

Ershi Qi
Jiang Shen
Runliang Dou *Editors*

The 19th International Conference on Industrial Engineering and Engineering Management

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Chapter 1

A New Waveform Design for Phase-Coded Quasi-CW Radar System

Wei-gui Zeng, Ying-feng Sun, and Ming-gang Liu

Abstract In this paper, we analyze the echo eclipse problem of phase-coded quasi-continuous wave (quasi-CW) radar using the echo eclipse ratio function and main lobe to side lobe ratio. And then we propose a waveform design method based on long short codes and synchronous alternation of carrier frequency. This method can not only solve the severe eclipse problem of short range target and simultaneously detect the whole range, but also increase the signal complexity and decrease the probability of interception. The simulation results show that the performance of phase coded quasi-CW radar can be effectively improved using the proposed waveform design method.

Keywords Echo eclipse • Long code • Phase-coded • Quasi-CW • Short code • Waveform design

1.1 Introduction

In the high-tech local war, battlefield situation awareness becomes more and more important, and radar is a key sensor which is a real time, fast and accurate access to the information of battlefield situation. However, along with the fast development of electronic technologies, the interception of radar signal, jamming, anti-radiation, and other techniques are increasingly diversified and becoming more and more effective. As a result, the countermeasure environment of radar is becoming more and more complicated. Low probability of interception (LPI) radar is a sensor of this kind that can adapt to complex countermeasure environment very well. LPI radar is a special radar system which owns special signal waveform, special antennas,

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controlled power, and low detected probability. At present, LPI radar system is continuous wave (CW) radar system or quasi-continuous wave (quasi-CW) radar system in most case (Zhang 2003; Liu et al. 2001; Sanmartin et al. 2000). CW radar has many excellent properties such as accurate velocity measurement, small size, and high mobility. However, the leakage of emission signal is very serious in CW radar. In order to avoid the leakage of transceiver, quasi-CW radar was introduced (Khan and Mitchel 1991; Gu et al. 1998; Yang et al. 2004). Quasi-CW radar is also called as interrupted continuous wave radar whose duty cycle is close to 0.5. Quasi-CW radar has low probability of interception and high transceiver isolation. Quasi-CW radar has a lower peak power and is more compatible with solid-state transmitter. Though quasi-CW radar has high transceiver isolation to avoid the leakage of emission signal, the high duty cycle of emission signal brings severe echo eclipse in some ranges. Because of echo eclipse problem, the main lobe level of echoes which originally has strongly self-correlation is decreased and the side lobe level is becoming relatively high, which has adverse effect on target detection. Therefore, solving the echo eclipse problem of quasi-CW radar system is becoming imperative (Yuan 2007; Wang et al. 2011). In this paper, the echo eclipse problem is studied from the perspective of waveform design, and a phase-coded quasi-CW waveform design method based on combination of long code with short code and synchronous CF alternation is proposed, which can solve the eclipse problem very well.

1.2 The Echo Eclipse Problem of Phase-Coded Quasi-CW Radar System

The signal of phase-coded quasi-CW has large time-bandwidth product, and the duty cycle is close to 50 % (Gao and Tian 2004). However, high duty cycle brings out the echo eclipse in some range (partly or completely). The echo eclipse in phase-coded quasi-CW radar system is shown in Fig. 1.1.

Let c denote the light speed, $\{c_m\}, m = 0, 1, \dots, N - 1$ denote the binary coding sequence, N denote the length of sequence, t_p denote the width of sub-code, T_r denote pulse repeat period, and R denote the target distance. According to the target range, there are three kinds of echo eclipse:

- (1) When $R < \frac{cNt_p}{2}$, the anterior of echoes is eclipsed, just like echo 1 shown in Fig. 1.1;
- (2) when $\frac{cNt_p}{2} \leq R < \frac{c(T_r - Nt_p)}{2}$, the echo is not eclipsed, just like echo 2;
- (3) when $\frac{c(T_r - Nt_p)}{2} \leq R < \frac{cT_r}{2}$, the posterior of echo is eclipsed, just like echo 3.

