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Study on Coding and Controlling Technologies of Wireless Measurement While Drilling System

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Study on Coding and Controlling Technologies of Wireless Measurement While Drilling System

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Abstract. In the drilling process, the purpose of using the wireless measurement while drilling system is to transmit the data measured by instrument in the hole to the ground in real time, the mud is used as the medium for transmitting data, the coding and controlling technologies are the core of the system. Firstly, according to the encoding rules, the data are encoded by the optimized combined coding technique and then are transmitted in a time-frame manner, each time frame is divided into *n* time-slots; secondly, the singlechip microcomputer is used to control pulse signal generator generate *m* pulses in different time-slots, the different data can be represented; thirdly, on the ground, the technical staff use pressure sensor to collect pulse signals, analyze them, and restore the data to provide a basis for drilling. The wireless measurement while drilling system based on the optimized combination of coding and controlling technologies has been used in the industrial test of ground directional drilling grouting for water hazard regional control of coal seam floor in Xin'an Coal Mine, the results show that the technologies have strong anti-interference ability, high measurement accuracy, simple operation and easy implementation.

1. Introduction

Measurement while drilling (MWD) is a process that the measurement tools installed in the bottom-hole drill assembly near 4the bit in a normal drilling state are used to measure the relevant information near the drill bit, and the information is transmitted to the ground through the information transmission channel and analysed [1]. Wireless measurement while drilling can measure parameters such as weight-on-bit, torque, well inclination and azimuth in real time during drilling operations, which is beneficial to control well trajectory and achieve directional drilling [2]. There are four kinds of information transmission modes for wireless measurement while drilling, such as drilling fluid pulse, electromagnetic wave, sound wave and optical fiber. Among them, the drilling fluid (also known as mud) pulse and electromagnetic wave modes have been applied to production practice, and the vast majority of wireless measurement while drilling systems utilize the drilling fluid pulse transmission mode [3].

In recent years, directional drilling technology has been widely used in coal mine gas drainage, water damage prevention, stratum reconstruction and other aspects [4-12]. At present, there are not many researches on the basic theory of the mechanism of mud pulse generators in China. Many of them rely on the introduction of foreign related products or technical services provided by foreign companies. Compared with foreign researches, they are still relatively backward. In particular, the study of continuous wave mud pulse generators is almost blank [13]. Imported foreign wireless measurement while drilling systems are expensive, inconvenient to repair and use and urgently need to be localized.

This paper achieved precise control of the directional drilling trajectory, through the research on coding and control technology of wireless measurement while drilling system based on time-frame and time slot technology and equipped with the self-developed TD-MWD1 wireless measurement while drilling measurement system.

2. Coding

The core of the wireless measurement while drilling system is the coding and control technology. Once the core is mastered, the system is easy to achieve. The wireless measurement while drilling system consists of ground equipment and downhole equipment. The ground equipment includes data acquisition interface, pressure sensor, drill display, computer and software. The downhole instrument consists of main control, inclinometer probe, battery and pulse signal generator.

The downhole instrument collects data such as the inclination angle, azimuth angle and tool face angle of the drill hole, and controls the switch of the pulse signal generator valve according to a certain coding rule, so that the mud pressure in the drill pipe changes regularly to form a mud pulse signal, which then is transmitted to the ground via the mud in the drill pipe and detected by a pressure sensor installed on the mud pipeline. The received mud pulse signal is decoded by the software to restore the data such as inclination angle, azimuth angle and tool face angle.

In order make the mud to generate a pulse signal, a positive pulse signal generator, a negative pulse signal generator, and a continuous wave pulse signal generator can be used. The positive pulse signal generator and the negative pulse signal generator use a combined coding code, while the continuous wave pulse signal generator uses phase coding.

At present, in the widely used wireless inclinometer while drilling, there are three commonly used probe data coding modes: pulse position modulation coding, Manchester coding and optimized combination coding. Pulse position modulation coding is a method of transmitting stream data at time intervals. Usually, one pulse represents one hexadecimal number, and its specific value depends on its position, that is, depends on its time interval from the previous pulse. The rule is: at the end of the previous pulse, after two times the standard pulse width recovery time, one pulse appears, which means "0"; If it appears when one standard pulse width is delayed, it represents "1"; By analogy, if fifteen pulse widths are delayed and a pulse occurs, then this pulse represents "F". With this coding method, the standard pulse width T needs to be determined first; secondly, the number of pulses representing each trajectory parameter is determined. For example, the angle of inclination is represented by 3 pulses, and the tool face angle is represented by two pulses. Finally, according to the conversion formula, the hexadecimal number transmitted to the ground is converted into a real physical measurement value. The disadvantage of this coding method is that the transmission time increases as the measured values enlarge [14].

