TELKOMNIKA, Vol. 11, No. 7, July 2013, pp. 3665 ~ 3672
e-ISSN: 2087-278X

The NC Power Supply Design of Large Current and Wide Frequency Pulse in SEAM

Jianping Zhou*[1,2,a] , Yan Xu [1,2,b] ,Qiang He [1,c], Bisheng Zhou [2]
1 School of Mechanical Engineering, Xinjiang University, Urumqi, China
2 School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an ,China
1 Yanan road 62, Urumqi, China 09918592303
Corresponding author, e-mail: linkzhou@163.com[a], lilixiu_z@163.com[b], 442112805@qq.com[c]

Abstract.

There are a lot of ways to achieve large current pulse power supply, and the more common way is to adopt the inverter switching circuit to achieve pulse power supply. The core of the NC power supply design of large current and wide frequency pulse in SEAM is using two-stage modulation. Combined with inverter technology, DC chopper technology and NC technology, it not only can achieve the adjustability of the output pulse amplitude, but also can realize continuous adjustment of the output pulses and the duty cycle. The front stage of power supply uses DC/DC transformation circuit with the UC3879 integrated control chip as the core. With the microcontroller as the control core, the backward stage uses DC chopper circuit to achieve the NC power supply of multi-parameter adjustable output large current pulse.

Keywords: *short electric arc machining, full-bridge inverter, DC chopper, adaptive voltage regulation*

Copyright © 2013 Universitas Ahmad Dahlan. All rights reserved.

1. Introduction

This design provides primarily a large current and wide frequency NC power supply which can adjust continuously output pulse amplitude, frequency and the duty cycle.

1. Compared with the traditional high-power pulse power supply, this power supply not only can achieve the continuous adjustability of the amplitude and duty cycle, but also can adjust continuously the output pulse frequency;
2. Power supply uses IGBT and MOSFET high-power switching devices, and the peak of output current is up to 2000A, also the power up to 72KW;
3. This NC pulse power supply uses two-stage modulation mode, and it can achieve continuous adjustment of the output pulse frequency within 50Hz-100KHz.It also can realize the online adjustment from low frequency to high frequency according to the actual machining conditions;
4. The output voltage amplitude of the power supply can be continuously adjustable from 3V to 36V;
5. This power supply has many protection circuits such as over-voltage, under voltage, phase lack, module failure, over-temperature, output over-voltage, output short circuit, fault display and so on, which play an real-time protection role for power supply.

2. The General Gtructure Diagram of Power Supply Structure

The overall structure of the power has been shown in Figure 1. By the above figure, the power supply uses two-stage modulation structure. Though the input circuit and the first modulation circuit, three-phase alternating current was converted into DC of adjustable amplitude.

With dedicated PWM chip UC3879 as the control core, the first modulation circuit produces the PWM signal to drives full-bridge switching devices after magnified by the driver circuit, and checks whether the input and output parameters are overload or not, then completed the correspond protection of switching devices.

Adopting microcontroller as the core, the second modulation circuit generate the drive signal to control the switching tube of the back stage. The one hand it can change the values of

Received January 25, 2013; Revised April 8, 2013; Accepted April 18, 2013

the output pulse amplitude, frequency, duty cycle values by the input of the key, and on the other hand detect each parameters of the output pulse voltage and display it.