1.2.1 Echo Eclipse Ratio Function

The echo eclipse of phase-coded quasi-CW radar can be evaluated by echo eclipse ratio function (Modarres-Hashemi et al. 1999). Let $x_T(t)$ denote the transmitting

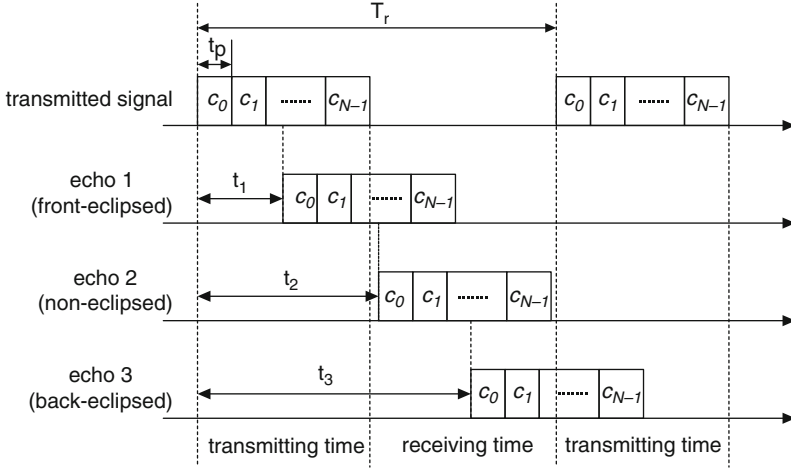


Fig. 1.1 The echo eclipse problem of phase-coded quasi-CW radar system

switch signal. When binary phase-coded signal is transmitted, $x_T(t) = 1$, or else $x_T(t) = 0$. The receiving switch signal is the opposite of transmitting switch signal, $x_R(t) = 1 - x_T(t)$. Echo eclipse ratio function $g(\tau)$ is defined as

$$g(\tau) = \frac{1}{T_r} \int_0^{T_r} x_T(t - \tau)(1 - x_R(t))dt \quad (1.1)$$

where τ is the delay time of echo. When $\tau = 0$, $g(0) = 1$, the echo is completely eclipsed. When $\tau \neq 0$, the echo is partly eclipsed, and $0 \leq g(\tau) < 1$. When $g(\tau) = 0$, the echo is not eclipsed. As $g(\tau)$ grows larger, the echo eclipse becomes more serious and the energy of echo into radar receiver is less.

1.2.2 Main Lobe to Side Lobe Ratio of Eclipsed Echo

In the signal processing, the pulse compression process of eclipsed signal is a partial correlation process (Baden and Cohen 1990; Zeraster 1980). It therefore causes that the main lobe level of compressed signals is decreased and the side lobe level is increased relatively. Then we introduce peak side lobe level (PSL) and integrated side lobe level (ISL) to evaluate the main lobe to side lobe ratio of eclipsed signal. PSL and ISL are defined as follows:

