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Output Characteristics of Mobile X-Rays Using a High Voltage Generator of Pulse Frequency Modulation

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Abstract

Therefore, to complement, we made a device that can generate high-dose radiation by using a high-capacity capacitor. The mobile X-ray device was designed for high factor and reduction in power consumption by applying pulse frequency modulation capable of variable driving frequency in a high voltage-generating device. In this paper, we studied frequency and output characteristics varying depending on the load fluctuation of the mobile X-ray machine. As a result, exposure dose and operation frequency linearly increased or decreased, depending on the changes in tube-voltage and tube-current.

Keywords: *Mobile X-ray, Pulse Frequency Modulation, Exposure dose*

1. Introduction

The spectroscopic characteristics of X-ray are used in various fields such as identifying components and structure of substances, and identifying the internal structure of the human body and substances, *etc.* [1-3]. X-ray diagnostic apparatus is used for a wide range of purpose such as noninvasive diagnosis using a method that has the penetrating power and makes the images according to its attenuation [4-5]. For generations of X-rays, a vacuum discharge X-ray tube was used. The X-ray tube accelerates electrons generated at the cathode and generates an X-ray by colliding them with the anode target. Therefore, a separate power source is essential because of the high power required to generate the high-volume of X-rays for scanning the entire body. X-ray diagnostic apparatus are classified into X-ray devices for taking blood vessels, chest, head and neck, and breast depending on the diagnostic part, and mostly used in the form of fixing the system in designated places to satisfy stable power supply and patient care environment. Using the fixed type of X-ray machine can be difficult in diagnosing patients quickly in an emergency because patients need to be moved to a designated area for diagnosis [6]. In order to solve this problem, the mobile type of X-ray is used but only commonly in localized diagnosis, such as hands and feet, because a limited amount of X-rays is generated [7-8]. Therefore, in this study, we made a mobile X-ray device that can generate high-power X-rays by applying high-volume capacity without a separate power source equipment. The mobile X-ray device was developed by applying pulse frequency modulation, and its characteristics were analyzed.

2. Concept

For safe use in the human body, an X-ray device consists of a variety of safety devices and apparatus. An X-ray device is basically composed of a power supply responsible for input power for X-ray generation, a console inputting and displaying operating conditions of the device, a control circuit responsible for the overall operation of the device, and a

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transformer passing high voltage to an X-ray tube. Figure 1 shows the configuration of the designed mobile X-ray device.

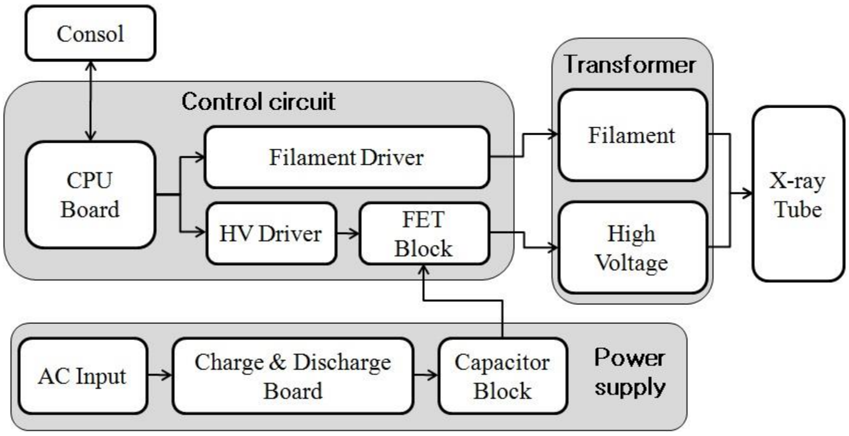


Figure 1. Configuration of a Mobile X-Ray Device

A console of the mobile X-ray can set the irradiation conditions such as on/off, tube-voltage, tube-current, and exposure time of mobile X-ray device, and also plays a role in transmitting and receiving X-ray factors set in the CPU board within the control circuit. A control circuit consists of a CPU board responsible for the control and operation of the mobile X-ray device, a filament driver generating a control signal in filament transformer to generate tube-current within the X-ray tube, a HV (High-Voltage) driver, and FET block supplying controlled voltage to the HV Transformer for high voltage generation. The designed device is used as a source for high voltage generation by using high-capacity capacitance charged by receiving 220 V alternating voltage. For the supply of DC voltage of 540 V, a capacity block of a mobile X-ray device composed capacity with 10,000 uF, 400 V capacity in series and parallel. The charging current of a capacity block is transferred to a FET block of the control circuit and is used as primary input power of the HV transformer as a switching signal in HV driver. The HV transformer receives voltage in the FET Block and is boosted to approximately 25 kV, according to the primary and secondary turns ratio of a high voltage transformer. The transformed high voltage generates DC high voltage of up to 150 kV by using a double voltage rectification circuit and using this generates high-dose radiation.