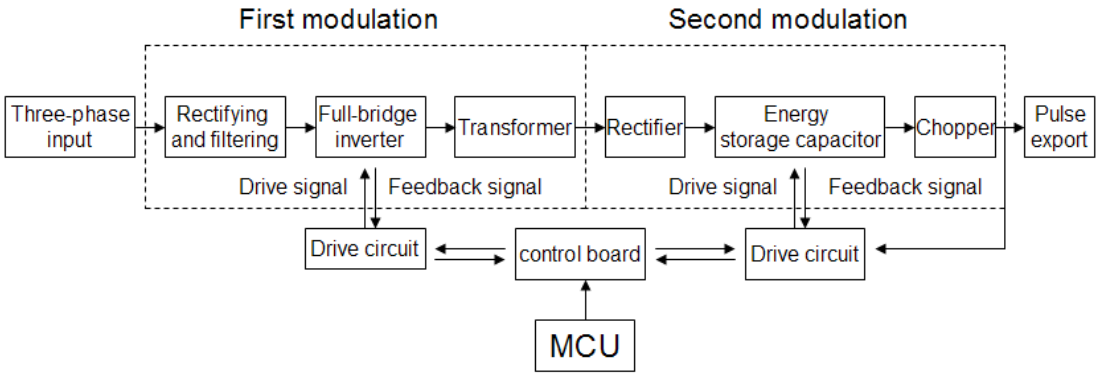

Figure 1. General structure diagram of the high-power broadband NC pulse power

In Figure 1, the first modulation circuit includes a labor frequency rectifier filter circuit, IGBT full-bridge inverter circuit, high frequency transformer; the second modulation circuit includes a high frequency current-doubler rectifier, the storage capacitor, MOSFET DC chopper circuit, a control circuit, the driving circuit and the auxiliary power supply circuit, etc.

Figure 2 shows the topology of the main circuit. Its major workflow: three-phase alternating current filtered by EMI, three-phase non-controlled rectifier, power frequency filtering, and through full-bridge inverter circuit , was transformed to symmetrical pulse voltage for the high frequency of positive and negative.

By high-frequency transformer and after the transformer rectifier of current-doubler rectifier circuit, the energy will store in the energy storage capacitor, which is provided for second modulation with continuous low-voltage DC. Chopper circuit puts the continuous low-voltage DC high frequency chopper into the loads.

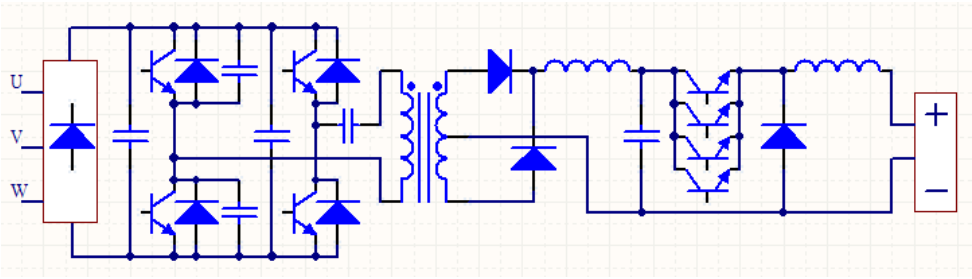

Figure 2. Circuit topology of the high-power wide frequency pulse pulse power

The high-frequency transformer is the core of design of inverter. Right transformer not only is able to increase the operating frequency and output maximum power, but also reduces energy loss and improves efficiency [1]. Design parameters of many components in main circuit depend on the parameters of the transformer. Transformer leakage inductance and magnetic bias also have important impacts on the performance of the main circuit.

The requirements of bridge inverter for transformer core are as followings: higher saturation magnetic flux density, lower residual magnetic flux density, smaller hysteresis loss and eddy current loss, and the saturation magnetic flux density not reducing even in the change of temperature and the frequency. From the above, the soft ferrite is the preferred material for

the transformer core. It is not only good for the coupling characteristics of the winding, but also convenient for forming. It is the most magnetic materials in power transformer [2].

The choice of transformer core structure depends on the factors, such as working system, core material, operating frequency, output power and so on. The soft magnetic ferrite core include can type, PM, RM, PQ, EE, EC, EP, ETD, RC, UU and others. Due to the different cost, magnetic field distribution, number of center tap and others, the various core can be applied to different occasions. The core structure of the power supply uses ring core. Its advantages is lower losses, magnetic field distribution uniformly, large output power, but it also has some difficulty in winding.

One of the reasons that the high-frequency transformer can't work properly is the phenomenon of core saturation. Figure 3 shows the hysteresis loop of the transformer cores. It shows the relationship that magnetic induction B of ferromagnet change with magnetizing field strength H. The area enclosed by the curve is the power loss of the core. In the full-bridge converter, due to the problems that each switch voltage drop and loss is different, the number of the positive and negative volt-second in the primary winding of the high-frequency transformer is inequality, and the flux in the core can not come back the starting point. After a number of cycles, the core flux will deviate from the hysteresis loop into the saturated zone. When the core is saturation, the transformer can not withstand voltage, and switch tube will be under higher voltage and current, resulting in the damage of the switch tube [3].