$$PSL = 10 \lg \frac{\max(\chi_m^2)}{\chi_0^2} \quad (1.2)$$

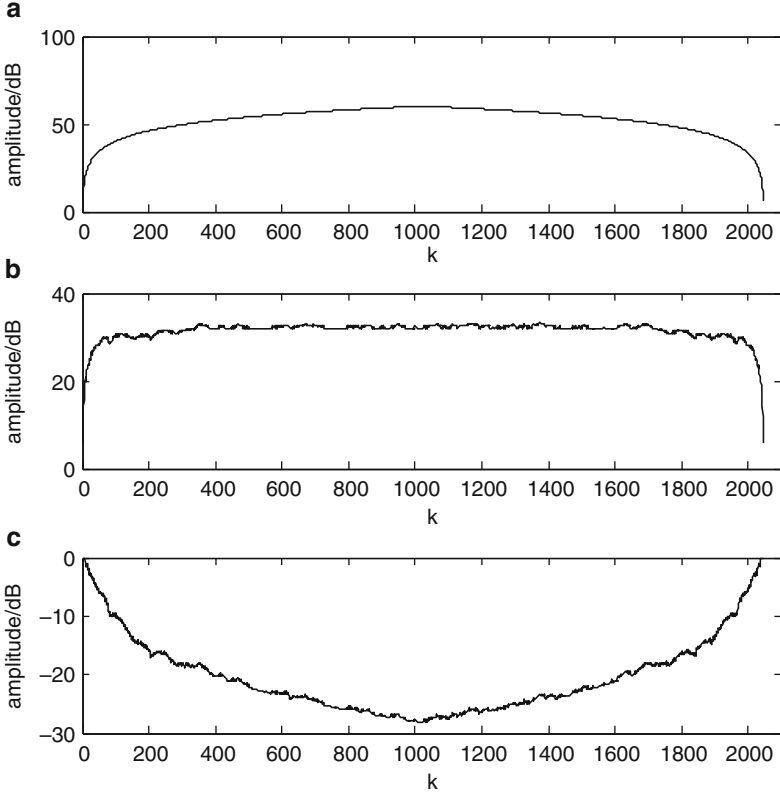


Fig. 1.2 The pulse compression performance simulation of eclipsed echoes for 1,023-elements m sequence code. (a) Main lobe amplitude, (b) Maximum sidelobe amplitude, (c) Peak sidelobe level

$$ISL = 10 \lg \frac{\sum \chi_m^2}{\chi_0^2} \quad (1.3)$$

where χ_m ($-N + 1 \leq m \leq N - 1, m \neq 0$) is m -th side lobe level and χ_0 is main lobe level.

Next, we make simulation to m sequence binary coded signal whose length is 1,023. Assume that the duty cycle of emission signal is 50%, and the target distance is $\frac{cNt_p}{2}$ ($1 \leq k \leq 2N - 1$). We analyze the main lobe and maximum side lobe of the compressed signals. When $1 \leq k \leq 1,022$, the anterior of echoes is eclipsed. When $k = 1,023$, the echo is not eclipsed; when $1,024 \leq k \leq 2,045$, the posterior of echo is eclipsed. The simulation results are shown in Fig. 1.2. The amplitude of main lobe changing with the target location k is shown in Fig. 1.2a, the amplitude of maximum side lobe with the target location k is shown in Fig. 1.2b, and the PSL changing with k is shown in Fig. 1.2c.

1.3 The Waveform Design Method Based on Combination of Long Short Codes and Synchronous Alternation of CF

1.3.1 Wave Design

Normally, radar always has to detect targets at different range, but the binary phase-coded radar based on long coding sequence is not suitable for the detection of close targets as analyzed above. In this paper, by referring to the waveform design method of matching the target range, we propose a waveform design based on the combination of long short codes and CF alternation. The waveform design method is shown in Fig. 1.3.

In a repeat period T , the emission signals contains a binary phase-coded signal based on short coding sequence (the sequence length is M) and a binary phase-coded signal based on long coding sequence (the sequence length is N). The binary phase-coded signal based on short coding sequence which owns a very low side lobe is used to detect targets in short range. Because the number of sub-codes is relatively smaller and the pulse width is narrower, there is no severe echo eclipse in the detecting range. Though the energy of emission signal is lower, the energy of echoes reflected from close targets is usually much stronger. So, the relatively lower emission power does not influence detection performance. The binary phase-coded signal based on long coding sequence is used to detect targets located in far range, the pulse width of signal is much longer than that of short signal, and the total energy of emission signal is much stronger, which is useful to detect distant targets. While the code type of emission signal is being shifted, the CF of signals is synchronously being alternated. When the binary phase-coded signal based on short coding sequence is transmitted, the frequency of CF is f_1 .

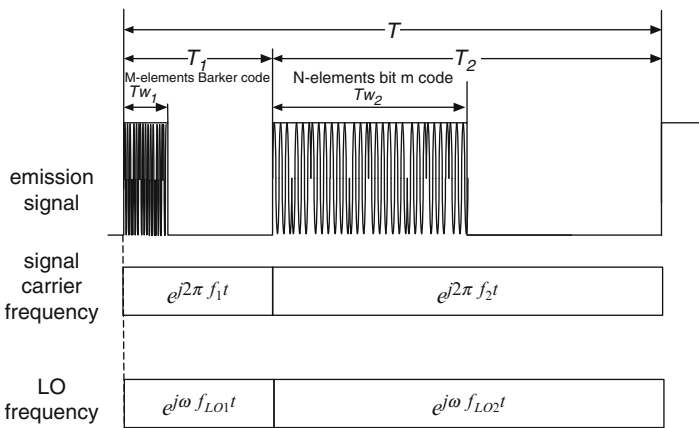


Fig. 1.3 The schematic diagram of proposed waveform design

When the binary phase-coded signal based on long coding sequence is transmitted, the frequency of CF is f_2 . After that, we can expand the signal bandwidth and increase the signal complexity. And it is also useful to improve the signal's electronic counter-countermeasure (ECCM) ability and to reduce the probability of interception.

