TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 12, No. 8, August 2014, pp. 5736 ~ 5742
DOI: 10.11591/telkomnika.v12i8.6266

Design of the Coal Mining Transient Electromagnetic Receiver with A Large Dynamic Range

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Abstract

Considering the influence of the transient process of transient electromagnetic receiving coil on the early signals detection of the secondary field, as well as the great change and the various decay rates in different periods of the secondary field signals, which will affect the secondary field signal collection, we aim at designing a new receiver with the variable stored program control receiving coil, prefixed amplifying circuit, programmable amplifying circuit and high-performance analog-to-digital conversion circuit according to the underground coal mining environment, in which we apply the different sampling interval software and self-adaptive filtering algorithm to eliminate the influence of transient process and filter out the 50Hz power line interference, thus to increase the data collection ability and improve the detection result. The whole device is suitable for underground coal mining environment with a small volume.

Keywords: *transient electromagnetic, coal mining, receiving coil, transient process*

1. Introduction

The transient electromagnetic method (TEM) applies the non-grounded return inside the underworkings, then with a certain quantity of transmitting current, a primary electromagnetic field can be produced, at the same time, the induced current will be generated in the conductive ore around the underworkings. When t=0, turn off the current, the corresponding magnetic field will disappear simultaneously. The severe change of the primary magnetic field is then transmitted back to the ore around the return through air and other conductive medium in the underworkings and thus generates the induced current, which will produce the secondary vortex field so that the magnetic field won't disappear immediately[1]. Various TEM research work has been carried out in many enterprises home and abroad, the products of which mainly include 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, as well as TEMHZ75 by High-tech Resources Detecting Instrument Research Institute of CUG, Wuhan, and YCS600-I by Shanxi Geosina Geological Instrument Co., Ltd, together with YCS40(A) of Fujian Huahong Intelligent Technology Co., Ltd. The TEM is not only successfully applied in detecting the water-abundance of the floor rock in the top of the coal seam and the buried water-conducting or water-bearing structure in coalmine driving, but also in water-filling drill and ponding goaf [1-10].

The resolution of the analog-digital converter (ADC) used in current TEM is low, and the sampling interval is fixed as well, so the sampling speed cannot be adaptively controlled according to the signals feature; moreover, the magnification times of the sampling amplifying circuit is small, and the sampling dynamic range is also limited. Furthermore, the transient process of receiving coil in daily use has a serious influence on the early secondary signals processing, thus to cause an inaccurate detecting result in shallow structure. As a whole, given problems such as the large change range of secondary signals, the different degree of attenuation in different periods, and the sampling circuit design as well as the interference from the 50Hz signals, a new receiver with a better performance must be designed.

Received March 22, 2014; Revised April 25, 2014; Accepted May 8, 2014

2. The Design Thought of the Receiver

In order to be suitable for underground environment, the receiver must meet the needs of coalmine security standards, anti-explosion, a small volume and a light weight and so on. In addition, we must focus on the common weaknesses in the current TEM when designing a new one. Because of the delay of primary field disappearance in the receiving process, the secondary field of the receiving coil is not pure, but mingled with some influence from the primary field, that is, the transient process of the receiving coil. Generally speaking, this process is quite short and won't appear in late signals, but still, it can't be ignored owing to its great effects on the early signals. The transient magnetic signal has a large dynamic range, large early signal amplitude, a high attenuation speed and a weak late signal, which require the system to be equipped with a high resolution, a quicker sampling speed and a strong anti-interference performance, as well as a large dynamic range [11-13].

The receiving coil can be generally regarded as LR circuit, thus the transient process is actually the same as LR circuit, that is, $V_1 = Ee^{(-R/L)t} = Ee^{-t/\tau}$, and $\tau = L/R$, t equals to the time constant of LR circuit. The larger L and smaller R will result in the larger t. The gain of receiving coil (L) is often expected to be larger, and the loss of which (R) to be smaller, causing a quite larger t, even reaching a millisecond order of magnitudes. However, sometimes, we want the time constant to be as small as possible to decrease the influence of transient process in an attempt to detect the early signals, which obviously is contradictory [14]. There are two solutions to this problem, one is, inserting a primary amplifier in the receiving coil and decreasing both turns and area of the coil, along with the whole recorded primary field data from the attenuation process of the transmitting current after turn-off to subtract the influence of transient process in the received signals data processing; another is, using the variable stored program control receiving antenna to remove that influence.