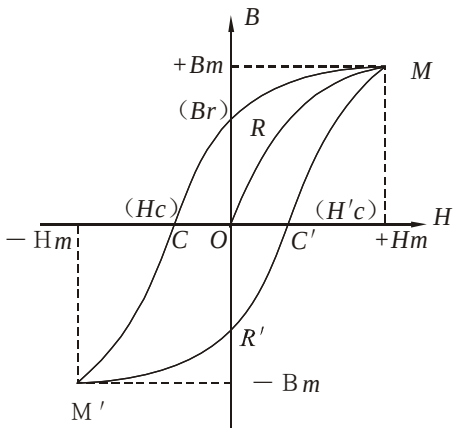

Figure 3. The hysteresis loop of ferromagnetic material

The direct cause of the saturation effect is due to the primary existing the DC component. The main effective measures of suppressing DC component have the following aspects. Firstly, Series connection blocking condenser in the transformer primary makes the transformer only have voltage component. Secondly, we can use the current instantaneous control technology to detect whether it is balance of each power tube emission level current, and then through the slope comparator, we can adjust the width of the trigger pulse of the power tube i to keep the average of the transformer flux density closing to B/H characteristic curve center point.

The power adopt two EACO SLA 800V 20uF capacitor in parallel, then connected tandem with the primary winding of the high-frequency transformer as transformer Blocking capacitor. The experiments show good results.

In the high-power low-voltage high-current switching power supply (output 36V-2000A) secondary output rectifier circuit, due to the limited capacity of a single rectifier diode, in order to improve the power of stand-alone power supply, we use a set of secondary side, Multiple rectifier diode parallel structure, as shown in Figure 4. The design uniformly installed multiple groups diode on the same piece of copper, which increase power output, as well as meet current requirements of multiple sets of diode.

The capacitor after full bridge inverter chooses electrolytic capacitor with high frequency and low resistance and large current capacitor with high frequency and high voltage to improve

the ability of the high-power output in seconds 0f the power supply system, but also have the lasting power performance.

The power supply control system uses the UC3879 as its control core. In addition to generate full-bridge drive signal, on the one hand, it can realize the protection of power device and the discharge circuit. On the other hand, it also can complete the adaptive voltage regulation function of the output voltage amplitude.

MCU generates post-chopper circuit drive signal and realizes human interface communication. The control structure is shown in Figure 5.

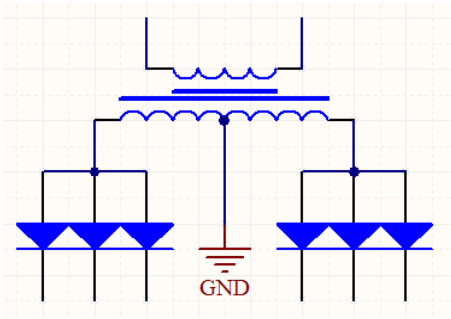

Figure 4. Secondary rectification structure

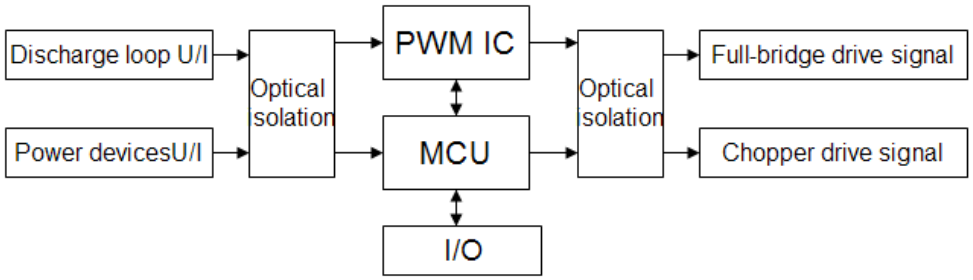

Figure 5. Control system diagram of power supply

3. The Self-adaption Pressure Regulator Theory and Planning of The Power

The large current wideband numerical control pulse power for short electric arc machining is composed of DC switching power circuit and chopper circuit in structure, the power work in CV mode When short electric arc machining.

So we can realize constant voltage output of DC switch circuit as long as we use closed-loop control to the duty cycle of IGBT drive signal in DC switching power circuit .Finally the power can supply stabilized voltage magnitude in the process of short electric arc machining. Figure 6. is the structure diagram of inverter system.