Manchester code (also known as split-phase code, bi-directional code) is a code that uses level jump to represent 1 or 0, whose change rule is very simple. Each element is represented by two different phase level signals, that is a square wave of one cycle, but the phases of 0 and 1 are exactly opposite. Manchester coding, also known as phase coding, is a synchronous clock coding technique used by the physical layer to code the clock and data of a synchronous bit stream [15]. In the coding, the synchronous clock signal is hidden in each bit transition of the data waveform, and the intermediate transition serves as both a clock signal and a data signal. A high-to-low transition indicates "1" and a low-to-high transition indicates "0". Manchester coding provides a simple way to binary sequences without long periods of cycle and conversion levels, thereby preventing loss of clock synchronization or analog link bit errors from low frequency shifts in the case of poor compensation. When binary data is transmitted through this coded form, they are not sent as a logical 1 or 0 of the sequence [14].

The coding mode of optimized combined coding is called componential coding. In this coding, data is transmitted in a time-frame manner. The time frame refers to dividing a certain time into n time slots, and the program control pulse signal generator generates m pulses at different positions of the specified time frame. Corresponding to one different binary number (according to a predetermined coding rule), C_n^m data can be coded [14].

The advantage of optimized combined coding is that after the binary digits of the measurement data are determined, the length of time for transmitting the data does not change with the variation of the binary value, which is convenient for detecting the signal pulse and deciding whether there is a lose; At the same time, the power consumption is relatively determined, and it is easy to save electricity[16].

These three data coding modes have been successfully applied in the wireless inclinometer while drilling [14].

The optimized combined coding is simple and easy to implement.

The combination is to select m ($m \le n$) elements from n different elements to form a group, regardless of their order. The combination number is the number of all combinations of m elements taken from n different elements. The calculation formula is as follows:

$$C_n^m = \frac{n!}{(n-m)!m!}$$

If the data precision equivalent to 10-bit A/D is selected (i.e. 2^{10}=1024), in order to ensure the accuracy of the data, it is necessary to select a combination whose combination number is greater than 1024. The n represents time slots, and the m represents the number of pulses. If n=20, m=3, the combination number is 1140; if n=15, m=4, the combination number is 1365; if n=13, m=5, the combination number is 1287. As can be seen from the above analysis, in the case where the accuracy of the data is satisfied, the fewer the number of pulses used, the more time slots required, that is, the longer the time to transmit data. Conversely, the more pulses used, the less time slots required, that is, the shorter the time to transmit data. At the meantime, the more pulses used, the more power the instrument consumes, and the battery life is reduced when the instrument is powered by the battery. Therefore, it is necessary to consider and select the optimal combination, such as n=15 and m=4.

The pulse width used for data coding can be based on 1 second. Generally, it is the same as the time slot and can be increased or decreased, so that the waveform generated by the mud is not deformed, and the data can be correctly transmitted.

Since the pulse signal generator generates a pulse signal relying on the pressure variation of the mud by mechanical movement, limited by the performance of the pulse signal generator, there must be a certain number of time slots as a separation between each pulse, otherwise the generated pulse waveform will be deformed and will not correctly reflect the data coding, affecting the identification of the data. For comprehensive consideration, three time slots are selected as the separation, that is, one pulse plus three time slots. For example, four pulses are used to represent the datum "0", as shown in Figure 1.

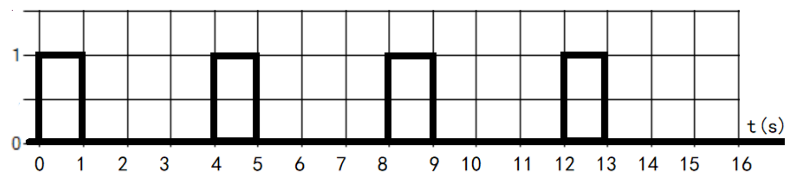

Figure 1. Data pulse

In the actual work process, it is required to transmit a variety of data such as well inclination, orientation, tool surface, temperature, voltage, etc., which needs to be distinguished. Twice the data pulse width is selected as the mark pulse of the data transmission, or as the synchronization pulse, followed by two marker pulses to distinguish the type of data transmitted. There are four combinations, and if it is not enough, the number of marker pulses can be increased to obtain more choices to satisfy the actual application requirement. The marker pulse is shown as Figure 2.