The filament transformer was configured to control the production of hot electrons by being depressurized to 7.7 ~10.4 V by the turns ratio of 3:1, by receiving the voltage of 36 V in filament driver. Also, in order to minimize the restriction of diagnostic areas, an X-ray tube of the rotating anode type was used.

A typical X-ray generator is used by applying the resonant inverter method [9]. The resonant inverter method can reduce heat loss and power consumption when transforming because its high voltage generation efficiency gets higher as driving frequency increases. In this study, we applied the variable pulse frequency modulation to the generation of high voltage by considering the characteristics of the inverter-type, and analyzed the characteristics of the designed mobile X-ray device.

3. Experiment

3.1. Frequency Control

SG3525 of ST Microelectronics was used as the frequency control for the high-voltage generation of the mobile X-ray device. The device generates a PWM (Pulse Width Modulation) signal divided into 4,096 steps in a CPU board by the setting values of the tube-current and tube-voltage, and X-ray exposure conditions input in consol. The generated PWM signal is used as reference data at mobile X-ray output control and converted into analog signal by a D/A (Digital to Analog) converter. Also, it generates feedback data by decompressing tube-voltage applied to actual X-ray tubes depending on the setting conditions to a constant rate. Reference data and feedback data generated like this are used as an input signal of Rt and Ct terminal of SG3525 through LM324 comparator. Signals through the comparator play a role of adjusting the frequency used for high voltage generation in SG3525, and a uniform high voltage can be always generated. Figure 2 shows the block diagram of SG3525.

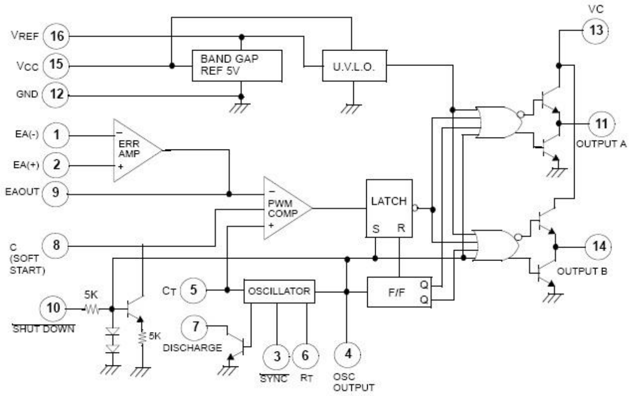
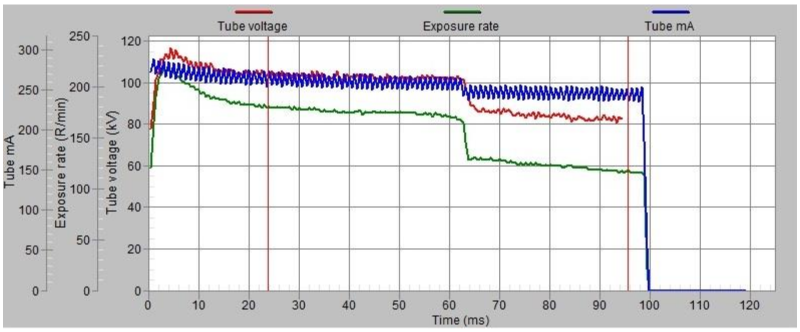


Figure 2. The Schematic Diagram of SG3525

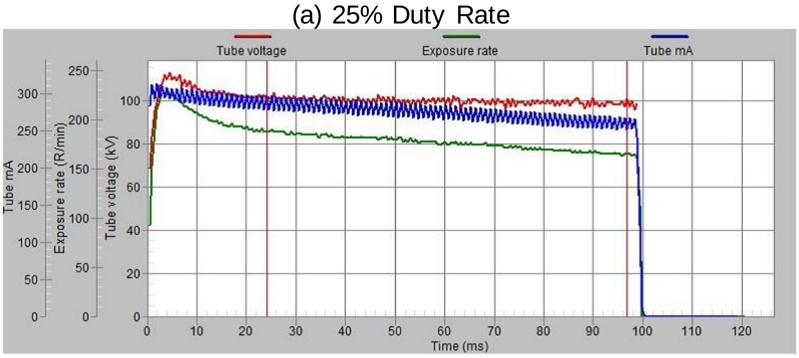
Pulse frequency modulation maintains duty rate equally because EA (+) used for pulse width control of SG3525 is fixed to a constant value and determines switching range of the FET block. The ratio of Rt and Ct corresponding to time constant of SG3525 is changed by reference data and feedback data, and oscillator oscillation frequency varies accordingly.

