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Equipment for measuring the characteristics of X-ray

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Abstract: X-ray measurement equipment is designed which utilizes a pair of photodiode detectors. The equipment is designed which utilizes a pair of photodiode detectors units which receive X-rays through filters with different attenuation coefficients for X-rays. The photodiode detector units preferably includes two pairs of photodiode detectors arranged symmetrically in four quadrants with the diodes in each detector unit in diagonally opposite quadrants. The outputs of the detector units are passed to variable gain amplifiers, gains of which are adjusted to bring the output voltages within a desired range, and the outputs of the amplifiers are integrated by integrators. After a selected period of time, the integration is stopped and the output voltages of the integrators are held and transmitted to an analog-to-digital converter. The ratio of the two output signals from a pair of photodiode detectors represents the kVp value of the X-ray machine and another pair of photodiode detectors used to measure the relative current in milliamps (mA) and exposure time of the x-ray unit.In this study, the equipment have been made for measuring the characteristics of X-Ray with an accuracy of kVp (kV), I (mA) is 5% and the 2% T.

Key word: *Test X-Ray, photodiode, the peak kilo voltage, kVp, mA*

I. INTRODUCTION

The routine measurement of the physical parameters determining the performance of X-ray machine is essential for every technical quality-control (QC). It directly affects the health of patients, operators of the equipment, as well as increased accuracy in the capture process projection.

A QC procedure of the x-ray generator usually requires semi-annual measurement of the peak kilo voltage (kVp) accuracy, mA linearity and exposure time. Previously, these measurements done by direct measurement. This method is very complex, too professional, time consuming and need a lot of tools and equipment to perform.

In order to simplify and to speed up the QC activity, scientists have developed indirect measurement method. This is a method of measuring and analyzing X-ray beam to give the parameters of the x-ray machine. Currently, the X-ray measurement equipment is using this method. By applying this method, the measuring equipment X-ray beam has become compact and QC activities take very less time. But the majority of these devices use ionization chamber so life span of the equipment is short and the cost is expensive.

Recently, scientists in the world have succeeded in using photodiode in replacement of ionization chamber to fabricate devices. This method has been used by many companies in the world in research and development many complete devices. The advantage of this method is the simple circuit design, long life, low cost...

Based on those criteria, the authors have chosen this method to implement the project

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"Research and manufacturing equipment quality assessment X-ray machine". This equipment is for measuring (during a single X-ray exposure) high-voltage waveform, kVp, mA and exposure time...

II. EQUIPMENT AND METHOD

A. Theoretical basics

Characteristics of X-ray beam.

- The maximum energy of X-ray beam is:

$$h\nu = T = eV \qquad (1)$$

where: h is the Planck constant

ν is the frequency of braking radiation

e is the electron charge

V is the accelerating voltage (kV)

- The intensity of X-ray beam is calculated according to expression of Ulrey experiment is as follows:

$$I = kZV^2 \qquad (2)$$

where: V is the electron accelerating voltage

Z is the atomic number

K is a constant associated with the electron current density in the X-ray tubes

- Attenuation of X-ray beam when passing through the thickness of material: X-ray beam passing through the material when they interact with materials so energy, their intensity is decreased. Beam intensity has been reduced by the formula:

$$I=I_0\, e^{-\mu x}B^E(h\nu, Z, \mu x) \qquad (3)$$

where:

I, I_0 : is the radiation intensity before and after passing through the material thickness x.

μ : linear attenuation coefficient depends on the nature of the material layer

B^E : cumulative energy coefficient taking into account the contribution of scattered radiation.

B^E depends on the radiation energy (hν=eV), atomic number Z and thickness x of the material

Determination high-voltage of X-ray machine

High-voltage of X-ray machine is linear proportional to the energy of emitted X-ray beam. Penetration of the beam depends on the beam energy. So the intensity of X-ray beams when passing through a filter is a function of the high-voltage of X-ray machine. Analyses of X-ray beam after passing through two filters of different thickness can determine the high-voltage.

