the capacitance can increase the jitter of the current fall, and the clamp voltage is as high as 600 V to 1420 V, which is too high to be suitable for the subsurface environment. Literature [13] proposed a simpler non-source constant voltage clamp circuit with smaller jitter of the current fall supported by TVS (transient voltage suppressors) and SIDAC (silicon diode for alternating current). In order to design a transmitting circuit appropriate for the subsurface environment as well as with a fast linear turn-off, two aspects must be considered, one is to improve the physical structure of the transmitting coil under the mine circumstances, and design a reasonable damping absorption circuit to shorten the turn-off time; another is to test the current attenuation after turn-off and provide some data to eliminate the effects of the primary magnetic field during the secondary magnetic data processing and finally better improve the test effects through numerical processing.

The structure of transmitting circuit coil circuit is as Fig. 2, as we can see, the transmitting coil is divided into two sections and controls the current direction by using of the on-off switch. K1, K2, K3, K4, K5, K6 are all controllable switches and different on-off switches together control the emission current forward and reverse. K1, K2, K3 and K4 consist of an inverter-bridge, among which K1 and K4 is one pair of the bridge arm; K2 and K3 is another pair. K5 and K6 divide the transmitting coil into two sections. L1 and L2 represent for two sections of the transmitting coil, and RS detects the resistance for the transmitting coil, and then detects the transmitting current, as for K7, K8, K9 and K10, comprised of controllable relays, they are the switches of the damping absorption circuits in the two transmitting coils respectively, in which C2~C5, R1~R4, D1~D4 are the circuit devices.

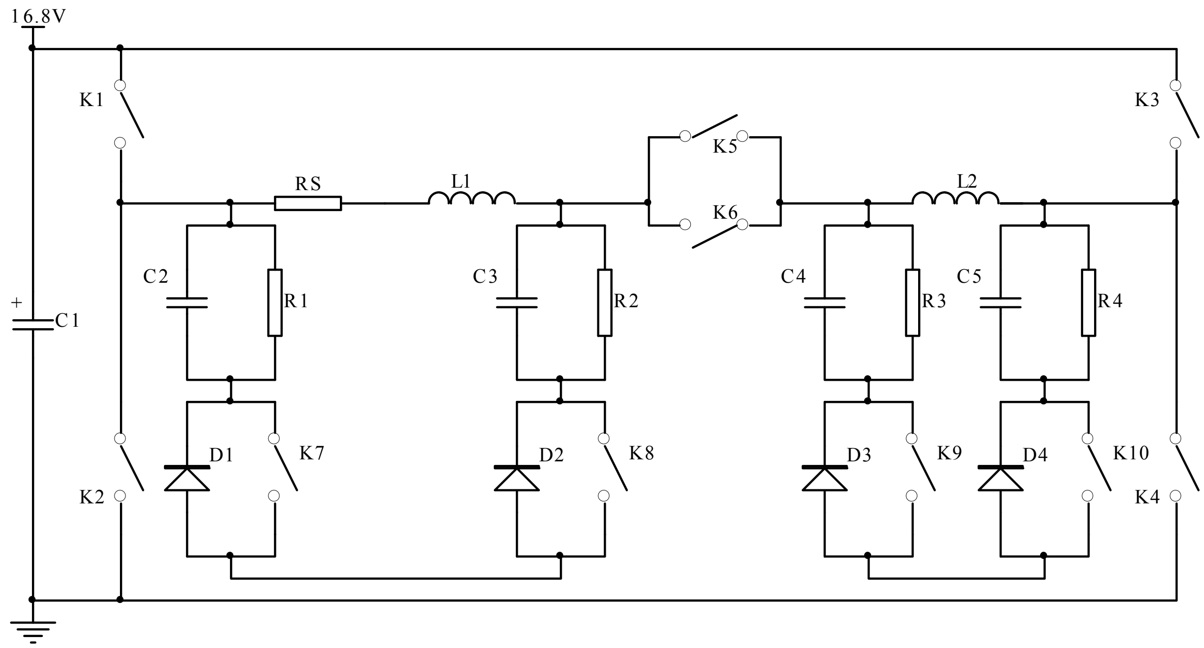

Fig. 2. Structure of transmitting coil circuit.

The working process is: when transmitted forward, K1, K4, K5, K8 and K10 are switched on, at the same time, L1 and L2 are in series, after the current reaches a stable value, the transmitting coil will set up a stable underground magnetic field. When the forward transmitting time is over, K1, K4 and K5 will be switched off, and L1, L2 will then be divided into two sections to release current through oscillation by respective resonance circuits; when transmitted reversely, K8 and K10 are switched off, meanwhile K2, K3, K6, K7 and K9 are switched on and L1, L2 are in series again, still after the current reaches a stable value, the transmitting coil will set up a stable underground magnetic field, finally, when the reverse transmitting time is over, K2, K3, K6 will be switched off and L1, L2 again be cut into two sections to release current through oscillation by respective resonance circuits.

