

Design of a Kind of Wireless Dynamometer with Low-Power Mode Used in Well Pumping Units

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Abstract. In view of the disadvantages of high fault rate of tie-line and angle dynamometer and high-power consumption of the wireless dynamometer in normal mode, a kind of wireless dynamometer with low-power mode is designed. The dynamometer can measure dynamometer card and transmit data not only according to commands received but also automatically according to the established procedure. A kind of comprehensive filtering algorithm is designed, which can effectively remove high-frequency and peak interference of the acceleration data. The hardware circuit, working mode and filtering algorithm are detailed. Tests of energy consumption and dynamometer card are given. The field application shows that the device has the advantages of high reliability, accurate measurement and low-power consumption.

1. Introduction

The dynamometer card, which is composed of the polish rod load and the corresponding displacement [1], is an important means to analyze and diagnose the working condition of well pumping units. The load can be achieved by the load transducer, and two means are used to measure the displacement. One is tie-line style or angle style, which depends on complex mechanical structure and has high fault rate; another is acceleration style, in which the displacement is obtained indirectly through acceleration and there is no complex mechanical structure to overcome the disadvantage of the former [2]. The dynamometer is gradually realized wireless with the development of the well pumping unit automatic monitoring system [3]. The dynamometer receives the upper computer commands and upload dynamometer card with the wireless module. Therefore, the wireless module must be in RX mode with high-power consumption for a long time, and not be in standby mode with low-power consumption, to reduce the battery life and increase amount of device maintenance.

According to the above problems, a new kind of wireless dynamometer based on the accelerometer is proposed. The dynamometer has normal and low-power modes. The dynamometer can not only operate by receiving the upper computer commands, but also operate automatically to realize the low-power consumption, long battery life and maintenance decrease.

2. Composition of wireless dynamometer

The composition of the wireless dynamometer is shown in figure 1. The dynamometer mainly includes MCU control module, power module, load module, acceleration module, storage module, wireless module and others.



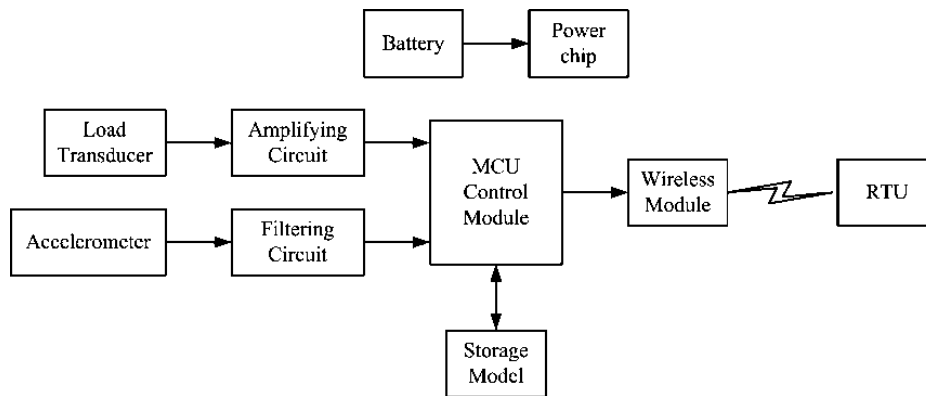


Figure 1. Composition of wireless dynamometer

The device is powered with a battery through power chips, and uses MSP430F1611 as the main control chip. The load signal is gathered with the load transducer and the acceleration signal with the accelerometer, and the signals are sent to MCU through amplifying circuit and filtering circuit. The digital load and acceleration data is got after AD conversion. The dynamometer card data is achieved through digital filter and integral, and sent to RTU with the wireless module. The following will explain the main components.

2.1 Power module

As well pumping units are generally in the wild and wireless dynamometers are fixed at the landing top of the well pumping units, batteries are hard to replace. The device uses the high energy lithium thionyl chloride battery, capacity 19Ah and voltage 3.6V, to ensure reliable power supply.

All the components of the device are powered by the battery through the power chip NCP500 with the voltage rated at 3V. In order to reduce the power consumption, the device uses two NCP500 chips. Chip 1 supply MCU and the wireless module and it is always in the working mode; chip 2 supplies the load module, acceleration module and storage module and it is in the working mode only during the measurement of the dynamometer card and operation of memory, and in standby mode at the rest of time.