According to formula (3) the beam intensity after passing through a filter will depend on the intensity before through the filter (I_0), the energy of the beam (hν=eV), the nature and thickness the filter. With the fixed filter, the intensity after passing the filter depends on the energy and intensity of X-ray beam before passing through the filter. Formula (3) can be rewritten as follows:

$$I=I_0\, e^{-\mu x}D(h\nu) \qquad (4)$$

where: D(hν)) dependent attenuation coefficient of radiation energy.

So when we take the ratio of the intensities of X-ray beam after passing through two filters of different thickness will be a function that depends only on X-ray energy or accelerating voltage.

$$I_1/I_2 = D(h\nu)\ e^{-\mu(x1-x2)} = D(eV)\ e^{-\mu(x1-x2)} \qquad (5)$$

where: I_1, I2: the radiation intensities after passing through the material thickness x_1, x_2.

From there we can build the function that indicates the relationship between the high-voltage and the logarithm of ratio of the beam intensities passing through two different filters.

Determination current of X-ray machine

Current of X-ray machine is proportional to the intensity of X-ray beam. We can build a function that indicates the relationship between the intensity of current-ray and the X-ray beam.

Determination exposure time of X-ray machine

We determined the exposure time by detecting the start signal and end signal.

B. Equipment

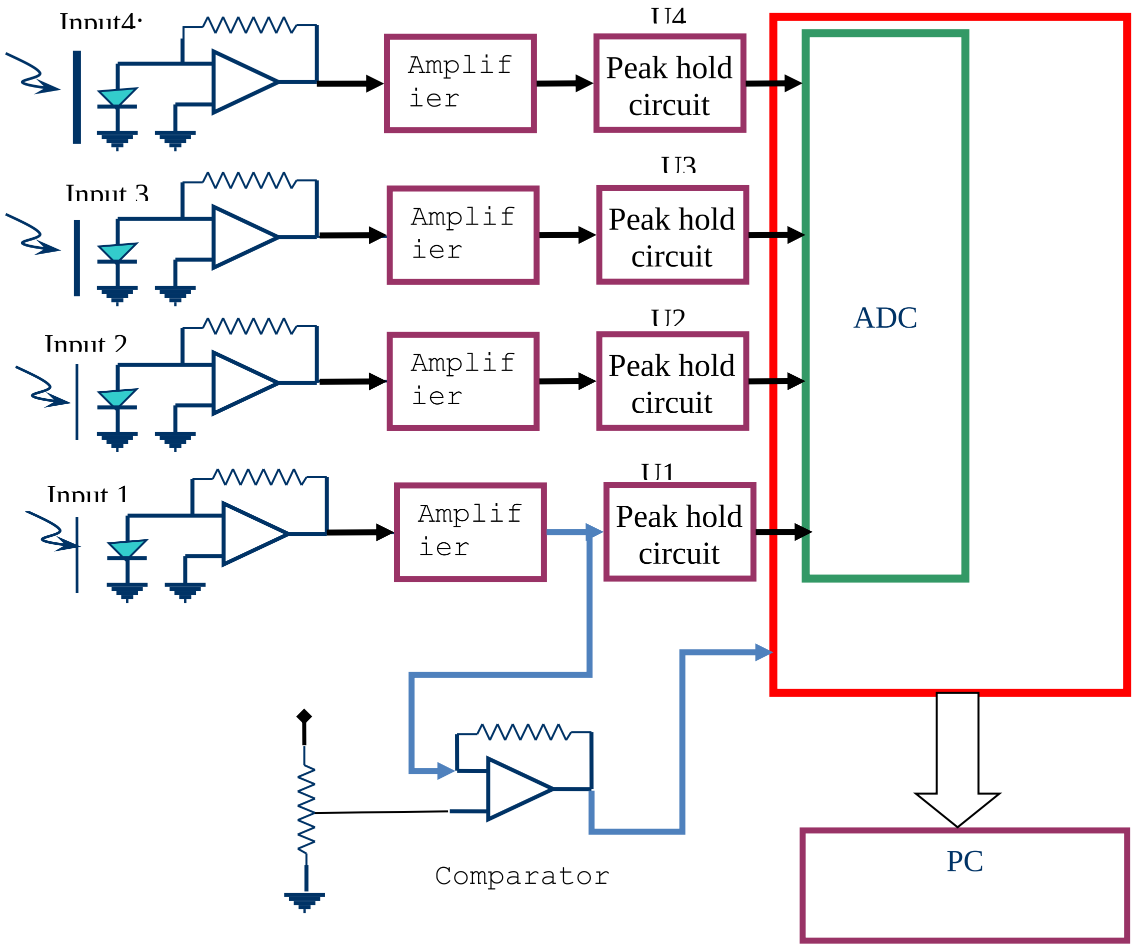

Fig. 1. Block diagram of the circuit.

