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Tethered Contactless Mobile Nuclear Environment Monitoring Robot

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1. Introduction

After Fukushima nuclear accident, which is one of the worst nuclear accidents, the importance of nuclear environment monitoring and security management system boost up significantly to guarantee the safety of nuclear power plants (NPPs) in the UAE while several NPPs are under construction [1]. In fact, the nuclear environment monitoring is significantly crucial for early detection of NPP accident, radiological emergency, the estimation of radiation exposure to nearby residents as well as the long term radioactivity [2]. In the UAE, the nuclear environment monitoring is, however, quite challenging because sampling locations are far from NPPs and the outdoor temperature and humidity are very high for NPP workers to collect soil, air, and water samples. Therefore, nuclear environment monitoring robots (Nubos) are strongly needed for the NPPs in the UAE. The Nubos can be remotely controlled to collect samples in extreme environment instead of NPP workers. Moreover, the Nubos can be unmanned ground vehicles (UGVs), unmanned aerial vehicles (UAVs) and unmanned marine vehicles (UMVs) to collect soil, air, and water samples, respectively. In this paper, the prototype development of UGV type Nubos using power cable for a long distance power delivery, called Tethered contactless mobile Nubo is introduced and validated by experiments.

2. Design of Tethered Contactless Mobile Nubo

2.1 Configuration of the Proposed Nubo

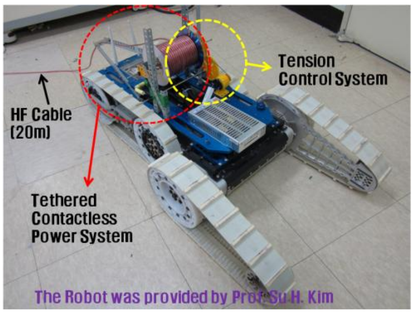
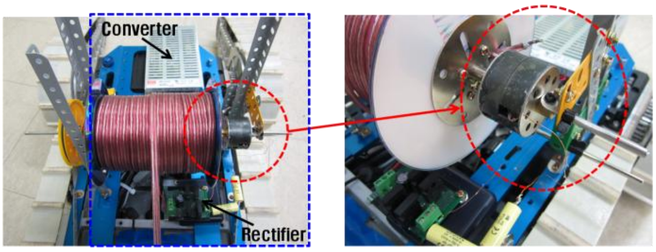


Fig.1 Proposed Tethered Contactless Mobile Nubo.

Tethered contactless mobile nuclear monitoring robot (TeCoM Nubo), which contactless power can be obtained by a high frequency (HF) cable enrolled on the robot, is proposed as shown in Fig. 1. In the TeCoM Nubo, it includes two sub-systems; tethered contactless power system and tension control system, which can supply contactless power to the robot and keep the high cable tension because power cable is likely to be tangled up [3].

2.1 Proposed Tethered Contactless Power System



(a) (b)

Fig.2 (a) Proposed Tethered Contactless Power System, (b) Rotational Transformer.

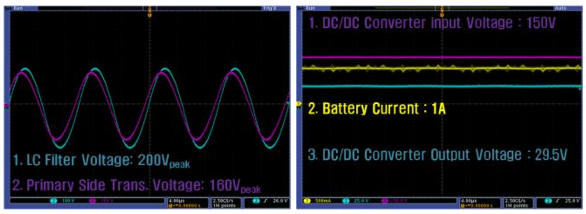
Tethered contactless power system (TCPS), as shown in Fig. 2 (a), is designed for long distance power delivery and the TCPS consists of HF power cables, rotational transformers, rectifiers and DC/DC converter while the HF power cable is powered by an inverter located in a nuclear power plant.

In order to realize the TCPS for long distance power delivery, the system requirements should be satisfied as follows:

1) For a long distance power delivery (~1 *km*), the power cable should be thin enough for the large winding number in the limited space of bobbin.
2) The operating frequency should be high (>20 *kHz*) enough and the voltage level should be high (>100 *V*) to minimize the size of the contactless transformer and wire.
3) For a stable battery charging of Nubo, 25 *W* power should be provided continuously.

Based on the system requirements, the preliminary TCPS is designed, however, high frequency ringing around 1.4 *MHz* occurred, which may break the power delivery system. This is due to the resonance between parasitic inductance and capacitance of the power cable.

LC filter, $L_r = 100\ \mu H$ and $C_r = 47\ nF$, is adopted as a remedy for this problem and the frequency ringing was completely eliminated as shown in Fig. 3.



(a) (b)

Fig.3 Voltage and Current Waveforms of (a) LC Filter, Rotational Transformer, (b) Converter and Battery.