2.2 Load module

The device uses load transducer to measure the load of the sucker rod string [4]. The transducer is rated at 0-150kN with the output rated at 0-4.5mV. The output voltage is low, so the signal should be amplified before sent to MCU. The integrated single supply instrumentation amplifier AD623 is used as the amplifier chip. The load acquisition circuit is shown in figure 2 [5].

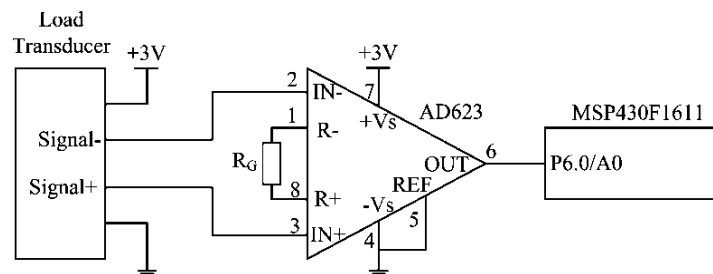


Figure 2. Load acquisition circuit

The input signal of AD623, u_c , is the difference between $IN+$ and $IN-$, and the output at pin 6 is [6]:

$$u_o = \left(1 + \frac{100k\Omega}{R_G}\right)u_c \quad (1)$$

R_G is a precise resistor of 400Ω to amplify the input signal by 251 times, and the output signal of the load transducer is amplified from 0-4.5mV to 0-1.1295V. The signal is sent to pin P6.0/A0 of MSP430 after amplified.

2.3 Acceleration module

The accelerometer of the device is ADXL103 with measurement range $\pm 1.7g$ and its low-pass filter bandwidth can be selected with capacitor placed at the output pin. The acceleration acquisition circuit is shown in figure 3 [7].

ADXL103 is powered with 3V, and the output sensitivity is 560mV/g. The filter capacitor of $10\mu F$ is added to Xout pin to set the bandwidth of 0.5Hz. The vertical acceleration of the landing top of the well pumping unit is measured by ADXL103 and sent to P6.1/A1 pin of MSP430 after filtered.

2.4 Wireless module

nRF905 [8] is used in the device, and its connection with MCU is shown in figure 4.

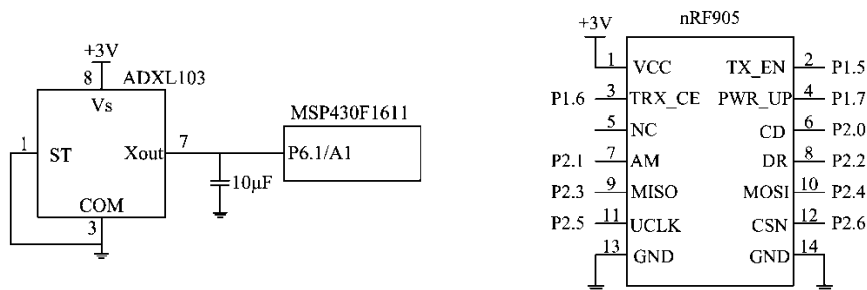


Figure 3. Acceleration acquisition circuit **Figure 4.** nRF905 connection graph

When a valid package is received, nRF905 removes the preamble, address and CRC bits, and the Data Ready (DR) pin is set high. Thus MSP430 P2.2 pin connected with DR is configured to be an interrupt on a rising edge. MSP430 is in the low-power mode LPM4 when waiting for commands from RTU, and when nRF905 receives commands from RTU, DR pin is set high and MSP430 is woken up by the interrupt.

3. Working mode of wireless dynamometer

The wireless dynamometer has two working modes, normal mode and low-power mode.

3.1 Normal mode

When commands from RTU are not received, the dynamometer is in waiting state, in which nRF905 is in RX mode, MSP430 in low-power mode and NCP500 chip 2 in standby mode. RTU sends the dynamometer card measuring command to the dynamometer at regular intervals. When the command is received, MSP430 is woken up from the low-power mode, and NCP500 chip 2 enters the working mode, and the dynamometer card begins to be measured. After the dynamometer card is measured, NCP500 chip 2 returns to the standby mode, and nRF905 to TX mode and the dynamometer card is sent to RTU. After transmitting, nRF905 returns to RX mode and MSP430 enters the low-power mode.

