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Performance of dynamic wireless charger of the mobile robot under speed variations along the charging line tract

***Abstract**. The Mobile robot is an eminent part of industry 4.0, needs a supply of electrical energy that enables it to work continuously. However, mobile robot operating time depends on the onboard battery capacity, which needs to recharge after working for some time. During the onboard battery charging time, consequently, the mobile robot stops operating or idle. Therefore, a dynamic wireless charging system is needed that could charge the robot battery while moving. Yet, there is not enough information about the charging technique of the onboard robot battery in motion. This article presented a dynamic induction wireless charger of a mobile robot. The robot battery is recharged wirelessly without stopping at the charging station. The proposed dynamic wireless charging system consists of a transmitter array along the robot track. The transmitter generates the magnetic field transmitted to the onboard battery charger receiver attached to the mobile robot while the robot passes through the charging line track. Experiment results indicated that the mobile robot without a wireless charger could run through a 7.9-meter-track for only 30 rounds. The onboard battery voltage drops from 7.1 Volts to 4.5 Volts. When the 1.5 meters long wireless charger track is activated, the mobile robot can run 100 rounds. Charging time was adjusted by the speed variation of the mobile robot along the charging line track. The onboard robot battery voltage drops from 7.1 Volts to 6.7 Volts. The voltage drop is only 0.4 volts after 100 rounds or equal to a 790-meter cruise. Finally, the experiment results indicated that the dynamic wireless charger designed and tested in this study successfully extended the working time of the mobile robot.*

***Streszczenie.** Robot mobilny jest wybitną częścią przemysłu 4.0, potrzebuje dostaw energii elektrycznej, która umożliwia mu ciągłą pracę. Jednak czas pracy robota mobilnego zależy od pojemności akumulatora na pokładzie, który musi się naładować po pewnym czasie pracy. W czasie ładowania akumulatora na pokładzie robot mobilny przestaje działać lub pracuje na biegu jałowym. Dlatego potrzebny jest dynamiczny system ładowania bezprzewodowego, który mógłby ładować akumulator robota podczas ruchu. Jednak nie ma wystarczających informacji na temat techniki ładowania akumulatora robota pokładowego w ruchu. W artykule przedstawiono dynamiczną indukcyjną bezprzewodową ładowarkę robota mobilnego. Akumulator robota jest ładowany bezprzewodowo bez zatrzymywania się przy stacji ładującej. Proponowany dynamiczny system ładowania bezprzewodowego składa się z układu nadajników wzdłuż toru robota. Nadajnik generuje pole magnetyczne przesyłane do pokładowego odbiornika ładowarki podłączonego do robota mobilnego, podczas gdy robot przechodzi przez tor linii ładowania. Wyniki eksperymentu wskazują, że robot mobilny bez bezprzewodowej ładowarki może przejechać przez 7,9-metrowy tor tylko przez 30 rund. Napięcie akumulatora na płycie spada z 7,1 V do 4,5 V. Po aktywacji toru ładowarki bezprzewodowej o długości 1,5 metra robot mobilny może wykonać 100 rund. Czas ładowania był regulowany przez zmianę prędkości robota mobilnego wzdłuż toru linii ładowania. Napięcie akumulatora robota na pokładzie spada z 7,1 V do 6,7 V. Spadek napięcia wynosi tylko 0,4 wolta po 100 rundach lub równy 790-metrowemu rejsowi. Wreszcie, wyniki eksperymentu wskazały, że zaprojektowana i przetestowana w tym badaniu dynamiczna ładowarka bezprzewodowa z powodzeniem wydłużyła czas pracy robota mobilnego. (**Działanie dynamicznej ładowarki bezprzewodowej robota mobilnego przy zmianach prędkości wzdłuż linii ładowania**)*

Keywords: wireless charging; induction; mobile robot
Słowa kluczowe: ładowanie bezprzewodowe; indukcja; robot mobilny.

Introduction

Mobile robots are programmed to run on a predefined path to perform high-end functions on a factory floor [1]. The drawback of mobile robot working time at the factory floor depends on the onboard battery's capacity. The recent development of battery technology has advanced in increasing battery power and capacity. However, it remains a weakness for mobile robot applications. Once the robot has worked for a certain period, it must return to the battery charging station to recharge the batteries. Therefore, the robot cannot operate during the battery charging process [2]. For the robot to continue to get electricity supply even though it is on the move, a dynamic battery charging system is required using wireless electrical energy transfer system technology.

