Research on the Wireless Charging System for the Performing Robots

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Abstract. This paper studies on non-contact charging system for performing robots based on the technology of the electromagnetic coupling resonance. Besidesthe system can charge the battery in the process of performance.The structure of the Wireless Power Transmission(WPT) is given,and its working principle is analyzed.Meanwhile, mathematical modeling is established for the main circuit.Moreover,the experiment for soft switching and output voltage is set up.The result of simulation and experiment shows the wireless charging system meets the requirements of reality and operation for performing robots.

Introduction

Performing robots can both show the individual and collective performance of street dance, gymnastics, stage plays and other kinds of action. The audiencesare being in enjoyment from the acting, at the same time, they can know the advanced technology in the field of robot.What's more,performing robots can inspirethe people's interestsin science and technology,which can promote the strategy of invigorating the country through science, technology and education.It is the optimal item to close the distance between the audiences and the robots.

The traditional charging way is not convenient to charge and affect continuous performance,howeverthe wireless charging system[1][2]overcomes these drawbacks.Therefore, this paper makes a special research on the wireless charging technology of performing robots. The wireless charging system is designed through the technology of electromagnetic coupling resonance[7][8][9], and it can continuously charge in the process of performance[10].

Principle Analysis of Wireless Charging System for Performing Robots

The performance robot wireless charging system structure diagram is shown in Fig.1.

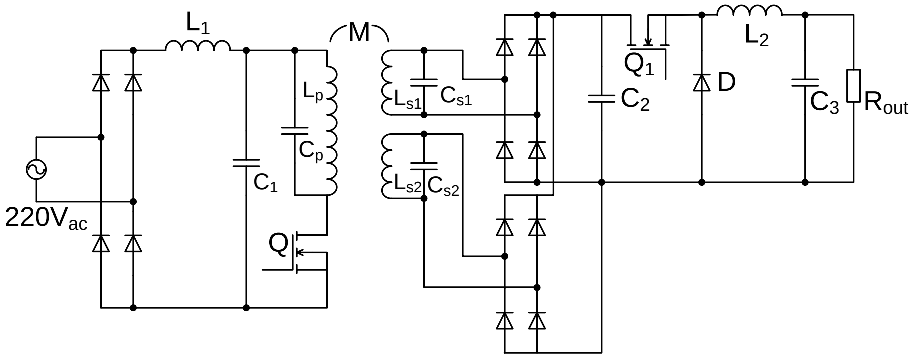


Fig.1. System structure diagram

Inductor L_1 and capacitor C_1 constitute the LC filter circuit.The emission coil L_p and compensati on capacitor C_p of primary side constitute a resonant network,Cpwhich resonates compensation for L_p.Secondary receiving coil L_{s1} and secondary compensation capacitor C_{s1} comprise a resonant cou pling network,and so do L_{s2} and C_s 。

C_{s1} resonates compensation for L_{s1}, C_{s2} resonates compensation for L_{s2}, inverting the DC voltage into high frequency AC square wave voltage through theswitch tube Q, which is controlled by the PWM produced from single chip microcomputer, achieving the soft switch. After the bridge rectifierand theLC filter,220$V_{ac}$is converted into voltage peak 310V_{dc},high frequency is invertedthrough switching tube Q, power is passed to the secondary coil of the L_{s1}, L_{s2} from the primary side coil L_p electromagnetic induction, via a filter capacitor $C_{2,}$ the rectified voltage is filtered, then reduced to the 6V_{dc}voltage by the Buck circuit.

Fig.2 shows the working process of the WPT charging system for the performing robots.

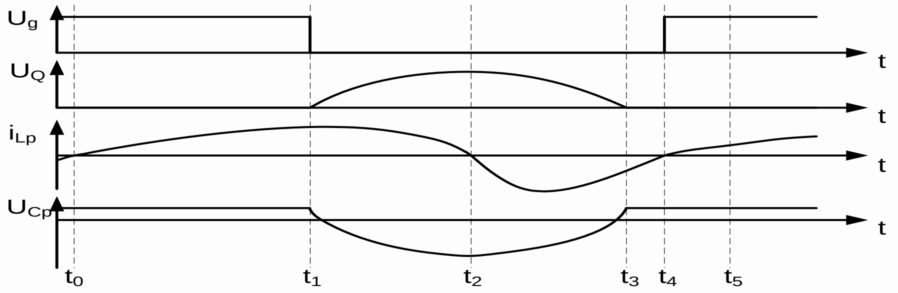


Fig.2. The working waveforms of main circuit

From Fig.2, the emission coil L_p has a current all the time whether the switch is in the open or off state. It shows that the power is always passed from the primary side to the secondary side during the whole cycle.