Normally, after the two kinds of binary phase-coded signals are transmitted, these two different kinds of signals will be reflected from target, and then enter radar receiver. As a result, it will probably cause the radar receiver saturated. Fortunately, that will not happen when the designed signals are transmitted, because the CF frequency of these signals is different. When the target appears near, the echoes mix with the LO (local oscillator) signal whose frequency is also synchronously alternated (at this time, the frequency of LO signal is f_{LO1}), and the long code signals is suppressed very well after passing through the low-pass filter (the CF frequency of long code signal is f_2 , and $|f_{LO1} - f_2|$ exceeds the bandwidth of low-pass filter). Similarly, when the target is located in far distance, the short code signal in the echoes can also be effectively suppressed. Meanwhile, by transmitting the designed signals, radar can detect targets located in different range at the same time, the dynamic range and sensitivity of radar receiver can be improved, and the interference between signals is weaker.

Set the short code sequence as $\{c_m\}, m = 1, 2, \dots, M - 1$, long code sequence as $\{\gamma_n\}, n = 1, 2, \dots, N - 1$, and the sub-pulse width as τ . Then emission signal can be denoted by

$$x(t) = \begin{cases} \frac{1}{\sqrt{M}} \sum_{m=0}^{M-1} c_m v(t - k\tau) e^{j2\pi f_1 t} & 0 < t < M\tau \\ \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} \gamma_n v(t - k\tau - T_1) e^{j2\pi f_2 t} & T_1 < t < N\tau + T_1 \\ 0 & else \end{cases} \quad (1.4)$$

where T_1 is the pulse repetition interval (PRI) of short code signal, M is the number of short coding sequence, N is the number of long coding sequence, $v(t)$ is sub-pulse function, f_1 is the carrier frequency of the phase-coded binary signal based on short coding sequence, and f_2 is the carrier frequency of phase-coded binary signal based on long coding sequence.

1.3.2 Parameters Calculation

In waveform design, we need to calculate the waveform parameters such as PRI, pulse width, code length and so on according to the application. Assume that the detection range of radar is (R_1, R_2) , and the delay of echo ranges from $\frac{2R_1}{c}$ to $\frac{2R_2}{c}$

accordingly. Make sure the short phase-coded echoes are received completely; the sub-pulse width is confined to the following condition:

$$\tau \leq \frac{2R_1}{Mc} \quad (1.5)$$

Then the pulse width of binary phase-coded signal based on short coding sequence T_{w_1} can be given by

$$T_{w_1} = M\tau \leq \frac{2R_1}{c} \quad (1.6)$$

Moreover, in order to ensure the correlation length and main lobe to peak side lobe ratio (MPSR) of long code sequence echoes which are reflected from a distant target, the eclipse ratio of echoes have to be less than g_{\max_2} . Assume that the target is located in R_2 and the eclipse ratio of echoes is g_{\max_2} , then

$$\frac{T_2 - t_2}{\eta T_2} = 1 - g_{\max_2} \quad (1.7)$$

$$T_2 = \frac{t_2}{1 - \eta + \eta g_{\max_2}} \quad (1.8)$$

where η is the duty cycle of long code sequence binary phase-coded signal. Let $t_2 = \frac{2R_2}{c}$, then

$$T_2 = \frac{2R_2}{(1 - \eta + \eta g_{\max_2})c} \quad (1.9)$$

So, the pulse width of long code sequence phase-coded binary signal T_{w_2} is given by

$$T_{w_2} = \eta T_2 = \frac{2\eta R_2}{(1 - \eta + \eta g_{\max_2})c} \quad (1.10)$$

From to (1.5) and (1.9), the sub-pulse number of long code sequence binary phase-coded signal N' can be given by

$$N' = \left\lceil \frac{2\eta R_2}{(1 - \eta + \eta g_{\max_2})\tau c} \right\rceil \quad (1.11)$$

Next, we select N which is close to N' to be the code length of long code sequence.