The equipment is designed with an X-ray detector and signal processing, the computer contains two boards. The first is an in-house-developed amplifier board for signal conditioning of the detectors outputs. This is required to match the input levels of the second board, a high-speed digitizer with simulation sample and hold.

The Block diagram of equipment is showed in figure 1, includes radiation detectors, four photodiodes: two pair of Siemens BPW34 (active area 7.34 mm2). The diodes in each pair work together and the pairs are devoted to different measurement tasks. The photodiodes are operated in photovoltaic mode as direct x-ray detectors.

The two pair photodiodes are covered by two filters, 2.2 mm Al and 0.15 mm Cu. This choice of filter thicknesses gives an approximately linear relationship between the x-ray tube kilo voltage and the ratio of the two photodiode signals.

One of the two BPW34 photodiodes is covered by a 0.5 mm AI filter; the other one is unfiltered. The output of detectors are used to determine relative exposure time and current I(mA).

The current signals of the four photodiodes are converted to voltage signals, electronically filtered, amplified and finally sampled by a four-channel simultaneous-sample and-hold circuit. The signals, after multiplexing, are digitized by a 10-bit analogue-to-digital (AD) converter of microcontroller. The acquisition starts when the output signal of the unfiltered photodiode exceeds a reassigned threshold. All digital data are stored in memory buffer. This allows the acquisition of the digitized radiation waveform can be detected by this photodiodes.

The whole acquisition process is managed by ad-hoc developed software. The data is digitized, and then the data analysis is performed as follows.

Let Ai,Cui,Ui ,Fi be the data sets, where Ai are the 2.20 mm AI-filtered photodiode data, Cui are the 0.15 mm Cu filtered photodiode data, Ui are the unfiltered photodiode data, and Fi are the 0.50 mm AI filtered photodiode data. Then the high-voltage waveform in the range 50-150 kVp is obtained by linear regression

$$kV = a\, Ai/Cui + b$$

Where the constants a, b are determined by exposing the probe to AI-filtered photodiode signal and Cu-filtered photodiode signal at known kV values.

The exposure time is calculated from the time of the photo signals start threshold to the end of the threshold.

III. LABORATORY TEST

The device performances were tested with the x-ray beam of a high-frequency (HF) Shimadzu generator.

High-voltage range: 50 – 150 kV

Current range: 80 – 500 mA

Exposure time range: 0-3s

The comparison between the measured parameters and those provided by the standard instrument is shown in figure 2. All the three parameters are obtained with good accuracy. Current I(mA) is the only parameter presenting a moderate variation with respect to the perfect working behaviour (dotted line). Nevertheless, the largest I(mA) variation is only ±5%.