The change range of the secondary field signals detected by the receiving coil is fairly large, from early V level to late mV level, so we need to adopt the programmable amplifying circuit when designing the amplifying circuit and choose different amplifying scales for the data of each time period. Besides, based on the signal attenuation speed of each period, the sampling intervals should be variable, and in order to erase the interference from the 50Hz signals in the selected signals, the self-adaptive filtering method is a must.

3. The Hardware Design of the Receiver

According to the design logic, the hardware structure of the receiver is shown as Figure 1, mainly including the controller, which is a 32-bit RSIC embedded processor of Nios II series, used to finish all the order control operation of the receiver; the variable stored program control receiving coil also has optional receiving ways, one is the common way while another is the program controlled way; the prefixed amplifying circuit and the programmable amplifying circuit are both gain-controllable; the analog-digital (AD) sampling circuit consists of the high performance AD chip; the receiving coil state monitoring circuit is for detecting the state of itself so as to give the user a comprehensive understanding of the real time status of the receiving coil.

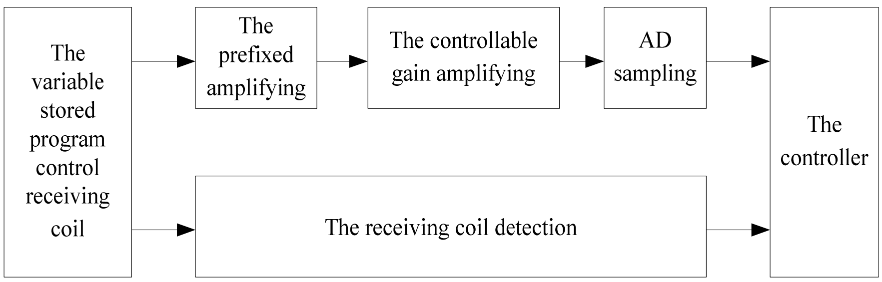

Figure 1. Structure Chart of Receiver

3.1. The Variable Stored Program Control Circuit of Receiving Coil

The structure of the receiving coil circuit is variable stored program control, shown in Figure 2. A and B are two coils with completely the same parameters, A+ and A-, B+ and B- are two output ends of A and B respectively, KS1, KS2, KS3, KS4, KS5 and KS6 are 6 switches. The coil has two working states, of which one is the non-stored program control state, known as a common coil, what needs to be done is just using a short circuit between the pin of 2 and 3, meanwhile, turning off KS1, KS2, KS3, KS4 and KS6 and turning on KS5 so as to form a single tandem coil between A and B; another is the stored program controlled state, which changes the connection state of A and B through different switch patterns of the stored program control in the receiving process in order to shorten the transient process of the receiving coil.

The working principle of the stored program control coil is: when KS1, KS2, KS3 and KS5 are all turned on, meanwhile KS4 and KS6 are turned off, A and B is in reverse connection, the signals output from A and B will offset with each other, as a result, the total output of the receiving coil thus becomes “0”. On the contrary, when KS1, KS2, KS3 and KS5 are turned off with KS4, KS6 turned on, A and B is, therefore, in straight polarity, consequently, the total output is the sum of the induced voltage of both A and B [15].

Despite the fact that the total output of the receiving coil is 0, A, KS1, resistance RK1 and B, KS2, resistance RK2 can still form two current loops, both with the transient process, and the transformation happens before the transient process disappears, when its influence still works. As for RK1 and RK2 in fig. 6, they are both of great significance, for if they are too small, the transient process will be too long, on the other hand, if they are too big to disconnect with each other, there will be a LC oscillator circuit. Actually, according to the experiment, for different initial sampling moment, the positive and negative oscillation does exist [14].

The six switches are comprised of a low on-resistance with ±5V voltage, four single-pole-single-throw (SPST) analog switches, respectively from MAX4677 and MAX4678. The working principle of each switch is: when in a low level, MAX4677 will be turned on, while in a high level, it will be turned off. MAX4678 is just the opposite working principle. Therefore, MAX4677 equals to KS1, KS2, KS3 and KS5, while MAX4678 replaces KS4 and KS6, altogether to complete the control of the stored program control coil only through a single control mouth of the processor.