Wireless electric power transfer technology has attracted the attention of researchers in recent years due to its wide range of applications [3]. The most promising application of this technology is in charging the Electric vehicle batteries wirelessly which, operates using the principle of magnetic induction and magnetic resonance. The working principle is like transformers that induce magnetic fields through coils around them to generate electric current on other coils or secondary coils in the vicinity [4]. The charger technology to charge the batteries of the electric vehicle applies to mobile industrial robots as well.

This induction system has been applied to the Tropllaxis Robot using a magnetic coupling system. A digital camera is mounted on the robot to correct the alignment between the sender and the receiver's coils [5]. A wire coil with a ferrite core placed underneath shielded by a reflector plate is used to increase the efficiency of electrical energy transfer. An electric ferrite core coil mounted underneath is intended to reduce the magnetic flux leakage [6]. Like mobile robots, the application of wireless charging applies in electric cars. Currently, there are two problems encountered by wireless power transfer, the gap and misalignment between the transmitter and receiver coils [7].

The previous researches on wireless charging systems showed that they are focusing on static charging systems. On the other hand, dynamic charging systems are only available in electric car applications. Moreover, the information about dynamic wireless charging system applications for an automated guided vehicle or mobile robot on a factory floor is limited. Therefore, this article hopefully will contribute to or enrich these information gaps. Hence, the dynamic wireless charging can be applied to industrial mobile robots soon. Experiment results revealed that the robot's working time is prolonged after passing through the wireless charging track.

Methodology

Figure 1 shows the experiment layout that consists of two main parts, the transmitter, and receiver. The transmitter coils are arranged in series underneath the charging line track to create a dynamic charging system. This arrangement will enable the moving robot to receive a continuous magnetic field along the charging line track.

The following is the description of the working principles of the wireless electrical power transfer system. Initially, a DC voltage supply from the rectification of the line source of electricity is acquired. This DC voltage serves to drive a low-frequency oscillator that works at a frequency of 20 kHz. This optimum frequency reversed to previous research [8].

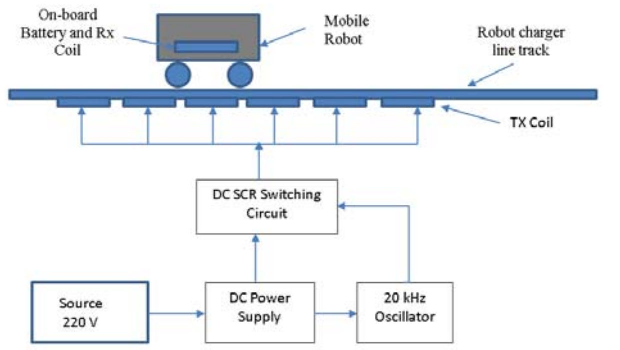

Fig. 1. Experiment Layout.

To increase the power transfer of the system, it uses a switching circuit that works at a frequency of 20 kHz using SCR transistors. The TX coil will convert the electric current into a magnetic field, which will further create magnetic field induction received by the onboard coil receiver of the mobile robot. The electricity generated on the receiver coil is further rectifiers using voltage regulators to produce a DC electric current required to charge the onboard robot's battery.

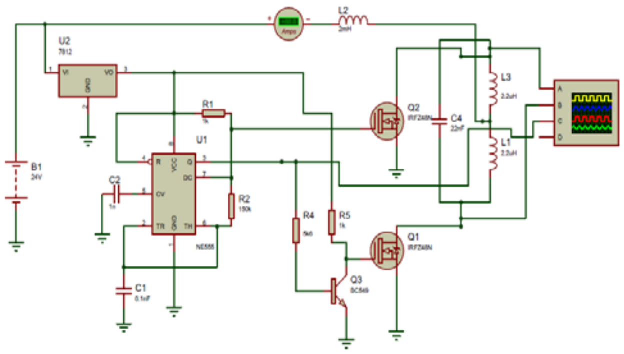

Fig. 2. Wireless power transfer driver using MOSFET IRFZ48N.

The driver circuit utilized in the experiment relies on the simulation result of both circuit drivers using Proteus 8.9 simulation software. The simulation result provided preliminary information on the properties of the transmitter driver signal required to set the optimum output signal.

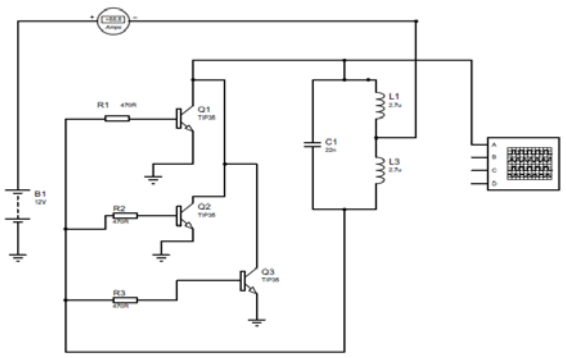

Fig. 3. Transmitter Driver Oscillator of Wireless Power Transfer using BJT transistor TIP35C.