In this diagram, input voltage v_i is a disturbance, the output not only was effected by given-signal v_g,but also related to v_i and load. We can get various results by analyzing system transfer function.

Regulator transfer function is denoted with $G_1(s)$, and time proportional control and pulse forming links can be generally equivalent to a linear proportional component, represented with the transfer function K_1.

The feedback circuit is generally a proportional component, represented with the transfer function H(s). The main circuit section writes transfer function $G_2(s)$. For an inverter control system, in order to make it stable and better performance, sometimes it can also be added a correction link. The correction link and the regulato can composing transfer function together.

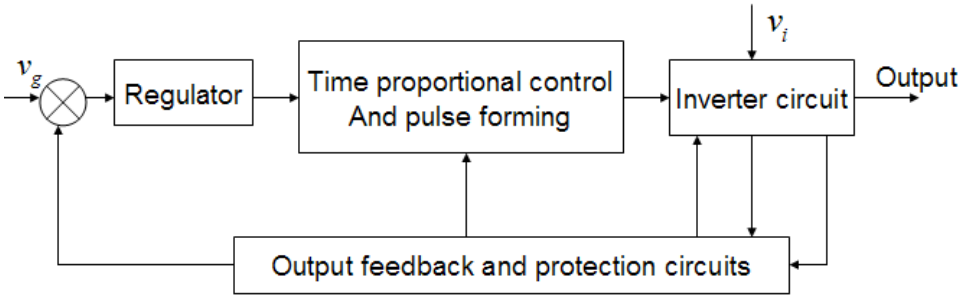

Figure 6. The inverter system structure diagram

From the analysis, the inverter control system can be Represented with the form of Figure 7.

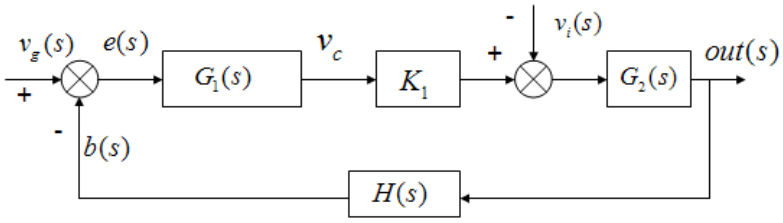

Figure 7. Inverter control system block diagram

The closed-loop transfer function of system output $out(s)$ to system input $v_i(s)$ is

$$\frac{out(s)}{v_g(s)} = \frac{K_1 G_1(s) G_2(s)}{1 + K_1 H(s) \cdot G_1(s) G_2(s)} = \frac{G(s)}{1 + H(s) G(s)} \quad (1)$$

In the equation, $G(s) = K_1 \cdot G_1(s) \cdot G_2(s)$, $G(s)$ is called forward paths transfer function.

The relationship between system error signal $e(s)$ and system input is called the error transfer function,

$$\frac{e(s)}{v_g(s)} = \frac{1}{1 + H(s) G(s)} \quad (2)$$

The closed-loop transfer function of system output $out(s)$ to interference signal $v_i(s)$ is

$$\frac{out(s)}{v_i(s)} = \frac{G_2(s)}{1 + K_1 H(s) \cdot G_1(s) G_2(s)} \quad (3)$$

Besides, the relationship between feedback signal $b(s)$ and error signal $e(s)$ is called the open loop transfer function

$$\frac{b(s)}{e(s)} = H(s) G(s) \quad (4)$$

In general, the design of a control system should take three aspects into full consideration. Firstly, control the value of steady-state error. Secondly, ensure the dynamic response speed of system, control the overshoot, adjust time .Finally ensure the stability of the system, design properly cross-over frequency, frequency band and stability margin.

The power supply uses adaptive voltage regulator system [4], and PWM controller uses integrated chip UC3879. adaptive voltage regulator is shown as Figure 8. The power supply works in constant pressure state. According to adaptive control, Vi is the noninverting input of error amplifier UC3879, and normally it connects to dividing resistor of a reference voltage. Vf is the reverse input of error amplifier, and it connects to resistor divider joined the output voltage. Compared inverting terminal voltage with noninverting terminal sample voltage, and its output signal with the triangular wave which oscillator generates, the junction points decides the size of phase angle. Thereby it can change the duty cycle of the output pulse, ultimately keep the output voltage constant [5].