The working principle of the damping absorption circuit: the capacitance starts from zero, in forward transmitting, K1, K4, K5, K8, K10 are switched on, after some time, K1, K4 and K5 are off, but K8, K10 are still on, besides, L1, L2 will form the follow current through RC network, D1 (D3) and RC network. Part of the energy will be consumed by the resistance, and the rest be stored by the capacitance, then after a while, the capacitance energy will be run out of by the resistance, at that time, the stored energy in the transmitting coil is all released. Likewise, when in reverse transmitting, the working process is the same as that of the forward transmitting, except for the different current paths.

4. Transmitting Monitoring Circuit

The monitoring circuit is mainly responsible for detecting and observing the working state of the whole system, and the main parameters to be monitored include transmitting current, transmitting voltage, transmitting coil resistance, the state of transmitting coil (short circuit or open circuit), turn-off time and the changes of transmitting current after the turn-off. Through all these observations, we can not only help the users to fully know the working state of the system, but also record the turn-off time of the transmitting current as well as the changes after the turn-off, which together play an important role in later data processing. Though the receiver starts to collect the secondary field signals from the very beginning, it still cannot deal with the mixed primary field signals mingled in the secondary field after that, and the traditional means of TEM to solve the problem is to discard the data in this part, which will definitely cause the subsurface shallow area to become the blind zone [14]. In other words, if the turn-off time and the value of current changes after turn-off can be accurately recorded, and if the detection of the current after the turn-off can be strictly synchronized with that of the secondary field data, the effects of the primary field on the secondary field will thus be eliminated through some numerical calculation so as to get some more accurate early data, which is of great significance for the detection in shallow areas.

Fig. 3 shows both the transmitting coil state and the transmitting voltage detection circuit. The ADG604 multi-way switch chooses the objects to be detected, and the state of the transmitting coil (short circuit, open circuit or resistance value) is detected when 0, 0 are input to A0, A1. The working principle here is that based on the flowing current in the transmitting coil and its working state, we can decide it's an open or short circuit, and then the resistance value is calculated with the transmitting voltage and current. Similarly, when 0, 1 are input, the voltage of transmitting battery both in transmission and non-transmission are detected, after that, the voltage of resistance 48 will be detected and then be used to calculate the battery voltage. The ADC (Analog to Digital Converter) is the low power, high performance successive approximation serial one, called AD7466 with a single channel and a resolution of 2^12.

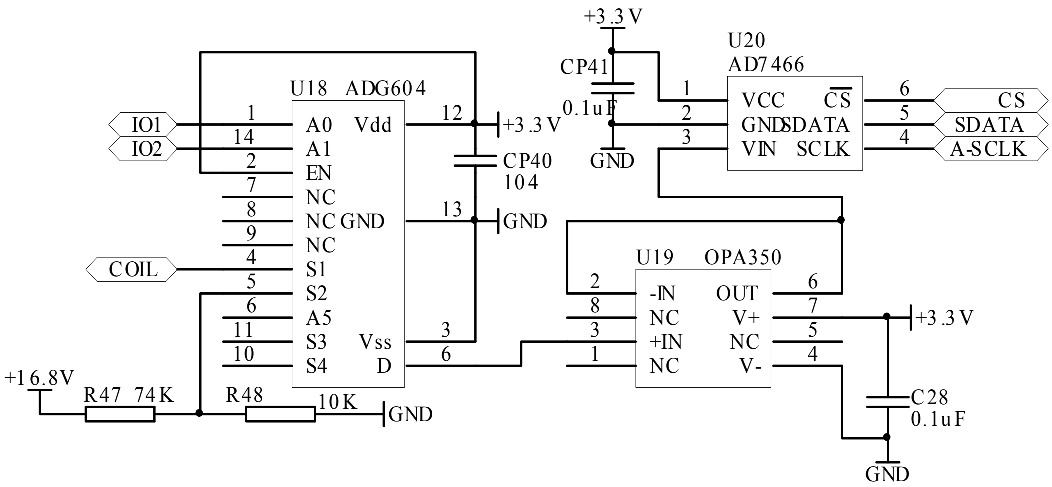

Fig. 3. Detection circuit of transmitting coil and voltage.