Result and discussion

After conducting a simulation test using Proteus 8.9 software, it appears that a one-stage oscillator circuit using a power transistor (TIP35c), as seen in Figure 3, showed a clean output signal (Figure 4). Simulation results of the driver circuit using IRFZ48N switching transistor showed ripple voltage at the peak of the output signal presented on the virtual oscilloscope screen in Figure 5.

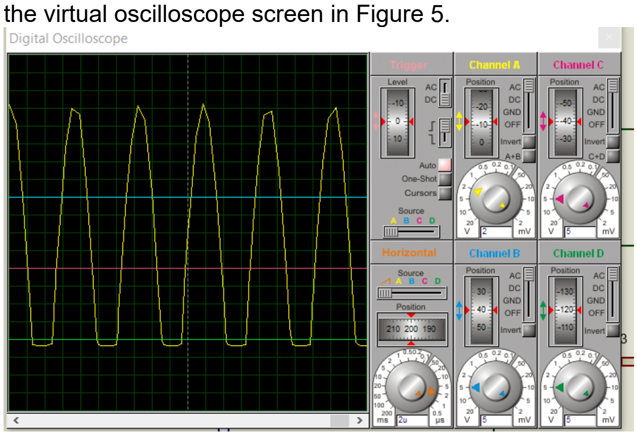

Fig. 4. Simulation results of the Colpitts type oscillator transmitter driver.

Based on the simulation result, the driver circuit (Figure 3) gave an excellent result. Therefore, the circuit driver described in Figure 3 is selected. Since L1 and L2 coils require a large current, there are three BJT TIP35C transistors installed in parallel to generate a stronger magnetic field. These BJT TIP35C transistors must have the same characteristics.

Another consideration in determining the driver network is the ease of making the hardware. Based on the oscillator circuit Figure 3, it can produce a smooth signal even if it arranges from a simple circuit of coils, capacitors, and resistors mounted on the base of the transistor.

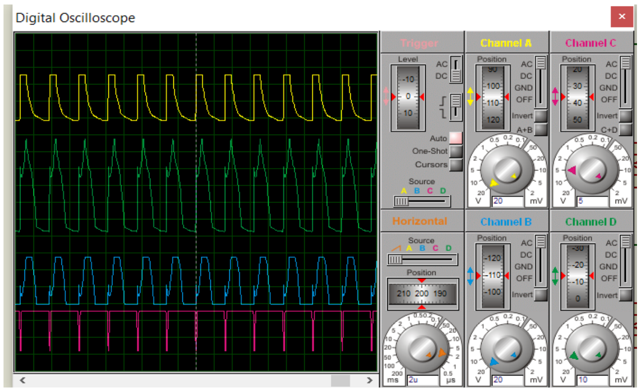

Fig. 5. Simulation results of circuit driver using MOSFET IRFZ48N.

Based on theory, the electromagnetic waves of the electric current at high frequencies flow on the surface of the cable. Therefore, using the large diameter of the wire is ineffective because only the outside produces magnetic flux. This phenomenon is known as the skin effect [9].

To overcome the flaws of the large-diameter conductor to work at a high frequency, then, several small diameter wires are wrapped in turn to form bifilier coil for transmitter and pancake coils for onboard battery charger receiver. The experimental results showed significant improvement that presented in Table 1.

Figure 6 shows the load test experiment of wereless energy tranfer using bifilar coils of transmitter and receiver repectively. The generated waveform by the transmitter observes using an oscilloscope.

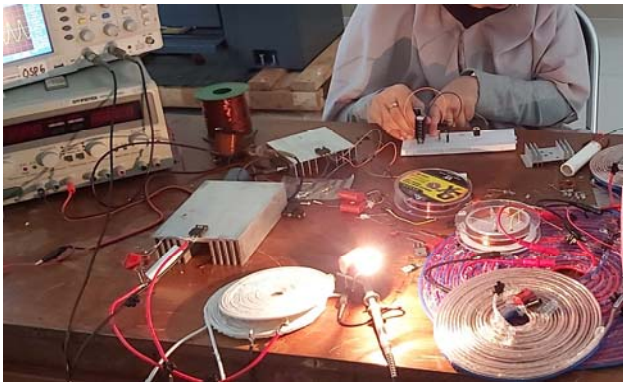

Fig. 6. Wireless Power Transfer load test experiment using bifilar coil of transmitter and receiver.