The adaptive voltage regulator system uses PI control, which has no steady-state error, but the dynamic response of the system is slower.

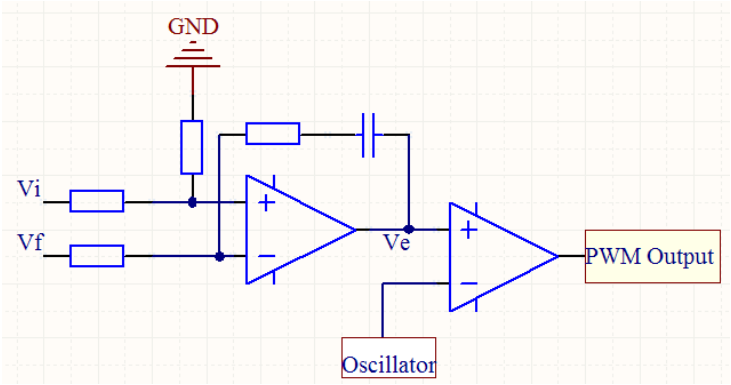

Figure 8. Schematic of PI adaptive voltage regulator

4. The Realization of the Power Supply

4.1. Pulse Amplitude Modulation Module

Phase shift PWM control mode is a combination of resonant transformation technology and conventional PWM converter technology, and the basic principle is: the complementary control of 180 degrees of the two switches for each bridge arm, a phase difference between the conduction of the two bridge arm, i.e. the phase shift angle. By adjusting the magnitude of the phase-shifting angle, we can adjust the pulse width of the output voltage, get the Adjustable duty cycle and positive and negative half-cycle symmetry of AC square wave voltage in the secondary side of the transformer, to achieve the purpose of regulating the output voltage. The main circuit of full-bridge transform for Phase-shift control PWM is shown in Figure 9, T1 and T3 compose leading leg arm, T2 and T4 compose lagging leg arm.

In full bridge phase shift switching converter, the breakover, turn-off time of switch is constant, and the order of conduction is T1-T4-T3-T2. The switches of the same bridge arm is inverting conduction, the diagonal switch conduction has phase angle, which makes diagonal common conduction time change with the phase angle. Because of the turn-off time of IGBT, tzhe breakover, turn-off of the two switches of the same bridge arm requires a certain delay time, that is dead time, to prevent shoot-through, which play the role of protection switch tube.

Through the soft-switch technology, the amplitude modulation modules achieves the power switch zero voltage and zero current, effectively reduces switching losses, greatly improves the efficiency of the power and the life of the switch. And it makes its own volume and weight greatly reduce, and have higher reliability [6].

In the Figure 9, Cf is100000uF bulk storage capacitor, and its role is to store the power of transforme. The magnitude of the stored voltage value determines the size of the output pulse amplitude.

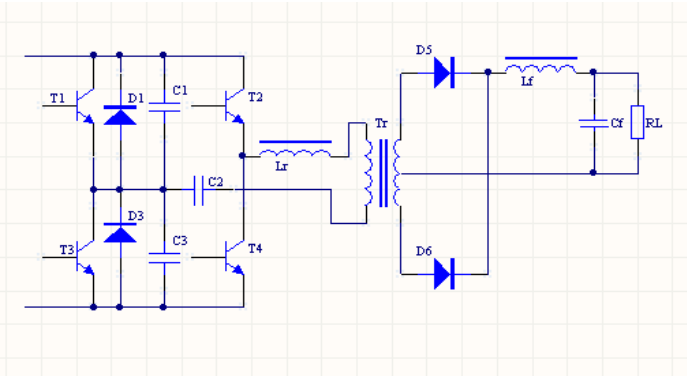

Figure 9. Phase shift control ZVZCS PWM full-bridge converter main circuit

Through changing the size of the phase angle between the lagging bridge arm and the leading bridge arm, we can adjust transformer secondary output voltage pulse width, reach the purpose of adjusting the amplitude of the output voltage pulses.