When close targets are detected, the anterior of echoes is eclipsed. Similarly, to ensure the correlation length and MPSR of long code sequence echoes, the eclipse

ratio of echoes have to be less than g_{\max_1} . Let the target is located in R_3 , at this time, the eclipse ratio is g_{\max_1} . Then

$$g_{\max_1} = \frac{T w_2 - t_3}{T w_2} \quad (1.12)$$

$$t_3 = (1 - g_{\max_1}) T w_2 \quad (1.13)$$

where the delay of echo is t_3 .

Let (1.9) into (1.12), we can get

$$t_3 = \frac{2(1 - g_{\max_1})\eta R_2}{(1 - \eta + \eta g_{\max_2})c} \quad (1.14)$$

When the echo delay is less than t_3 , the eclipse ratio is greater than g_{\max_1} , and the MPSR is becoming lower. At this situation, we need to use the binary phase-coded signal based on short coding sequence to detect target. In other words, R_3 is the maximum detection range of short code signal, and the eclipse ratio of short code sequence echoes is kept to 0. Therefore, the PRI of short code sequence signal T_1 is required to meet the following condition:

$$T_1 \geq t_3 + T w_1 = \frac{2(1 - g_{\max_1})\eta R_2}{(1 - \eta + \eta g_{\max_2})c} + M \tau \quad (1.15)$$

When (1.5) and (1.14) both take mark of equality, we can get that

$$T_1 = \frac{2(1 - g_{\max_1})\eta R_2}{(1 - \eta + \eta g_{\max_2})c} + \frac{2R_1}{c} \quad (1.16)$$

1.4 Example and Simulation

Using the proposed waveform design method, we make simulation to phase-coded quasi-CW radar with a detection range of 0.2–50.0 km. The main parameters of radar are shown in Table 1.1.

In the short distance range (200 m–9.0 km), the radar signal is 13-elements Barker code phase-coded signal, the echoes reflected from targets in this range is not eclipsed, and the compressed signals' MPSR is 22.3 dB. Meanwhile, 1,023-elements m sequence phase-coded signal is used to detect targets in the range of 9.0–50 km. The echoes reflected from targets in the range of 9.0–15.345 km are front eclipsed echoes, but the echo eclipse ratio of these echoes is less than 0.42,

Table 1.1 Example of X band phase-coded quasi-CW radar waveform parameters

Radar parameters	
Code type	Short code: 13-elements Barker sequence Long code: 1,023-elements m sequence
The width of sub-code (T_p)	0.1 μ s
The frequency of CF (f)	$f = 9.170$ GHz, when $0 < t < T_1$ $f = 9.370$ GHz, when $T_1 < t < T_2$
Pulse repeat period (T)	Where, $T_{w1} = 0.1\mu$ s, $T_1 = 62.4\mu$ s; $T_{w2} = 102.3\mu$ s, $T_2 = 409.2\mu$ s;
Detection range (R)	Minimum detection range: 200 m Maximum detection range: 50 km Detection range section 1 ^a : 200 m–9.0 km Detection range section 2 ^b : 9.0–50.0 km
Echo eclipse ratio($g(t)$)	$g(t) = 0$, when 1.3μ s $\leq t \leq 60.0\mu$ s; $0 \leq g(t) < 0.42$, when 60.0μ s $< t \leq 102.3\mu$ s; $g(t) = 0$, when 102.3μ s $< t \leq 306.9\mu$ s; $0 \leq g(t) < 0.26$, when 306.9μ s $< t \leq 333.3\mu$ s;
Emission power (P)	43 dBmW
MPSR	> 22.0 dB

^aDetection range of short code signal

^bDetection range of long code signal

and the number of correlated sub-codes is greater than 594, and the MPSR is greater than 22.0 dB. The echoes reflected from targets in the range of 15.345–46.035 km are not eclipsed. The echoes reflected from targets in the range of 46.035–50.0 km are back eclipsed, but the echo eclipse ratio of these echoes is less than 0.26. The number of these correlated sub-codes is greater than 757; and MPSR is greater than 25.3 dB. When the target is located in 12.0, 27.0, and 50.0 km, the corresponding compressed signals are shown in Fig. 1.4.