This observation was measured using a two-channel Tektronix oscilloscope (Figure 7). Channel one is yellow show the signal received at the DC Lamp of 12Volt/55Watt load. The second channel presented the transmitter oscillator signal. The waveform of the transmitter is spike-shaped, with the maximum amplitude reaching 283 Volt peak to peak. On the receiver coil of the receiver voltage at the DC lamp load terminal was 14.9 Volts.

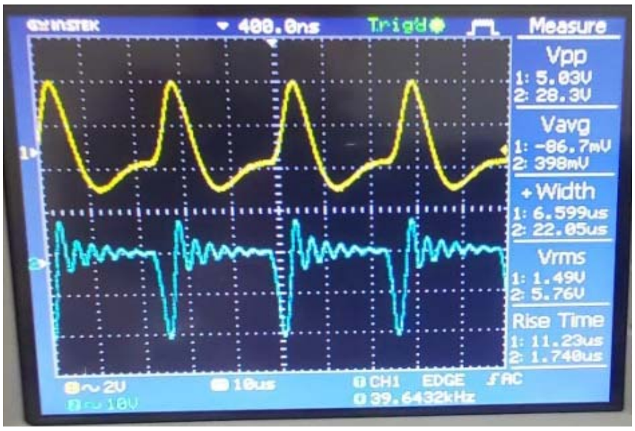

Fig. 7. The Waveform of transmitter and receiver signals.

The comparison results of the DC input power and received power of the receiver determine the performance and efficiency of the wireless power transmitter

Table 1. Measurement Results of statics wireless power transfer.

Input Voltage (V)	Input Current (A)	Input power (W)	Output power (W)	Efficiency (%)
11,7	3,85	45,045	44,080	97,86
11,7	3,83	44,811	44,080	98,37
11,7	3,85	45,045	44,829	99,52
11,7	3,85	45,045	44,950	99,79
11,7	3,86	45,162	45,122	99,91

Measurements were conducted at 5-minute intervals to validate the observed data. The measurement results are presented in Table 1.

Performance of dynamic wireless charger

The performance of Wireless Electrical Energy Transfer System carried out in this study were observe based on received voltage of robot onboard receiver. There were two scenarios carried out to obtain valid results. First, the transmitter driver was off state. Second, all the transmitter's coil drivers were at the on position. All scenario begins at a full charge battery voltage of 7.1 Volt DC. The results obtained from the experiments are as follows:

Wireless charger off.

Experiment begins with the first scenario; the wireless charger was off. The mobile robot is activated and runs to follow the trajectory installed on the workshop floor. At first, the robot was running normally. In the first ten rounds, the onboard robot battery voltage is stable at 7.1 Volts. But after entering the 11th lap, the battery voltage began to drop from 7.1 Volts to 7.0. In the next five laps, the battery voltage drops to 6.9 Volts and so on. Finally, at the 30th round, the battery voltage dropd to the lowest level of 4.9 Volts.

After reaching the 30th laps, the robot stops because the L298N driver motor used on the robot line follower requires a power supply of at least 5 Volts. The experiment result can be seen in Figure 8.

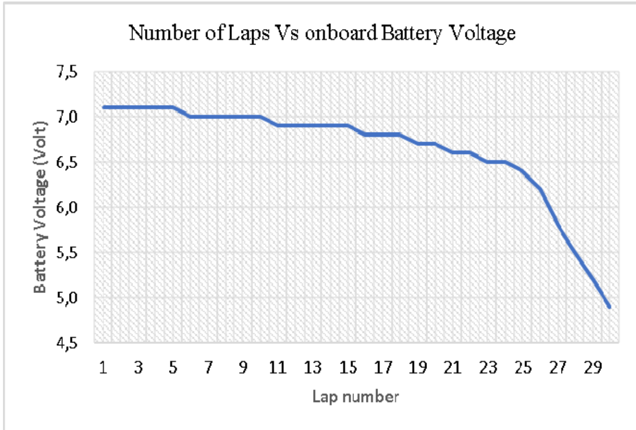

Fig 8. Voltage drops of the robot battery without a wireless charger.

Wireless charger on.

The next experiment was to activate the wireless transmitter installed under the the mobile robot line tract. The observation was conducted twice, with different robot speed settings. The robot speed depends on the duty cycle of motor driver (IC- L298N) through the microcontroller program on Arduino UNO R3 [10].