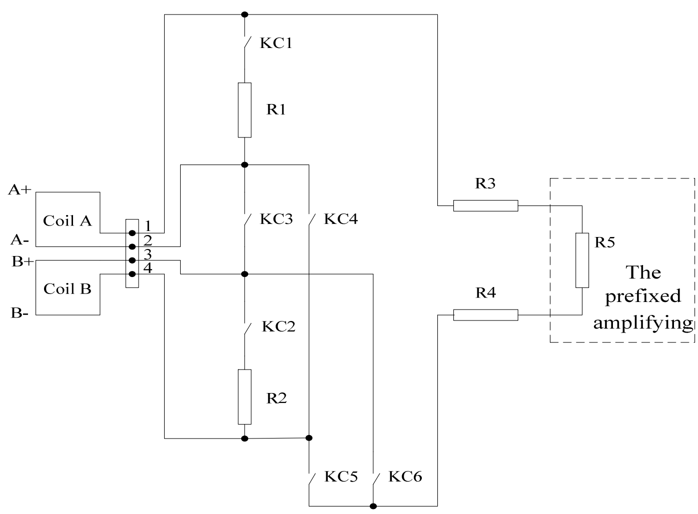

Figure 2. Structure Chart of Variable Stored Program Control Receiving Coil

3.2. The Detection Circuit of Receiving Coil

This circuit is responsible for the state detection of the receiving coil, including the short circuit, the open circuit and the resistance value of the coil. The structure is shown in Figure 3, in which IO4 is stalled to control the TX-S Panasonic relay so that the receiving coil can be switched to the detection circuit from the signal receiving circuit.

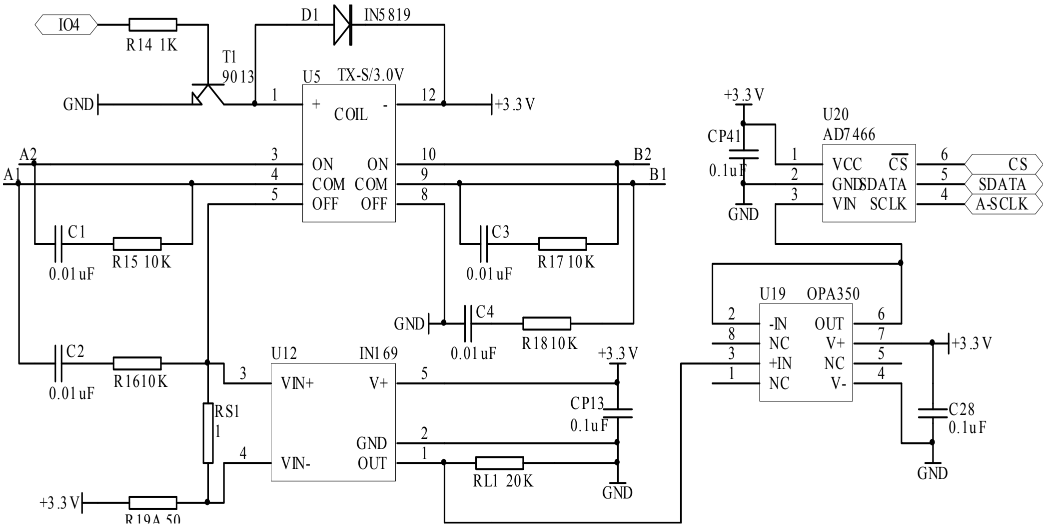

Figure 3. Detection Circuit of Receiving Coil

Also, after detecting the resistance RS1 by the current in the receiving coil, the current signal can be transformed into the voltage signal and then be transferred to the ADC for analog-digital conversion. If the collected data approaches to 0, there is an open circuit in the receiving coil, whereas, if the data turns to be the largest, there is a short circuit. However, the coil resistance can be calculated when the data is a medium value.

3.3. The Signal Amplifying Circuit

A reasonable and suitable signal amplifying circuit is of great significance for the collection of the receiving signal. As it is illustrated before, when the receiving coil is in a transient process, we can only decrease the inductance L or increase the resistance R in order to decrease the time constant τ, considering it's inappropriate to increase R, we choose to decrease L, that is, to decrease the turns and area of the receiving coil, even it will cause the decrease of the gain from the receiving coil, we can later make some compensation by using of a prefixed amplifying circuit. The change range of the transient electromagnetic receiving signal is quite large, from mV to V, and the early, medium as well as late signals of the secondary field are all different in terms of their attenuation speeds and amplitudes, which thus requires the amplifying circuit with a controllable amplifying scale to meet the sampling needs for different circumstances.