1.5 Conclusion

In this paper, the echo eclipse problem of phase-coded quasi-CW radar system was analyzed, and a waveform design method which is based on combination of long code with short code and synchronous CF alternation was proposed. The echo eclipse problem was resolved very well, and the signal bandwidth was expanded and the ECCM ability was improved as well as the probability of interception was decreased using this method. The simulation results show that the radar signal designed by using the method proposed in this paper can effectively improve the performance of detection.

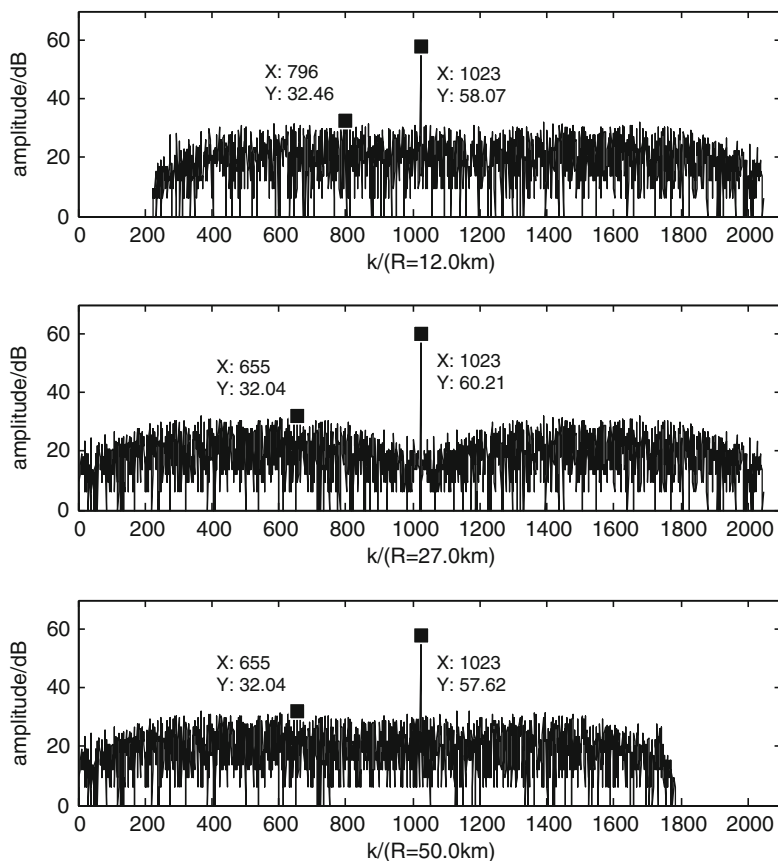


Fig. 1.4 The simulation of compressed signals reflected from targets in different range

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Chapter 2

Research on Human Factors Engineering of Chinese Traditional Armchair with Four Protruding Ends

De-hua Yu

Abstract Ming-style furniture is the elite of Chinese traditional furniture, which is doing well in human factors engineering. Chinese traditional armchair with four protruding ends has backrest, neckrest, armrest, footrest, and so on, which support the body properly. Based on the study of Chinese traditional armchair with four protruding ends, the practice of human factors engineering in Ming-style furniture is summarized, which is meaningful for the design of Chinese traditional furniture to develop ergonomics.

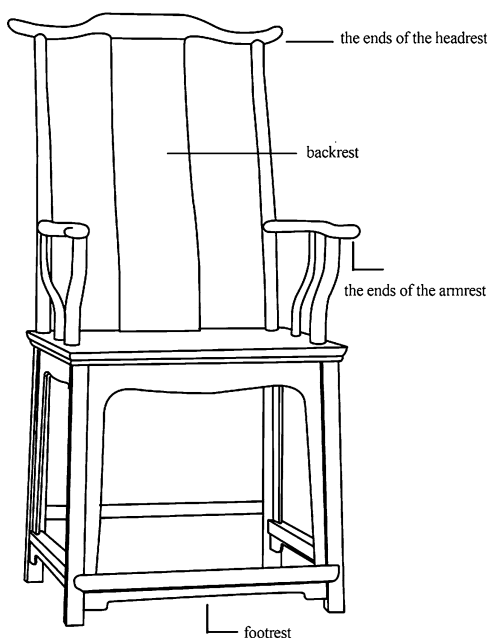
Keywords Chinese traditional armchair with four protruding ends • Design of Chinese traditional furniture • Human factors engineering • Ming-style furniture

2.1 Definition

Chinese traditional armchair with four protruding ends (Fig. 2.1) is the typical and common chair of Chinese traditional furniture, which is also called yoke back armchair because of the yoke-like headrest, and also the north official's armchair as the headrest looks like the official's hat (Shixiang Wang 2008). The four protruding ends of Chinese traditional armchair refer to the ends of two armrests and the ends of the headrest, compared with the Chinese traditional armchair whose armrest and headrest doesn't have protruding ends, which is also called southern official's armchair (Gustav Ecke 1991).