In the first experiment, the motor driver module L298N runs at a 50% duty cycle. When the robot leaves the charger line track, the PWM motor driver L298N returns to a 75% duty cycle.

Before starting the experiment, the robot's onboard batteries were in a fully charged state. Therefore, the battery voltage started at 7.1 Volts. When the battery voltage reached 7.1 volts, the robot turned on. The counting of the robot laps around the line follower track begins. In the first ten laps, the robot's voltage level remains stables at 7.1 volts. However, in the next ten rounds, the situation was different from the previous experiment. The onboard battery voltage was constant at 7.1 Volts.

At laps 21 to 27, the voltage level drops to 7.0 Volts. The 28th lap drops again to 6.9 Volts and lasts until the 50th lap. The 51st lap again dropped to 6.8 Volts and lasted until the 79th lap. When entering the 80th lap, the robot voltage drops again to 6.7 Volts and survives until the 100th lap. After that, the robot stopped because the dc motors overheated.

The experiment results with a 50% PWM duty cycle appeared that the onboard battery voltage dropped slowly. However, this voltage drop was slower than the result of the previous experiment without wireless charging. After the robot run for 100 rounds, the battery voltage only drops by 0.4 Volts. Recorded data indicated that there is no trend to rise. Therefore, the result of the experiment showed that the discharge rate was higher than the battery charging rate.

To overcome the flaws of a 50% PWM duty cycle, the mobile robot motor driver duty cycle was adjusted to a lower level that of 40%. This attempt successfully reduces the robot speed when it runs over the wireless charger track. The robot speed reduction will provide additional battery charging time while running over the wireless charger track.

The investigation that resembles the previous test with a 50% PWM duty cycle intended to observe the effects of robot speed reduction. Initially, the mobile robot performs static charge until the battery voltage level returns to 7.1 Volts. Next, the mobile robot was turned on and run encircled the predefined line tract.

This speed reduction gives more charging time of the robot onboard battery while running through the wireless charging tract. The observations result provides information that the battery voltage level lasts at a voltage level of 6.7 - 6.9 Volts or a standard voltage deviation of 0.2 Volts.

When the battery voltage starts to drop below 6.7 Volts, it will produce a significant voltage difference between the charger and the batteries. As a result, the battery charging current increases, therefore, the battery voltage level rises up to 6.9 Volts.

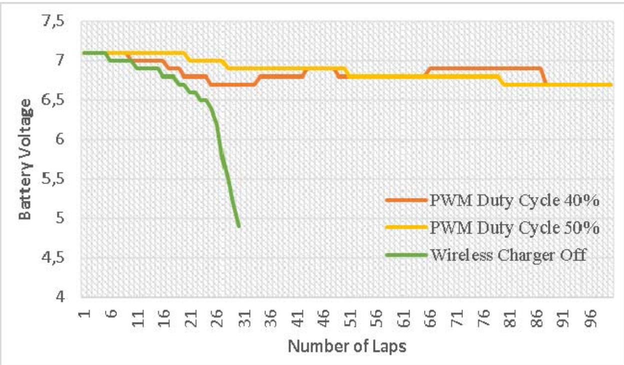

Fig. 9. Comparison of Battery Voltage Level between active and inactive wireless chargers.

Figure 9 shows that the dynamic wireless power charger developed in the study successfully extended the robot's working time from 30 laps to 100 laps or more. From the same image, it appears that the change in duty cycle from 50% down to 40% or, in other words, the robot speed reduced by 10% makes the battery voltage more stable. Since the PWM duty cycle of 40%, the robot has a longer battery charging time than the PWM duty cycle of 50%. Therefore, the wireless power charger developed in this study successfully maintains the voltage level of the robot battery that reaches the 100th lap. In other words, the robot can run as far as 790 meters without a stop to recharge the onboard battery.

Conclusion

The results obtained in this study show that the wireless charger using a bifiliar coil transmitter and onboard pancake coil receiver successfully transfer electric energy wirelessly. The transmitter coil generates magnetic flux. It generates an electricity source onboard to recharge the mobile robot batteries. The onboard batteries successfully recharged while the robot was moving over the charger track.

The performance of the mobile robot without a wireless charger is only capable of performing 30 laps on the test track. Since the wireless charger is activated, the robot can run through the test track up to 100 rounds without stopping to charge the batteries. Changes in the robot speed when passing the charger track give significant affect of the charging time of the onboard mobile robot battery.However, this research work is still on a prototype scale, therefore, it needs to be further studies on a larger scale. Power transfer efficiency and safety factors should be among those to be taking into account in future development.

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