Figure 4 is the structure of the prefixed amplifying circuit and the programmable amplifying circuit. The former is the precise and low power consumption INA128 instrument amplifier, which uses IO2 and IO3 mouths of the processor to control the multi-way switch ADG604, and the different resistance R5, R6, R7, and R8 to choose various amplifying scale. Besides, the on resistance value of ADG604 is 85Ω, and there are all together four types of amplifying scale, namely, 1, 10, 100 and 1000. The operational amplifier of the later is OP4227, owing to the low speed of the amplifier in gain transformation, which cannot reach our sampling demands, we need to adopt several operational amplifier in parallel and set their own gain before, thus to switch over the gain by the high-speed analog switch ADG604 to realize the dynamic process of the signal amplitude of the receiving coil. Similarly, the amplifying scale includes: 100, 10, 1 and 0.1.

The dynamic process of the signal receiving can be divided into three stages: the early, medium and late stage. In the early stage, the attenuation speed and the signal amplitude are the largest; in the late stage, they are the smallest; as for the medium stage, the two are between those of the early and late stage [16]. Hence, during the dynamic process, both the amplifying scale and the sampling interval are controllable, which can be categorized into three classes according to the change characteristics of the secondary field signal. As it's shown in Table 1, the amplifying scale and sampling interval need to be matched in the three stages. Altogether there are four groups, if we choose the first one, the amplifying scale and sampling interval in the early, medium and late stage will respectively be 0.1, 1, 10 and 10μs, 20μs, 30μs, the rest three groups are of the same logic.

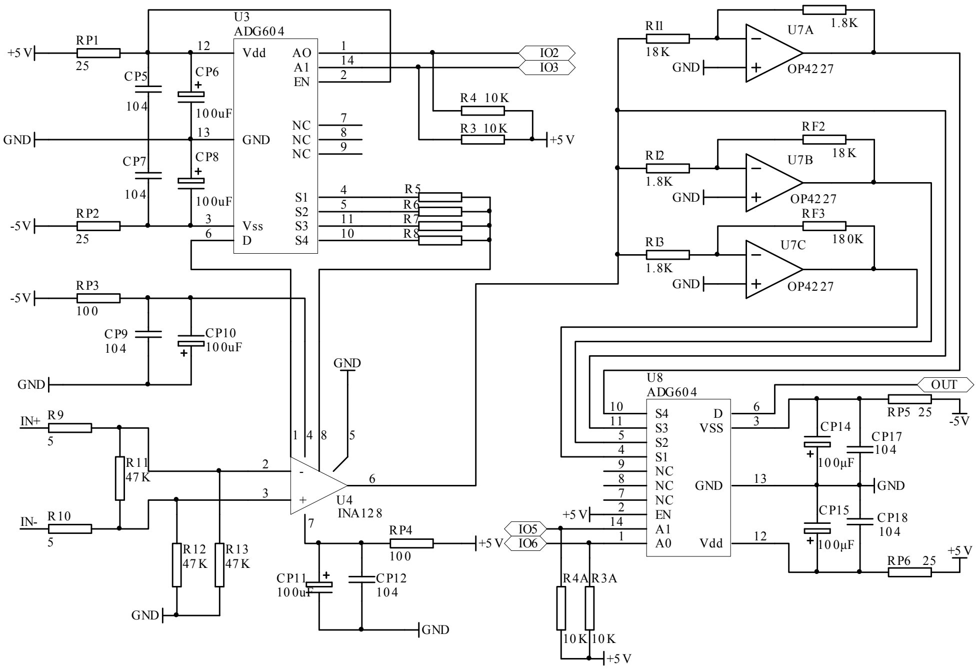

Figure 4. Preamplifier Circuit and Programmable Amplifier Circuit

Table 1. Early, Medium and Late Stage Parameter Selection

Stage \ Group / Amplifying scale	The first group	The second group	The third group	The fourth group	Sampling interval
Early stage	0.1	1	10	100	10μs
Medium stage	1	10	100	1000	20μs
Late stage	10	100	1000	10000	30μs