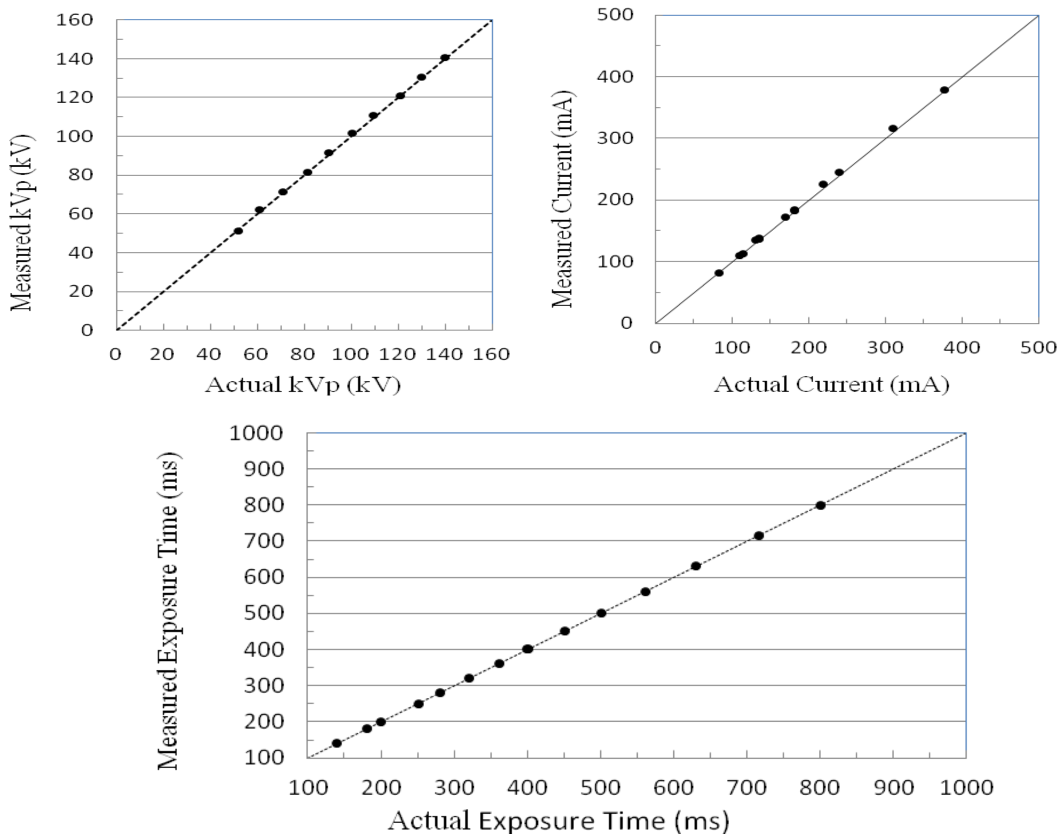

Fig. 2. An analysis of the instrument performance

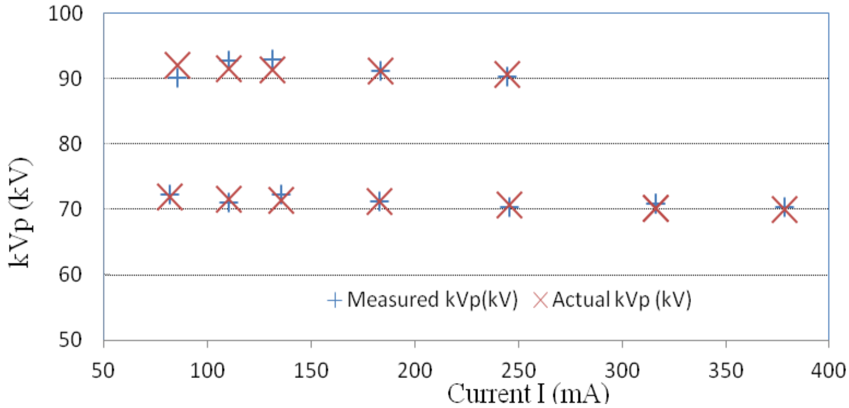

Fig. 3. The stability of the High-voltage when the Current changes

Table I. The The performance High-voltage of the instrument

STT	Current (mA)	Actual kVp(kV)	Measured kVp(kV)	Accuracy (%)
1	378.4	69.96	70.3	-0.49
2	316.1	70.18	70.9	-1.03
3	316.1	70.18	70.9	-1.03
4	245.7	70.65	70.4	0.35
5	183.1	71.28	71.3	-0.03
6	135.6	71.31	72.3	-1.39
7	110	71.59	71	0.82
8	82.06	71.87	72.3	-0.60
9	244.5	90.65	90.4	0.28
10	183.3	91.15	91.2	-0.05
11	131.4	91.43	92.9	-1.61
12	110.4	91.56	92.7	-1.25
13	85.35	92.06	90.2	2.02