The collected sensor data such as well inclination, orientation, tool surface, temperature, voltage, etc. are sequenced as needed. And according to the sequence of the synchronization pulse signal, the data type marker pulse signal and the data pulse signal, the data to be transmitted is assembled into a series of codes in accordance with the rule of optimized combined coding, stored in an array, and sent out one by one by the control program. The action of the pulse signal generator is controlled to produces a series of regular, coded, continuous pulse signals ultimately.

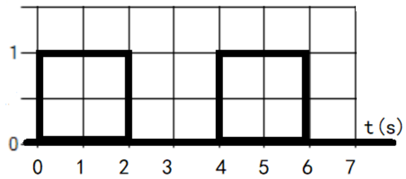

Figure 2. Marker pulse

3. Pulse signals

The pulse signal is generated by a pulse generator controlled by a single-chip microcomputer. The pulse transmitting circuit is designed to control the pulse generator to emit a mud pressure pulse. The logic level of control signal of the pulse generator currently used is 3.3V, same as the logic level of the single-chip microcomputer, which can be driven by the I/O port of the single-chip microcomputer directly [17].

In order to generate the pulse signal, the timer and I/O (input and output) port of the single-chip microcomputer are used to generate the control signal. The timer of the single-chip microcontroller is set to work in the timer interrupt mode, and the specified I/O port is set to work in the output mode. So, the timer will interrupt when the set time is reached, and then the interrupt program is executed to read the codes in the array in order in the program, control the I/O port to open or close, and output a code at a time. After that the interrupt program exits. Later the timer will interrupt again, and that cycle repeats, sending out the codes in the array in order one by one till the end. And then, a series of regular control signals are generated to achieve the purpose of transmitting data.

A series of control signal waveforms generated by the single-chip microcomputer according to the rule of optimized combined coding, are shown in Figure 3.

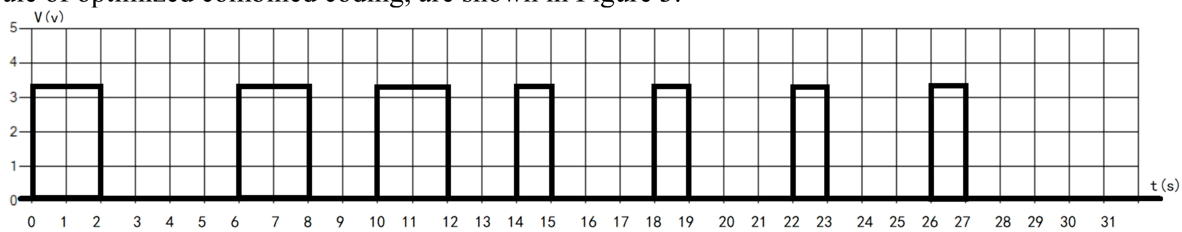

Figure 3. Control signal waveforms

The optimized combined coding mode is based on the time slot, so the accuracy of each time slot is particularly important. Since the timer works in the interrupt mode, the interrupt program is required to be as short as possible to decrease the time taken by the interrupt program to process events, reduce the timing error, and increase the timing accuracy.

The timing accuracy of the timer depends on the crystal oscillator used by the single-chip microcomputer, which can use an internal or an external crystal oscillator. The precision of the internal crystal oscillator is low and not recommended. External crystal oscillators include passive crystal oscillator and active crystal oscillator. It is recommended to use an active, compensated crystal oscillator with good signal quality, high stability, and a timer of high timing accuracy.

The timing accuracy of the control signal is mainly affected by the crystal oscillator, timer, interrupt response program used by the single-chip microcomputer, so it is necessary to optimize the timing accuracy. The oscilloscope can be used to measure and compare the output control signals, and then adjust the parameters to compensate. Repetition can achieve the best. The reduction of the timing error of the control signal can improve the accuracy of the computer software to identify the pulse signals and ensure the accuracy and reliability of the data identification.

The data needs to be continuously transmitted to the ground. When the single-chip microcomputer continuously outputs the control signals, it will generate a cumulative time error, causing an error in the time series of the control signals. Assuming that the frequency stability of the crystal oscillator is ±10ppm, we take 10ppm to calculate, so the program continuously runs for 100000 seconds, one second more than the actuality, resulting in the shift of the control signal waveform, which cannot correctly reflect the original data coding, seriously affecting the accuracy of the control signals and data identification consequently.