Fig. 4 shows the detection of transmitting current and the turn-off time as well as the current changes after turn-off. The detection of transmitting current detects resistance RS by the current in the transmitting coil, thus to turn the current signal into the voltage signal and then to transfer that to the bi-directional current monitoring chip INA170. After this process, one of the voltage output is transferred to the high-speed, single-supply comparator AD8611, and then to comparatively input CUT-TIME connected processor, which is used as the determining signal to see whether the turn-off current has declined to 0 or not. Besides, if the transmission is turned off when it's stable, then the t_{off} time used for the stable current when it is turned off to drop to 0 is defined as the turn-off time. The concrete steps are: start the timer to count when the transmission is suddenly stopped; then after some time, when the current drops to 0 and when CUT-TIME drops to a low level from a high level, entering into the interrupt routine, stop the counting; at last, calculate the turn-off time through the recorded time in the timer. The other one of the voltage output is then transferred to analog-digital conversion circuit for detecting the transmitting current value. As for the detection circuit, we choose ADS1271, which is an industrial high bandwidth ADC with a resolution of 2^24, to realize the transformation from the analog voltage to digital value, moreover, the reference voltage is offered by chip REF3125 and operational amplifier OPA350. In addition, a 10 μF tantalum capacitor and a 0.1 μF ceramic capacitor are used in parallel in the input end REFP and REFN, and use OPA1632 are employed as the operational amplifier in the analog input end, meanwhile, a 1 nF capacitance in parallel connection is inserted between AINP and AINN, after that, connect 100 pF will be connected between each analog input end and the ground so as to guarantee the performance of AC [15]. There is a MODE on the pin of switching control for choosing the working pattern of AD, in addition, CLK and SCLK stand for the main clock input and serial clock input respectively; DOUT represents the data output; SYNC means synchronizing signal for starting the current sampling, which ensures the synchronization with the voltage signal sampling of the receiving coil.

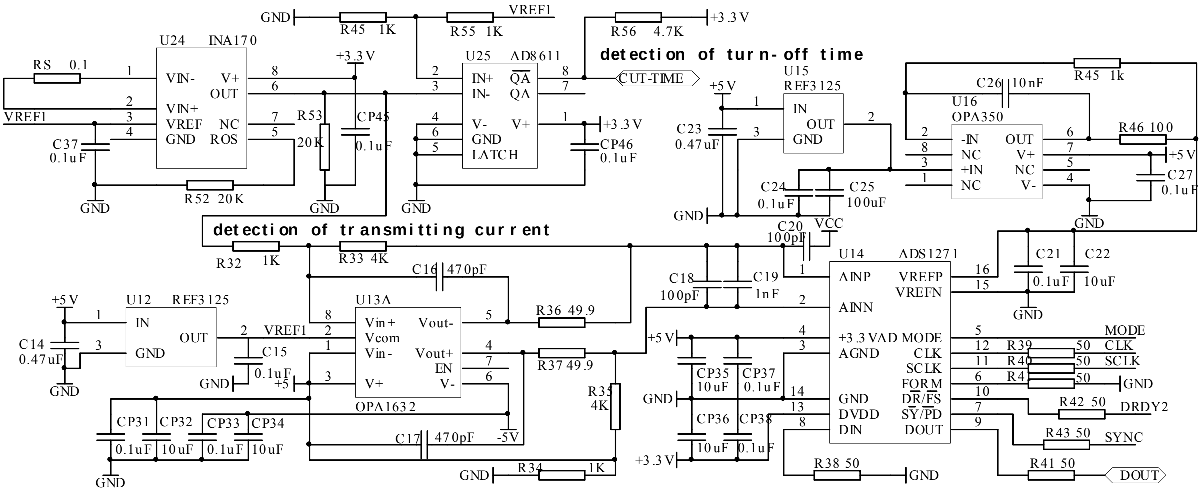

Fig. 4. Acquisition circuit of transmitting current.

5. Measured Results

When using a 20 turns square transmitting coil with a side length of 2 meters, we can collect the transmitting current data after turn-off, according to which we can draw the figure of the waveform of transmitting current falling edge as Fig. 7. As it shows, the waveform of transmitting current falling edge climbs to the highest level 2.5 A when the turn-off time is 0 μs, furthermore, the longest turn-off time is 200 μs.

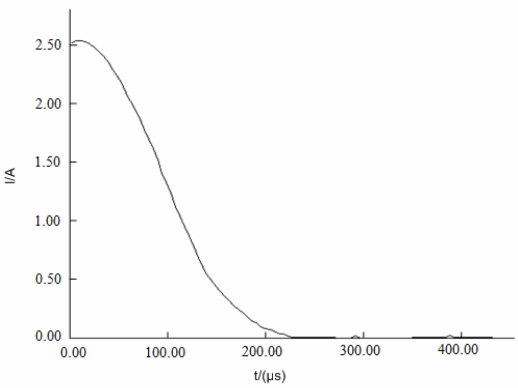

Fig. 5. Waveform of transmitter current falling edge.

6. Conclusion

The newly designed fast turn-off mine transient electromagnetic transmitter features a small volume and a portable retractable coil with both functions of transmitting and receiving, suitable for the narrow underground space. By replacing the constant voltage clamp circuit with a two-section transmitting coil and a damping absorption circuit, we can not only simplify the circuit to avoid the high voltage, but also effectively reduce the turn-off time. Besides, the transmitter can synchronously record the current changes in the transmitting coil after turn-off, which can provide us with the primary field data for the early secondary field signal processing, and after the accurate numerical algorithm, we can restore the early secondary field signal for more efficient exploration in the shallow structure. So far, this system has been applied in underground detection successfully. Whereas, considering the anti-explosion and the coal mine safety standards, it's pretty difficult to increase the power of the mine transient electromagnetic device; as a consequence of which, the future research should be focused on increasing the transmitting current and transmitting power as well as reducing the turn-off time.

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