3.2. Output Characteristic

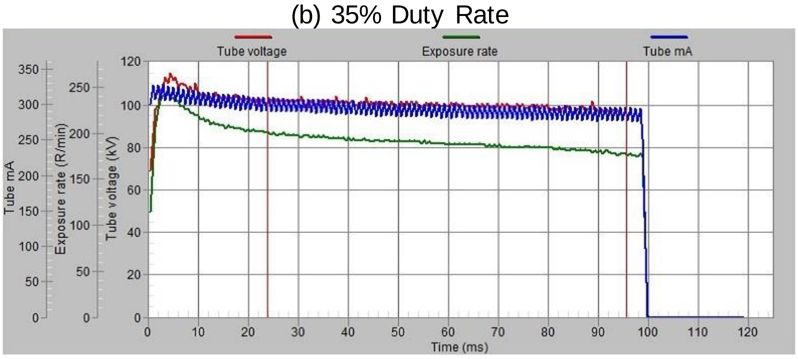
An X-ray device requires uniform generation of X-rays in order to minimize radiation exposure and obtain a high quality image. To do this, the amount of X-rays actually generated according to irradiation conditions should be uniform and this is closely related to uniform generation of tube-voltage and tube-current used in X-ray generation. In this study, in order to analyze the operating characteristics of SG3525, we identified the change in tube-voltage, tube-current, and exposure dose while changing the resistor by setting duty rate applied to EA (+) of SG3525 to 25%, 35%, 45%. Considering the high output situation, the experiment was carried out under the conditions of tube-voltage 100 kV, tube-current 300 mA. Based on 0.1 second of irradiation time, Barracuda dose meter (RTI Electronics AB, Mölndal, Sweden) capable of measuring tube-current, tube-voltage, and exposure dose was used for the experiment. Figure 3 shows output characteristics depending on duty rate variation of SG3525.



(a) 25% Duty Rate



(b) 35% Duty Rate



(c) 45% Duty Rate

Figure 3. Output Characteristics Depending on Duty Variation

As a result, tube-voltage and tube-current were reduced dramatically at 25% duty based on about 63 ms, and the amount of exposure dose was lowered accordingly. In case of 35% duty rate, tube-current has been constantly lowered for 100 ms and the actual measured average tube-current was shown to be 274 mA, not set 300 mA. Finally, relatively uniform tube-voltage and tube-current could be generated at 45% duty rate. This is due to different conversion efficiencies in the actual transformer even when using the same input power, because the switching range applied in FET block is changed by duty rate.

Therefore, we measured the exposure dose generated while setting to apply 45% of duty rate to EA (+) used in the pulse width of SG3525 and changing tube-voltage and tube-current.

The experiment was carried out by dividing tube-voltage in 20 kV unit up to 40~80 kV, and dividing the measured points in 50mA unit up to 50~300 mA in case of tube-current. Changes in exposure dose depending on change in tube-voltage and tube-current are shown in Figure 4.