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Fig. 2.1 Chinese traditional armchair with four protruding ends



2.2 Background

The ancient Chinese sat on woven mat more than 2,000 years ago, when there was only low furniture around them. It was not until the Han Dynasty (206 AD–220BC) that the high furniture spread into the Central Plains influenced by nomadic tribes and also the migration of Buddhism. According to the historical records, the Han emperor called Lingdi were much interested in the custom of the nomadic tribe called hu, including the folding chair (huchuang) (Fan Ye 2007). The folding chair was the early high seating, which became more and more popular among the nobilities of Han Dynasty. During the Northern and Southern Dynasties (386–586 AD) to the Tang dynasty (618–907 AD), high chairs were becoming more and more popular among the elite and then the common people, which was the transitional period from sitting on the mat to on the chair. By the Song Dynasty (960–1279 AD), high chairs and tables were already common among all the social classes (Yao Yang 2002a). Various types of high furniture like tables, chairs, beds, stools and so on were recorded in the paintings, murals and unearthed relic, which indicated that the transition from sitting on the mat to on the chair had finished, and high seating had already maintained the dominance. From then on, people were already accustomed to high furniture. In the late Ming and early Qing Dynasty, a unique style called Ming-style furniture came into being, which was brilliant in the whole world (Zongshan Li 2001).

Chinese traditional furniture in the ancient times indicated the masters' social status, wealth, and also the social etiquette, while the comfort was considered less, which was different from that of western countries. Shape, decoration, dimension and materials of the furniture varied in different classes. For example, the throne chair is the specific chair of the emperor, which is large enough to support the emperor, and indicates the authority and the status of the emperor (Jiaqing Tian 2003), although it is not comfortable and considerate. The only auxiliary thing for comfort is the cushion on the throne chair to support the emperor. In the pavilion, terrace, and the hall of the nobilities' houses, there were also chairs of different grades. In a standard hall of the house, the master usually sat in the chair of smart shape, well decoration and big dimension, like the armchair with round back, armchair with four protruding ends, etc., which highlighted the status of the master. Chairs of guests were not as particular as the master's chair, and usually simpler. And the last chair in the hall might be just a stool rather than a chair without the backrest and the armrest, which was prepared for the lowly person. The stools with four legs and seat surface were the common seating for the ordinary people.

Social status and etiquette was more important than the comfort when sitting in the chair in the ancient times. Upright sitting was the required posture for even the emperor and the nobles, and if the posture was sustained for a while, the lumbar muscle would be under great strain, which was not comfortable.

However, the comfort was not the neglect factor when making a chair in the ancient times. Based on the consideration of the social status and etiquette, the comfort was also the important factor to make chairs comfortable and considerate. For example, the S-shaped backrest is compatible with the curved spine. Actually, carpenters in ancient China usually fit in with the basic principle of human factors engineering although without the guidance of modern theory of human factors engineering (Zengbi Chen 1981).