In this mode, the wireless dynamometer receives the RTU commands passively, and doesn't measure and send dynamometer cards actively. It's a common mode, in which one RTU can communicate with multiple dynamometers. But in this mode the wireless module is in RX mode with high-power consumption for a long period of time, and the battery life is shortened.

3.2 Low-power mode

The device can work in the low-power mode in order to reduce power consumption and prolong the battery life. In this mode, the wireless dynamometer measures the dynamometer card automatically at set intervals. nRF905 is in standby mode before the measurement is finished; nRF905 enters TX mode

after the measurement and transmits the dynamometer card to RTU. After transmitting, nRF905 is set to RX mode for 5 minutes, and during the period the dynamometer can receive the RTU commands to change working mode or the interval and perform other operations. After 5 minutes, nRF905 returns to standby mode and stays in this mode until another measurement is finished.

The dynamometer card is only measured hourly or half-hourly, so the dynamometer is in idle mode and nRF905 in standby mode for most of the time, and power chip 2 is only set to the working mode when the dynamometer card is being measured. Thus the consumption is reduced greatly. But this mode can only be applied to the condition where there are only one RTU and one wireless dynamometer to avoid multiple wireless dynamometers sending data to RTU at the same time.

4. Filtering of acceleration data

The displacement of the dynamometer card can be achieved by the quadratic integral for acceleration data [9]. The acceleration data contains much interference because of mechanical vibration and self-reason of the accelerometer. The direct integral for the acceleration data magnifies the inference and leads to a big error in the displacement calculation. So the acceleration data must be filtered before the integral. A comprehensive filtering algorithm is proposed to remove the interference in the acceleration data.

The algorithm firstly removes the high-frequency noise with moving average filtering [10], and then calculates a threshold value automatically, with which the peak interference is removed. The algorithm includes the following steps.

(1) The acceleration data is sampled and stored in array X , including $X(0), X(1), \dots, X(N-1)$.

(2) The acceleration data is processed with seven-point moving average filtering twice to reduce the high-frequency noise. Compared with other filtering algorithm, the seven-point moving average filtering has advantage in filtering effect and saving system resources. The seven-point moving average filtering equation is:

$$X(i) = \frac{X(i-3) + X(i-2) + X(i-1) + X(i) + X(i+1) + X(i+2) + X(i+3)}{7} \quad 3 \leq i \leq N-4 \quad (2)$$

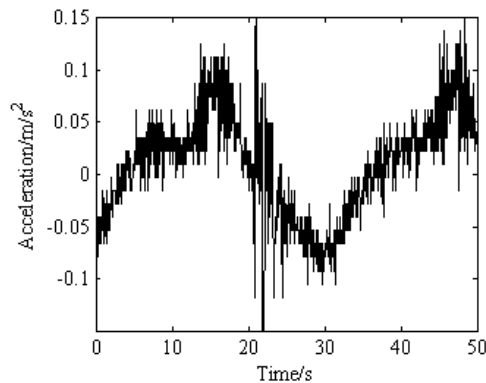
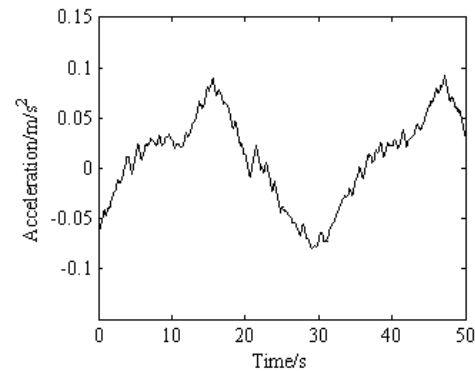
(3) A threshold value is calculated according to the filtered acceleration data, and the equation is:

$$T = \frac{\sum_{i=4}^{N-4} |X(i) - X(i+1)|}{N-7} \quad (3)$$

(4) The peak interference is removed from the accelerate data with the threshold value, and calculation steps are as follows:

A constant k is selected and the difference of two adjacent points is calculated, $D = X(i) - X(i+1)$, $3 \leq i \leq N-5$. If $|D| \leq k * T$, $X(i+1)$ remains unchanged; if $|D| > k * T$, $X(i+1) = X(i) - k * T$ when $D > 0$, and $X(i+1) = X(i) + k * T$ when $D < 0$.