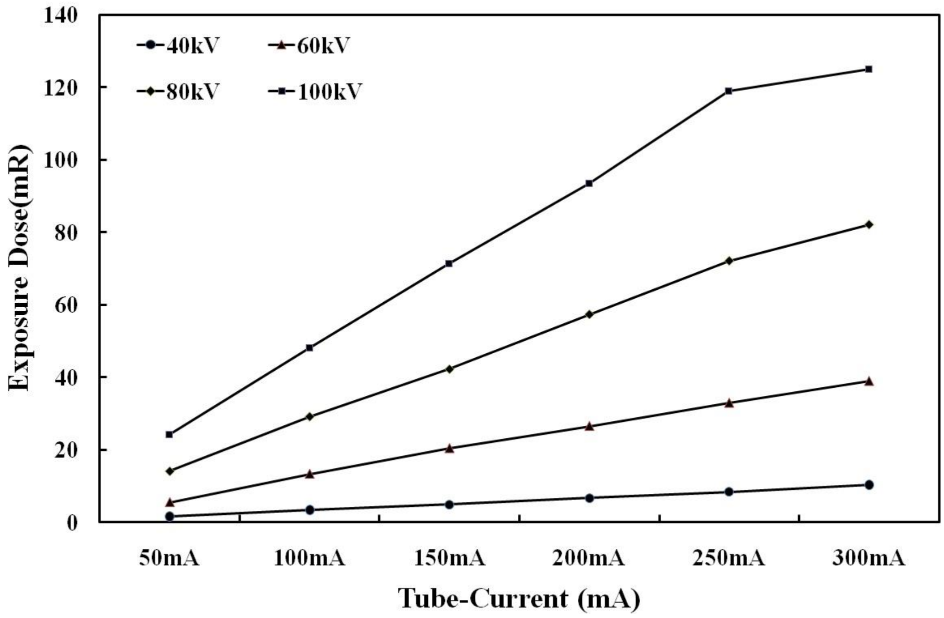


Figure 4. Changes in Exposure Dose of Tube-Voltage and Tube-Current Variation

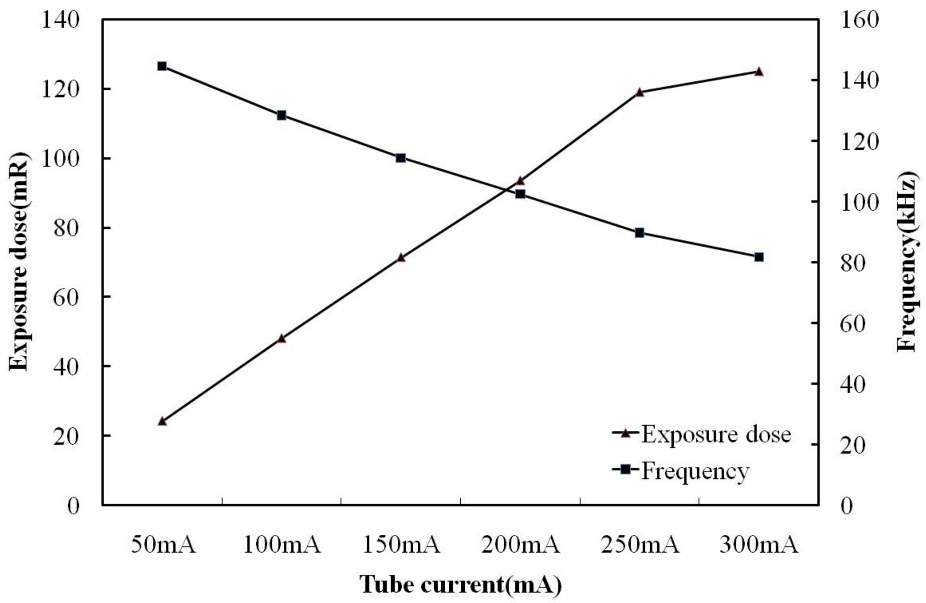


Figure 5. The Change of Exposure Dose and Frequency According to the Increased Tube-Current in High Voltage Condition

As a result, it was found that it is operating at low driving frequency as tube-current is higher. In this study, SG3525 for variable frequency set minimum frequency to 80kHz for device protection. Therefore, the increase range of frequency and exposure dose was not uniform by the limit of driving frequency in the conditions of 100 kV, 300 mA with the highest power.

4. Conclusions

In this study, we designed mobile X-ray device to generate high dose X-rays by using charging voltage of high volume capacity. The designed mobile X-ray device applied the pulse frequency modulation to the generation of high voltage in order to generate high dose X-rays by using limited input power. We used SG3525 for the frequency control of the device and measured tube-voltage, tube-current and exposure dose while changing duty applied to EA+ of SG3525 in order to study the efficiency characteristics for operation. As a result, relatively uniform tube-voltage and tube-current were generated at duty 45 %. These results occurred because the conversion efficiency of transformer varied by changes in the switching range for the generation of high voltage in FET block. Therefore, we analyzed the output characteristics of the device after setting duty of the designed device to 45 %. We measured exposure dose at each measurement point while changing tube-current and tube-voltage and as a result, we found out that exposure dose changed relatively linearly as tube-voltage and tube-current change and this suggests that uniform output control is possible depending on changes in exposure conditions. Also, in order to study the change characteristics of driving frequency when high-dose X-ray is generated, we measured frequency change patterns depending on tube-current change at 100 kV. As a result, it was found that driving frequency is lowered as tube-current increases. These results show that the designed X-ray device can use the high driving frequency compared to the inverter method and reduce loss by heating of transformer and power consumption.

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