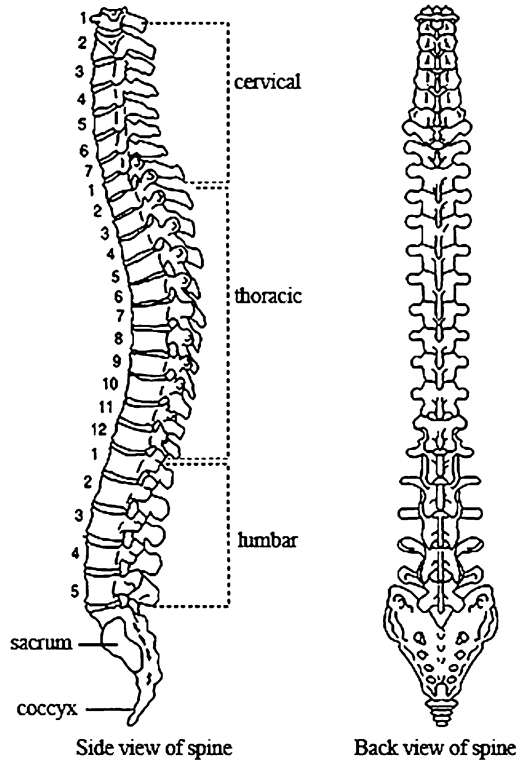
2.3 Analysis

Most of people nowadays spend most of the days sitting at a desk at work and also after work, and we call it sedentary behavior, which may make the irreparable damage on the body. Therefore, the correct sitting posture and chairs that are beneficial to the health is vital important for people.

Chinese traditional armchair with four protruding ends pays more attention to the comfort, and several details indicate the consideration of the human factors engineering.

Considered from the human factors engineering, the support from the seating includes three parts: the spine support, the buttock support, the foot support and the arm support (Yuanbo Sun 2010).

Fig. 2.2 Structure of the spine

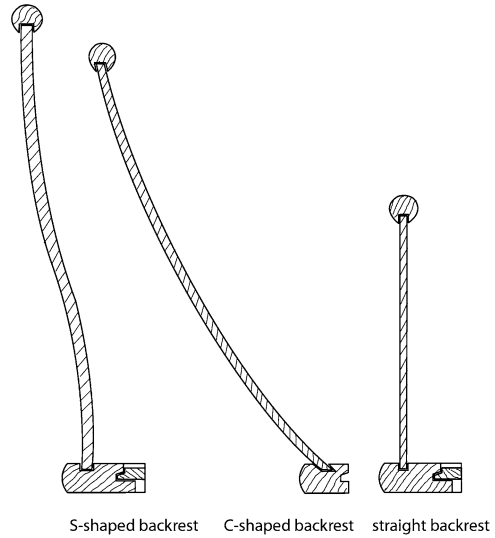


2.3.1 The Spine Support

The spine provides structural support the body and protects the spine cord, which is made up of 7 cervical (neck) vertebrae, 12 thoracic (chest, dorsal) vertebrae, 5 lumbar (lower back) vertebrae, 5 sacral vertebrae (fused triangular bone) and 3 or 4 little vertebrae fused into a coccyx at the lower end of the spinal column (Fig. 2.2). The spine usually gets so many burdens due to bad posture while being seated, especially the long, motionless hours of sitting, which would lead to body damage, and become chronic and impossible to undo. The cervical (neck) regions, the 3–4 thoracic regions and the 4–5 lumbar regions are mostly under pressure, and easily wounded. The three regions should be paid more attention to when making a chair, especially the 3–4 lumbar regions which sustain the most pressure. If the backrest of the chair supports the 3–4 lumbar regions actively, people will be more comfortable (Leiqing Xu 2006).

Chinese traditional armchair with four protruding ends has curved backrest and headrest, which are prepared to support the curved spine properly. Chinese traditional armchairs with four protruding ends have different backrests of different curves influenced by the shape, the time and region that the furniture was made, including S-shaped, C-shaped and the straight backrests (Fig. 2.3). S-shaped

Fig. 2.3 Backrest of different shapes



backrests are more than the C-shaped, and the straight backrests are rare. The S-shaped backrests are the most compatible with the S-shaped curved spine. The 3–4 thoracic regions and the 4–5 lumbar regions of the spine get the proper support from the S-shaped backrest, and the cervical (neck) regions get the active support from the curved headrest (Fig. 2.4). The C-shaped backrest neglects the accurate support of the 4–5 lumbar regions, but its considerate C-shaped curve fit in with the whole spine properly, which would also finish the function of comfort. The straight backrest is only fit for upright sitting, which is lack of the consideration of human factors engineering.

2.3.2 *The Arm Support*

Chinese traditional armchair with four protruding ends has the armrest to support the arm properly. The height of the armrest is so appropriate that the arm could be laid on it with ease. The armrest is also curve-shaped, and different chairs have armrests of different curves. The end of the armrest is round and smooth, which could help massage the palm of the hand. That would be useful for the health from the perspective of traditional Chinese medicine.

2.3.3 *The Buttock Support*

The maximum pressure of the buttock from the seat surface should be on the ischium, which could bear the burden most of the body. The pressure around the