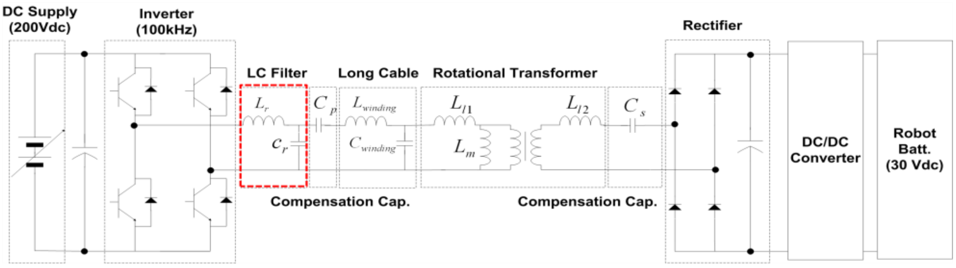


Fig.4 Equivalent Circuit of the Proposed Tethered Contactless System.

The 25.5 *W* power for the battery charge of the Nubo is well achieved by the proposed tethered contactless power system as shown in Fig. 4.

2.2 Proposed Tension Control System

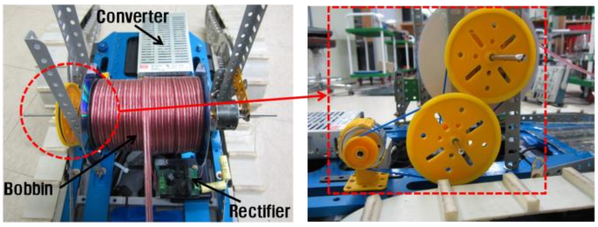


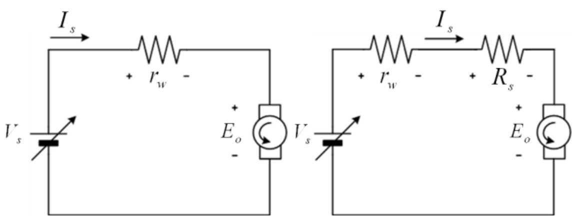
Fig.5 (a) Proposed Tethered Contactless Power System, (b) Rotational Transformer.

Tension control system (TCS), as shown in Fig. 5, is designed to avoid tangled cable during the operation and it contains motor, reduction pulley, bobbin, and wire guidance. For the realization of the TCS system, the system requirements are as follows:

1) Since the tensile strength of the power cable selected for the proposed Nubo is 400 *N*, the maximum force taken in the cable should be under 40 *N*, a tenth of the tensile strength.
2) By a preliminary experiment, only small force of 1~2 *N* on the power cable is needed to perform the tension control.
3) The tension control system should provide a constant force regardless of the direction and speed of the Nubo.

A DC motor, as shown in Fig. 6 (a), is used for the proposed TCS. However, from (1) it leads to a significant problem that the current I_s increases rapidly when the DC motor operates in full load region because counter electromotive force E_o becomes zero.

$$I_s = \frac{V_s - E_o}{r_w} \qquad (1)$$



(a) (b)

Fig.6 Equivalent Circuit of (a) DC Motor, (b) proposed DC Motor.

The overflowing current leads to the result in breaking the DC motor. In order to solve this problem, additional resistor R_S is inserted, as shown in Fig. 6 (b), so that the current of the DC motor can be under the rated current when it is in full load region.

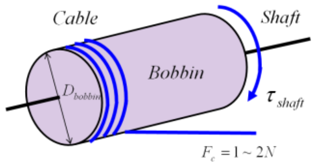


Fig.7 Schematic of Bobbin and Cable Winding.

From (2), the torque should be 4.5 *N·cm* for the tension control when D_{bobbin} is 6 *cm* and the DC motor should provide this torque in the opposite direction of a bobbin rotation as shown in Fig. 7.

$$\tau_{shaft} = F_c \times R_{bobbin} = F_c \times \frac{D_{bobbin}}{2} \qquad (2)$$

In order to meet the requirement torque, the R3429A DC motor made by D&J corp. which has the 0.5 *N·cm* in rated current and 1:9 pulleys are selected as shown in Fig. 5 (b). By indoor demonstration of the TeCoM Nubo, it is found that the DC motor and rotational transformer are in the normal thermal operating condition after 10 minutes operation.

3. Conclusions

In this paper, the prototype development of Tethered Contactless Mobile (TeCoM) Nubo, which can be powered continuously within several *km* distance and avoid tangled cable, and the indoor test are finished. As further works, outdoor demonstration and a grand scale R&D proposal of practical Nubo will be proceeded.

REFERENCES

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