The dynamic process analysis on each stage of the switching cycle is shown as follows.

Mode1(t0<t<t1):In this mode, the switch Q is turned ON. The primary inductor current increases and, at the end of this mode, the primary inductor current is equal to the maximum.

Mode2(t1<t<t2): When the switch Q turns OFF, mode 2 begins. After turning OFF the switch Q, the primary inductor L_p and the primary compensation capacitor C_p start their resonance because of the energy exchange betweenthem. At t2 the switch Q voltage and the voltage of the primary compensation capacitor C_p reach the maximum at the same time. Meanwhile, the inductor L_p current is equal to zero.

Mode3(t2<t<t3):At t2, the inductor $L_p$current begins increasing in reverse. When the voltage of the primary compensation capacitor C_p is equal to zero, the inductor L_p current reaches the maximum.

Mode4(t3<t<t4):At the beginning of this mode, the switch Q still is OFF. However, due to the body diode turning ON, the switch voltage is clamped to zero. At t4,as soon as the inductor $L_p$current has reached zero, the body diode of main switch is turned ON naturally. In this case, the switch Q turns ON.

Through the mutual inductance model, the main circuit can be analyzed. From fig.3, it's the equivalent circuit diagram of the WPT charging system the performing robot. In Fig.3, the $U_{i.FHA}$ is the input voltage of resonant network. R_p and R_s is the coil resistance of primary and secondary side. M means the mutual inductance between emission coil L_p and the receiving coil L_s.Ro is the load resistance, and the R is equivalent load resistance.Zs means the equivalent impedance of secondary circuit and Z_e means the equivalent impedance of Z_s equivalent to the primary side.

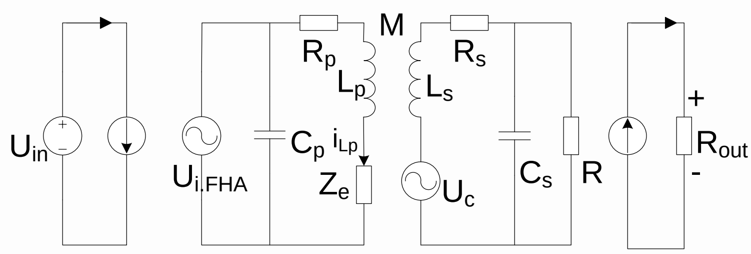


Fig.3. The equivalent circuit diagram of main circuit

From Fig.3 that the modeling and analysis of equivalent circuit, and according to the reference[3,6],some equations are derivated.

$$R = \frac{8R_o}{p^2} \quad (1)$$

$$Z_s = jwL_s + R_s + \frac{R}{1 + jwC_sR} \quad (2)$$

$$Z_e = \frac{w^2M^2}{jwL_s + R_s + \frac{R}{1 + jwC_sR}} \quad (3)$$

$$Z_R = R // \frac{1}{jwC_s} = \frac{R}{1 + jwC_sR} \quad (4)$$

$$\dot{U}_{i.FHA} = \dot{I}_p * \left(jwL_p + R_p + Z_e \right) \quad (5)$$

The voltage $U_{i.FHA}$ is a square wave, then the effective value of fundamental component is:

$$U_{i.FHA} = \sqrt{2}U_{in} / p \quad (6)$$

The voltage of secondary receiving coil is:

$$\dot{u}_c = jwM\dot{I}_p \quad (7)$$

Then the output voltage is:

$$\dot{u}_{out} = \dot{u}_c * \frac{Z_R}{Z_s} = jwM\dot{I}_p * \frac{Z_R}{Z_s} \quad (8)$$

From equation(5)and(8), the voltage gain of resonance network is:

$$M_v = \left| \frac{\dot{u}_{out}}{\dot{u}_{i.FHA}} \right| = \left| \frac{jwM\frac{Z_R}{Z_s}}{jwL_p + R_p + Z_e} \right| \quad (9)$$

Simulation and Experiment

According to the design and analysis of the wireless charging system for performing robot, the simulation and experiment of the soft switch and output voltage of the switch are carried out by using Saber simulation software. Saber simulation waveforms isshown in Fig.4.