In order to reduce the above-mentioned possible effects, after each sequence transmission is completed, the timer is turned off, and after waiting for the data preparation of the next sequence to be completed, the timer is turned on, the timing operation is restarted, and then the control signal is continuously transmitted. In this way, the timer does not work continuously for a long time, and each sequence uses a time base alone. The cumulative deviation of time is limited in each sequence, so that the cumulative deviation of time becomes smaller and the timing is more accurate.

After encoding the data to be transmitted, the pulse signal generator is controlled by the single-chip microcomputer to generate a pulse signal, so that the mud pressure in the drill rod produces corresponding high or low change, which is transmitted to the ground through the drill rod. The pressure sensor is installed on upright tube for conveying mud, it transmits the signal to the data transmission connector, and the connector collects the pressure value of the mud. It is necessary to reflect the process of the mud pressure change as comprehensively as possible, and lay a foundation for computer decoding.

4. Decoding

The computer software reads the mud pressure value collected by the data transmission interface, stores them in the database, performs digital filtering through a mathematical algorithm, filters out the interference signal in the pressure value, restores the pulse signal waveform from the collected pressure value, decodes according to the coding the rules, then analyze the sensor data transmitted from the downhole instrument, such as well inclination, orientation, tool surface, temperature, voltage, etc., and stores them in a database, displays the pulse waveform and data on the computer and sends them to the driller's display, providing a basis for drilling directional personnel and drillers.

The waveform of mud pulse signal generated according to the rule of optimized combination coding is as shown in Figure 4.

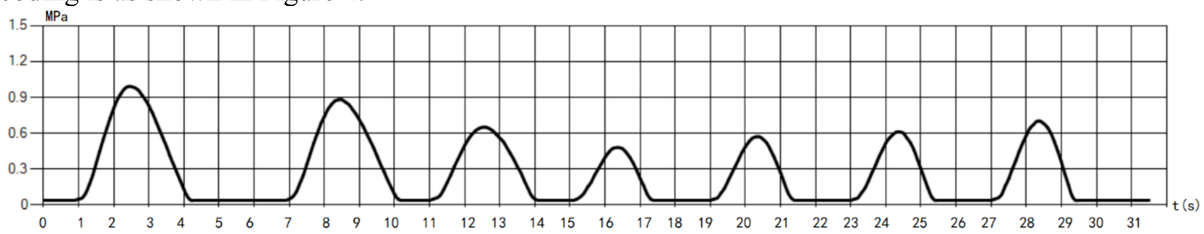

Figure 4. The waveform of mud pulse signal

The waveform of optimized combination coding recovered from the mud pulse signal is shown in figure 5.

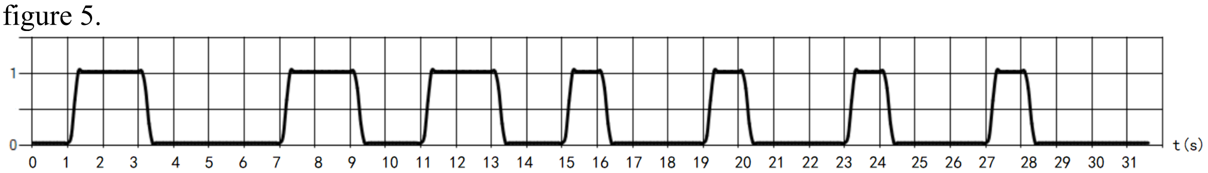

Figure 5. Recovered waveform of optimized combination coding

The change of mud pressure will postpone, mixed with various interference signals, such as the vibration of the mud pump and the reciprocating motion of the piston, the vibration generated by the drill, the drill pipe hitting the well wall, etc., which will affect the change of mud pressure and cause deformation of the pulse signal waveform. Therefore, when designing the algorithm of computer software, it needs to reserve a certain redundancy, improve the fault-tolerant ability, adapt to the complex pulse waveform, accurately analyze the data, and improve the efficiency.

With the utilization of optimized combined coding mode for data transmission, the process of data transmission in software can be observed visually. It can better judge whether the data transmission process is correct, take timely measures to correct errors and avoid unnecessary waste.

At this point, a complete data packet is composed of the synchronous pulse signal, the data type marker pulse signal and the data pulse signal. A series of regular, coded, continuous pulse signals are generated by the pulse signal generator, then become the variation of mud pressure transmitted to the ground through the drill pipe and converted to electric signals through a pressure sensor. The data transmission interface collects the signals of the sensor and transmits them to the computer. The software stores, analyzes and decodes the data, and restores the measurement data such as well inclination, orientation, tool face, temperature, and voltage collected by the downhole instrument, which are shown on the computer and driller display. In this way, the process of transmitting the measured data collected by the downhole instrument to the ground using the mud as the medium is completed, and the function of data transmission of the wireless measurement while drilling system is realized, which provides a basis for drilling and meets the requirement of drilling construction.