Figure 5 and figure 6 are the contrast of the acceleration data before and after filtering. The horizontal axis shows the sampling time, and the vertical axis shows the acceleration data. The contrast indicates that the filtered acceleration data is of relative smooth variation and less interference.

**Figure 5.** Acceleration data before filtering**Figure 6.** Acceleration data after filtering

The period is judged with the comparison of extreme points, and the displacement is calculated with quadratic integral.

5. Test analysis

5.1 Power consumption test

The supply current of the battery in different working mode is shown in table 1.

Table 1. Supply current of dynamometer battery

Working Mode		Normal Mode			Low-power Mode		
Working State	Measuring	Transmitting	Awaiting Commands	Measuring	Transmitting	Awaiting Commands	Idle State
Current/mA	18.05	14.6	13.54	5.97	14.6	15.75	3.72

It's assumed that the dynamometer card is measured hourly, and the consumption and battery life in different working mode are analyzed as follows.

(1) Normal mode

In this mode, measuring a dynamometer card takes about 240s, transmitting a dynamometer card about 2s, and awaiting commands about 3600-240-2=3358s. The total power consumption of an hour is about 49828.52mA s calculated according to table 1. The battery capacity is 19Ah, and the battery life is:

$$19 \times 1000 \times 3600 \text{ mA s} / 49828.52 \text{ mA s/h} \approx 1372.7 \text{ h} \approx 57 \text{ d} \quad (4)$$

So the device can continuously run for about 2 months powered by the battery in this mode.

(2) Low-power mode

In this mode, the time of measuring and transmitting is the same to the normal mode, and awaiting commands takes about 300s, the idle time about 3600-240-2-300=3058s. The total power consumption of an hour is about 17562.76mA s calculated according to table 1.

In this mode the battery life is:

$$19 \times 1000 \times 3600 \text{ mA s} / 17562.76 \text{ mA s/h} \approx 3894.6 \text{ h} \approx 162 \text{ d} \quad (5)$$

So the device can continuously run for about 5 months powered by the battery in this mode.

The actual battery life is similar to the above calculated results. Through the analysis, the low-power mode can reduce power consumption greatly and prolong the battery life.

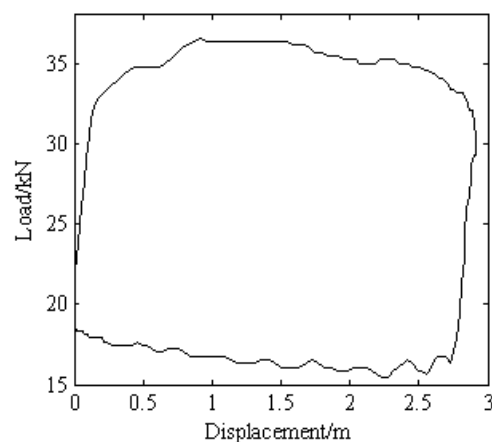
5.2 Dynamometer card test

The dynamometer is fixed and tested at multiple well pumping units in Huabei Oilfield, and table 2 shows the contrast between the measured and real value of 3 well pumping units.

Table 2. Measurement data of dynamometer

Well Pumping unit		RXJ8	Ren264	Ren60-1
Stroke Frequency/min ⁻¹	Measured Value	6.7	3.9	1.8
	Real Value	6.7	4.0	1.8
Stroke/m	Measured Value	3.03	2.91	2.80
	Real Value	3.06	3.01	2.72
Load Range/kN	Measured Value	24.82~56.92	15.43~36.64	49.31~75.74
	Real Value	25.24~55.25	15.51~35.43	50.65~76.75

It can be seen that measured values of stroke frequency, stroke and load are accurate, close to the real value. Figure 7 is the measured dynamometer card of Ren264.

**Figure 7.** Dynamometer card of Ren264 measured by dynamometer

The test indicates that the dynamometer can accurately measure the dynamometer card of well pumping units with the stroke 2-5m and stroke frequency 1-7, and correctly transmit the dynamometer card to RTU. The dynamometer has stable operation and good performance.

6. Conclusion

The wireless dynamometer researched in this paper calculates the displacement with the quadratic integral for acceleration data, transmits the dynamometer card to RTU with the wireless module, and has normal and low-power mode for difference conditions to prolong the battery life, and the designed comprehensive filtering algorithm can effectively remove the high-frequency and peak interference. The results of field measurement show that the device is reliable and accurate and has high practical value.

7. References

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