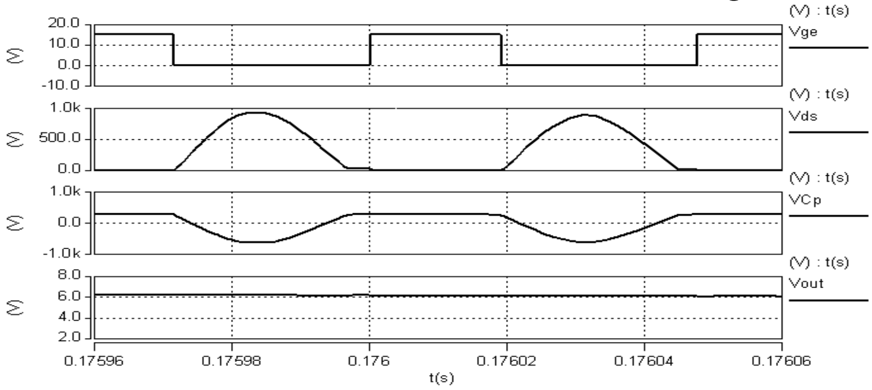


Fig.4. Simulation waveforms of the main circuit

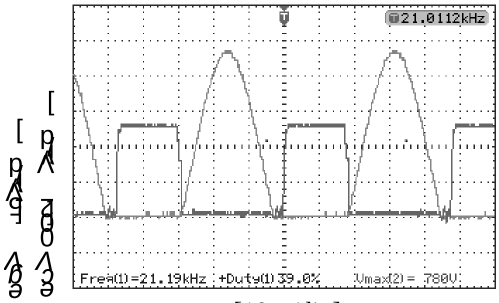
In Fig.4, the V_{ge} is the driving waveform, V_{ds} is the collector-emitter voltage of the switch tube, V_{Cp} is the compensation capacitor voltage of the primary side emission coil,and V_{out} is the output voltage. It can be seen from the figure, when the $V_{ge}$from the high level to low,the switch tube voltage V_{ce} rise slowly, the switch can realize zero voltage turn-off, before V_{ge}changes from low to high, the switch Q's body diode has been turned on and the primary compensation capacitor voltage is clamped to 310V, so it can realize switching tube zero voltage turn-on; output voltage of $6V_{dc}$, shows that the designed performance robot wireless charging system is feasible.

According to the design and simulation as discussed above, we build a robot performing wireless charging system power supply prototype. The main design parameters of the circuit as shown in Table1:

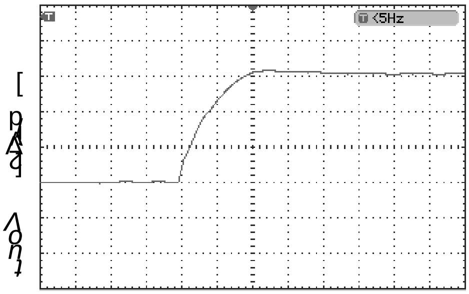
Table1The main parameters of circuit

U_{in}/V_{ac}	U_{out}/V_{dc}	L_p/uH	L_{s1}、L_{s2}/uH	M/uH	C_p/nF	C_{s1}、C_{s2}/nF	R_{out}/Ω
220	6	225	84	15.75	165	100	6

The primary coil diameter of 21cm, the secondary coil diameter of 5cm, the primary and secondary coil distance is 35mm, when the offset amount that the receiving coil in the emission coil facing is not more than 7.5cm, soft switching waveform and the output voltage waveform as shown in Fig.5 and Fig.6.



t[10us/div]



t[200us/div]

Fig.5. Soft switching waveformFig.6. Output voltage waveform

Fig.5 shows that, when the driving signal V_{ge} variable prior to the high level, the switch tube voltage V_{ce} has dropped to zero, the realization of the zero voltage turn-on; the driving signal V_{ge} variable after the low level, the switch tube voltage V_{ce} rise slowly, the switch tube and can achieve zero voltage turn off. As shown in Fig.6, the output voltageV_{out} can be stabilized at $6V_{dc}$ after about 600us. Through the comparison between Fig.4 and Fig.5, the simulation and experiment can realize the soft switch control, reduce the switch loss, and improve the transmission efficiency.

Conclusion

According to the magnetic coupling resonance technique, a set of wireless charging system is designed, which is based on the reasonable mathematical modeling and parameter selection. The simulation and experimental results show that the design of the robot wireless charging system realizes the soft switch control of the switch tube, which makes the coil in the whole cycle pass energy, and reduce the switching loss. In addition, when the robotsare performing on the stage, the charging system output voltage in the battery management circuit, you can continue to provide energy for performing robots.

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