5. Engineering application

According to the optimized combined coding and control technology, we have developed the TD-MWD1 wireless measurement while drilling system. The system consists of computer and software, data transmission connector, driller display, pressure sensor, main control, inclinometer probe, pulse signal generator and battery (Figure 6 and Figure 7).

Figure 6. Ground equipment of TD-MWD1 wireless MWD measurement system
1-data transmission connector; 2-driller display; 3-computer; 4-pressure sensor

Figure 7. Downhole instrument of TD-MWD1 wireless MWD measurement system
1-master control; 2-pulse signal generator; 3-inclinometer probe; 4-battery

The system has been put into practical use in the 1-11 grouting hole of water damage area control project of 216 mining area in Xin´an Mine of Jizhong Energy Fengfeng Group Co., Ltd. The project requires to find out whether the 216 mining area has concealed water-conducting structure and block the water passage. The Daqing aquifer is transformed into a water-resisting layer (or poor aquifer), which can block the hydraulic connection between the Damei coal seam floor and the Ordovician limestone, and further improve the integrity of the floor and the ability to block water, thus ensure safe mining the Damei coal seam under pressure.

The designed coordinate of Daqing limestone is: (X: 21423, Y: 13884, Z: -782.6); the final hole coordinate is: (X: 20490.10, Y: 13659.95, Z: -816.04). According to the latest drilling situation of the underground roadway in the mining area 216, in order to avoid the distance between the branch drilling trajectory and the underground roadway being too close and the damage to the roadway or the difficulty of drilling, the designed directional deflecting section of the 1-11 grouting hole is 430 m~ 1175.32 m (segment length of 745.32 m), and the horizontal section is 1175.32 m ~ 2163.90 m (segment length of 988.58 m).

In the actual construction, the deflecting section of the 1-11 grouting hole is directionally drilled from 428 m, with a final hole depth of 1161 m, and the actual drilling quantity in the deflecting section is 733 m; The horizontal section of the 1-11 grouting hole is directionally drilled starting from the final hole (1161m) of the deflecting section, with a final hole depth of 2158 m, and the actual drilling quantity in the horizontal section is 997 m. Figure 8 is the cross-section profile of the actual trajectory of the directional drilling and horizontal section of the 1-11 grouting hole.