4.2. Frequency Modulation Control Module

The FM control module of the power belongs to the secondary modulation circuit, and can complete the adjustment of output pulse frequency and duty cycle. The module consists of four MOSFET connected in parallel, as shown in Figure 10. Four switch can turned on and off in the same time, and the drive signal is generated by the microcontroller programming. The Cf is a large-capacity electrolytic capacitors. On the hand, the Cf can storage energy, improve the ability of the power system high-power output in short time, and have lasting power performance. On the other hand, the Cf can filter and supply a steady low-voltage DC for chopper circuit. LF is the equivalent inductance of load and transmission line, D3 is the freewheeling diode of discharge circuit. Since the presence of the load LF, after the end of each discharge pulse, the loop still have a large induction current, and D3 can guid the induction current into the load avoiding damage to the switching device.

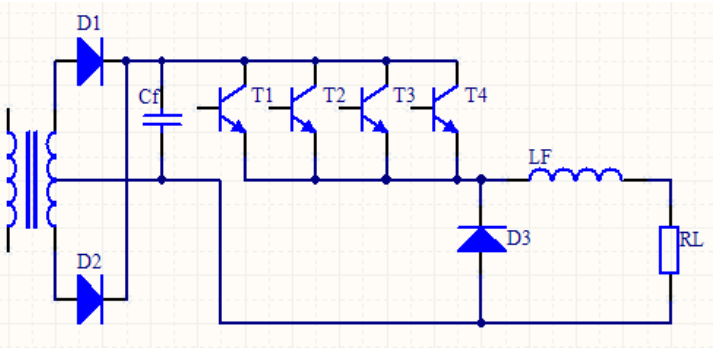

Figure 10. DC chopper circuit

In the case of the MOSFET used in parallel, the two conditions will cause the damage of the transistor. First, when the circuit is fully loaded and the parallel devices is fully turned on ,the quiescent current allocation can be balanced or not; Second, in the on-off conversion process of the transistor, the dynamic current can equitably distributed or not. The phenomenon of the currents uneven distribution is due to the differences in the pressure drop of the transistor, and transistor internal resistance having a positive temperature coefficient. Therefore, in order to avoid or reduce the damage of the transistor, we placed the device in parallel with a heat sink, and as close as possible.

The power supply completes the transformation of power by using high power IGBT and MOSFET module and the DC side of amplitude modulation is 520V high pressure.

Considering the 2 times the safety margin, we selected the FF200R12KT4 IGBT module of Infineon Company. The module is half bridge packaging and composed of two IGBT. Its Emitter voltage of the largest set is 1200V and the biggest collector current peak is up to 400 A.

The maximum output current of power discharge circuit is 2000A; the maximum voltage amplitude is 36V. And the power discharge circuit uses average-current chopper circuit and consists of four decompression chopping circuit. Because the shunt characteristics and loop current characteristics of the circuit belong to low voltage-high current, the power switch tube of the module selected the VMO1200-01Fpower field-effect transistor produced by IXYS Company. The transistor can bear 100V voltage and 1220A current at room temperature, so the transistor can meet the power demand and ensure the safety of the power switch tube.

Finally a short arc machining numerical control pulse power supply which has large current wide frequency and continuously adjustable output pulse amplitude, frequency and duty ratio is designed.

5. Conclusion

This chapter studies mainly a kind of short arc machining control power supply which has large current wide pulse numerical and consists of DC switch transform part and average-current chopper part. By using inverter technology, chopped wave technology and numerical control technology, finally it finish the power output pulse amplitude, duty ratio and frequency continuous adjustable and has the characteristic of easy control, reliable performance.

Acknowledgements

This work was financially supported by National Natural Science Foundation of China (No: 51065027).

References

[1] Xue Pei. High Frequency Superpower transformer design. *International reported in the literature: international electronic transformer*. 2005
[2] Yue Peng. *The Main Circuit Research of High-power Switching Power Supply*. Guangzhou, South China University of Technology. 2010.
[3] Abraham I. Pressman Keith Billings SWITCHING POWER SUPPLY DESIGN. Third Edition BEIJING: Electronic Industry Press. 2010; 63-71: 181-194.
[4] ZHANG Haifeng, LIU Yonghong. *The Design of EDM pulse power of efficient voltage regulator Journal of China University of Petroleum*. 200; 33(6): 116-120.
[5] Zhong Yanping. Power Electronic Circuit Design. Wuhan: Huazhong University of Science and Technology Press. 2010: 96-105.
[6] RONGJUN HUANG. Soft Switched Dc-Dc Converter for High Power-Frequency-Link Power System. BEIJING: Beijing Jiaotong University. 2001.