3.4. The Analog-To-Digital Conversion Circuit

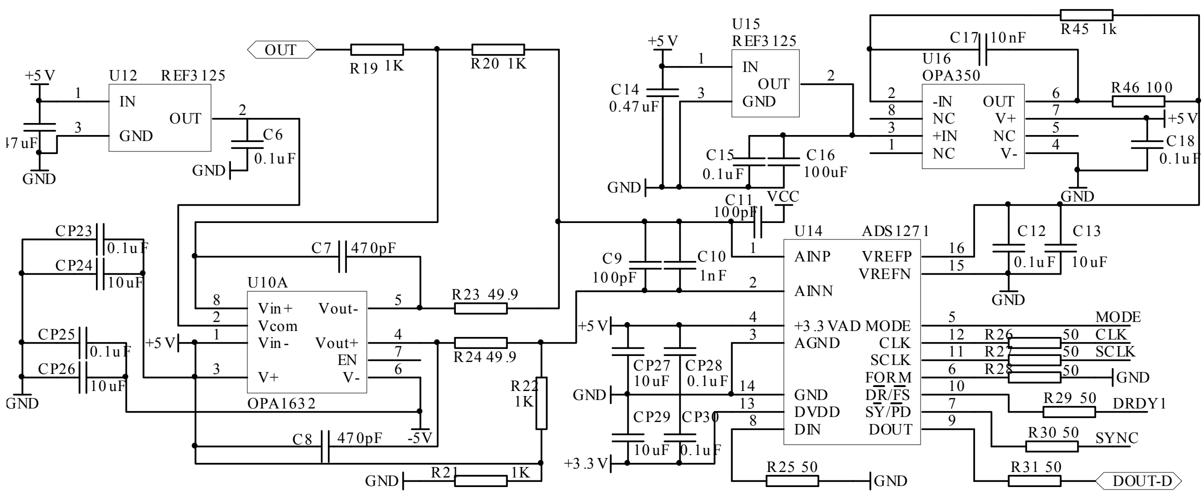

Figure 5. Analog-to-digital Conversion Circuit

The analog-to-digital conversion circuit is shown in Figure 5. As we can see, the circuit 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 jointly provided by chip REF3125 and operational amplifier OPA350, besides, we install a tantalum capacitor of 10μF and another ceramic capacitor of 0.1μF in parallel within the input end REFP and REFN. The operational amplifier OPA1632 is used in the analog input end, and a 1nF capacitance is applied between the input end AINP and AINN in parallel as well, thus each analog input end can has a 100pF capacitance with the ground to keep the performance of AC [17]. The OUT signal comes from the output of the programmable amplifying circuit, shown in Figure 4. Also, the pin of the switching control has the MODE for choosing the working mode of AD; CLK and SCLK represent for the input of the master clock and the serial clock; DOUT-D means the date output; SYNC is the synchronizing signal for starting the signal sampling in the receiving coil and ensuring the sampling synchronization with that of the transmitter current signal after turn-off.

4. The Contrast and Conclusion of the Test Results

After having collected the same signal through the newly designed receiver and other transient electromagnetic receiver, the result is shown in Figure 6, Figure (a) comes from other receiver, while Figure (b) is from our newly designed receiver, both are the attenuation curve of the secondary field signal. It turns out that the sampling site of new one is much denser, and the data is much larger, presenting a regular attenuation curve with a better data consistency, which is definitely better for late data processing.

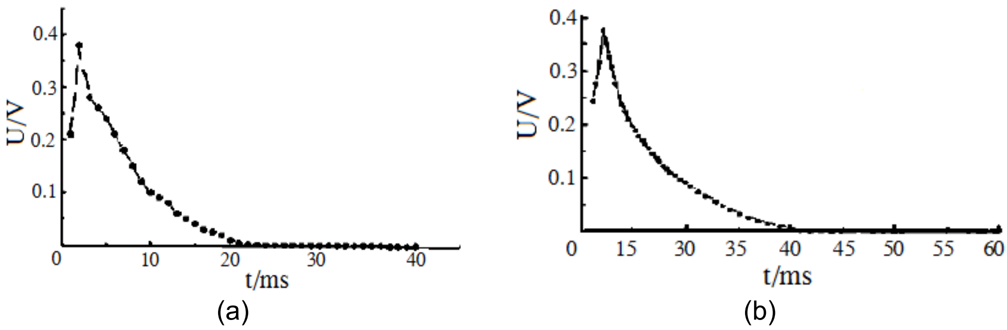

Figure 6. Test Results Contrast

The receiving coil of the newly designed receiver is smaller in volume, thus more suitable for the narrow space in the mine. In addition, for removing the influence of signal gain because of the small volume and the transient process of the receiving coil on data collection, we respectively adopt the prefixed amplifying circuit and the variable stored program control coil. For other aspects, we use the programmable amplifying circuit with multi-amplifying scale to meet the needs of the large change range of the transient electromagnetic secondary field signal, furthermore, the different sampling intervals are applied to distinguish the sampling in the early, medium and late stages to satisfy the various attenuation speed needs in each stage; for the sampling data processing, we use the software self-adaptive filtering algorithm to effectively filter out the 50Hz power line interference. All in all, the new receiver is not only with a smaller volume but also a better performance.

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