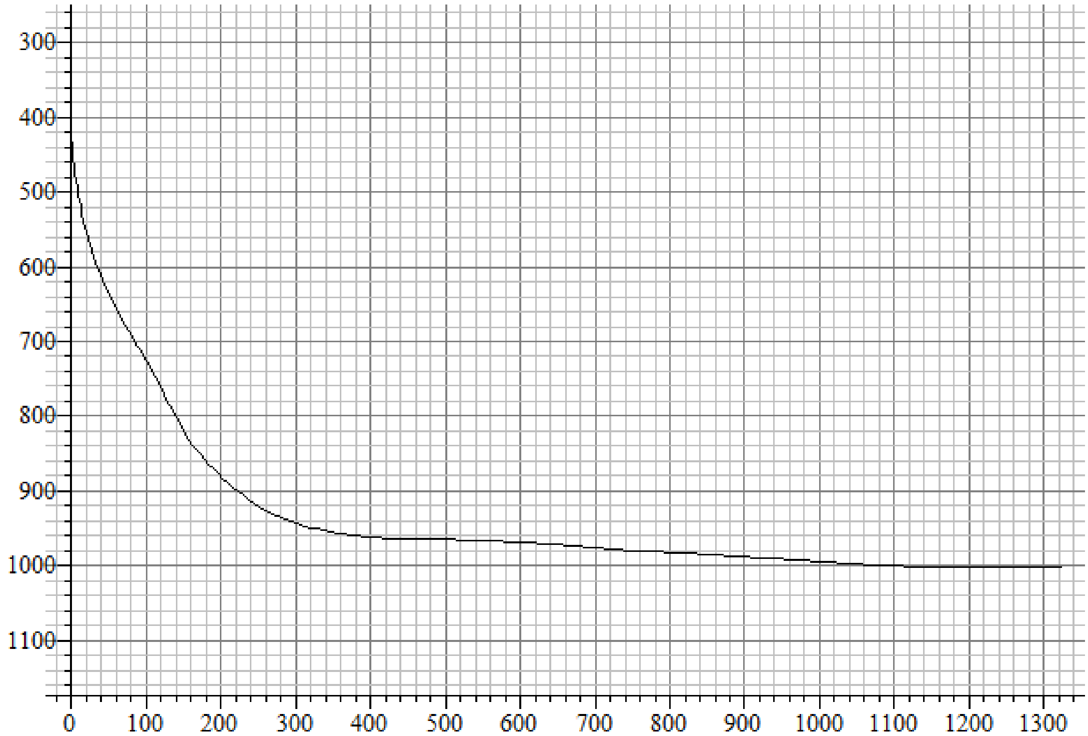

Figure 8. Actual trajectory cross-section profile of directional drilling and horizontal section of 1-11 grouting hole

According to the return rock sample on the hole mouth and the variation of Gamma value of the instrument, the deflecting section of the 1-11 grouting hole enters the Daqing limestone at the hole depth of 1151 m and reaches 10 m of the target layer, which meets the design requirements.

The actual target coordinates of the horizontal section of the drill hole (X: 21437.76, Y: 13882.83) and the designed target coordinates (X: 21423.0, Y: 13884.0) have an absolute deviation of 14.81 m and entered the target point 14.81 m ahead of time. The deviation of the actual trajectory and the designed trajectory plane position is less than $\pm$5m, which met the design requirements. Table 1 is the deviation analysis of the local trajectory plane position of the 1-11 grouting hole.

In the on-site construction, the system has withstood the test of severe working conditions, with stable and reliable data transmission and accurate decoding, which provides guarantee for the drilling of the 1-11 grouting hole, and the drilling task has been successfully completed.

6. Conclusions

(1) Optimized combined coding and control technology is simple and clear, convenient to control, with strong fault tolerance, and easy to achieve. When the data accuracy and the number of pulses used are fixed, the size of the transmitted data does not affect the number of pulses, and it is easy to

estimate the power consumption and the battery consumption, providing a more accurate basis to better control the drilling process, reasonably arrange the drill down and improve the drilling efficiency.

(2) According to the type of data, different data coding precision is selected, and different pulse numbers are used, to optimize the data coding mode, reduce data transmission time, improve data transmission efficiency, reduce battery consumption, increase battery life, decrease the construction cost, and enhance economic benefits.

(3) The precise orientation of drilling can be achieved by reducing the width of the time slots, improving the performance of the pulse generator, and compressing the codes using data compression techniques.

Table 1. Deviation analysis of the local trajectory plane position of the 1-11 grouting hole

Serial number	**Elevation /m**	**Design horizontal coordinate /m**		**Real drilling horizontal coordinate /m**		**Deviation /m**
		X	**Y**	**X**	**Y**	
1	-775.82	21387.70	13878.54	21387.70	13874.44	4.10
2	-778.21	21341.95	13870.55	21341.95	13866.77	3.78
3	-778.95	21296.71	13861.17	21296.71	13858.19	2.98
4	-780.02	21251.44	13850.99	21251.44	13848.09	2.90
5	-781.95	21206.30	13840.40	21206.30	13837.01	3.39
6	-784.25	21161.45	13829.36	21161.45	13825.97	3.39
7	-787.85	21116.57	13818.02	21116.57	13815.87	2.15
8	-791.73	21071.58	13806.51	21071.58	13804.71	1.80
9	-794.58	21026.78	13794.98	21026.78	13793.24	1.74
10	-796.64	20982.21	13783.17	20982.21	13781.18	1.99
11	-799.28	20937.56	13771.36	20937.56	13770.61	0.75
12	-802.08	20893.14	13759.68	20893.14	13759.56	0.11
13	-804.78	20848.74	13747.94	20848.74	13748.34	-0.39
14	-807.54	20803.97	13736.16	20803.97	13736.89	-0.73
15	-810.39	20758.98	13724.76	20758.98	13725.57	-0.81
16	-813.09	20714.55	13713.73	20714.55	13714.38	-0.64
17	-815.04	20669.92	13702.66	20669.92	13703.14	-0.48
18	-816.70	20624.94	13691.71	20624.94	13692.14	-0.43
19	-816.87	20579.89	13681.09	20579.89	13681.38	-0.29
20	-816.08	20535.11	13670.59	20535.11	13670.60	-0.01
21	-816.04	20490.10	13659.95	20490.10	13660.03	-0.09

Acknowledgments

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