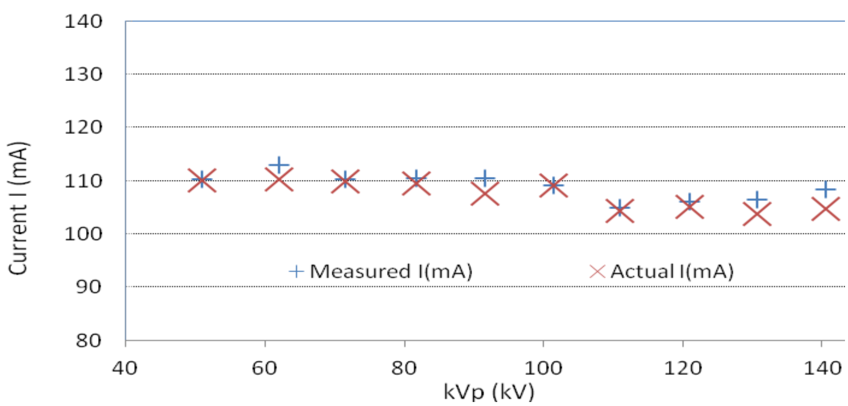

Fig. 4. The stability of the current I(mA) when the High-voltage kVp(kV) changes

Table II. The The performance High-voltage of the instrument

STT	Actual kVp(kV)	Actual I(mA)	Measured I(mA)	Accuracy (%)
1	130.7	103.8	106.4	-2.50
2	111	104.3	105	-0.67
3	140.6	104.8	108.4	-3.44
4	120.9	105.1	106	-0.86
5	91.62	107.6	110.5	-2.70
6	101.5	109.2	109.2	0.00
7	81.65	109.5	110.4	-0.82
8	71.59	110	110.2	-0.18
9	51.03	110.1	110.2	-0.09
10	62	110.2	113	-2.54
11	111.2	110.3	109.8	0.45
12	91.56	110.4	108.1	2.08
13	101.4	112.3	115.1	-2.49

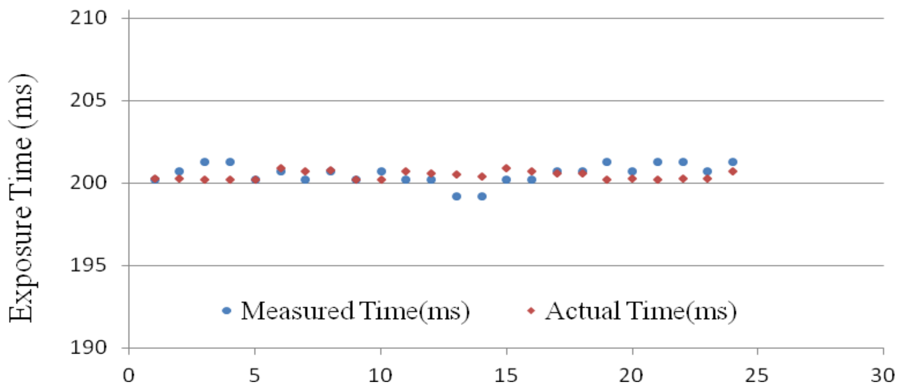

Fig. 5. The stability of the current I(mA) when the High-voltage kVp(kV) changes

Table III. The performance High-voltage of the instrument

STT	Actual Exposure Time (ms)	Measured Exposure Time (ms)	Actual kVp (kV)	Actual I(mA)	STT	Actual Exposure Time (ms)	Measured Exposure Time (ms)	Actual kVp(kV)	Actual I(mA)
1	200.3	200.2	101.6	109.3	13	200.5	199.2	60.96	183.4
2	200.3	200.7	111	109.6	14	200.4	199.2	51.15	182.7
3	200.2	201.3	120.8	108	15	200.9	200.2	81.46	137.9
4	200.2	201.3	131.1	107	16	200.7	200.2	80.84	183.8
5	200.2	200.2	91.78	109.8	17	200.6	200.7	80.93	234.7
6	200.9	200.7	91.09	182.7	18	200.6	200.7	80.59	310.7

7	200.7	200.2	81.12	181.8	19	200.2	201.3	120.8	109
8	200.8	200.7	81.28	182.4	20	200.3	200.7	111.2	110.9
9	200.2	200.2	91.18	180.1	21	200.2	201.3	131	82.69
10	200.2	200.7	91.18	180.1	22	200.3	201.3	121.1	82.45
11	200.7	200.2	81.28	172.1	23	200.3	200.7	111	109.4
12	200.6	200.2	70.9	184.3	24	200.7	201.3	120.9	103.6

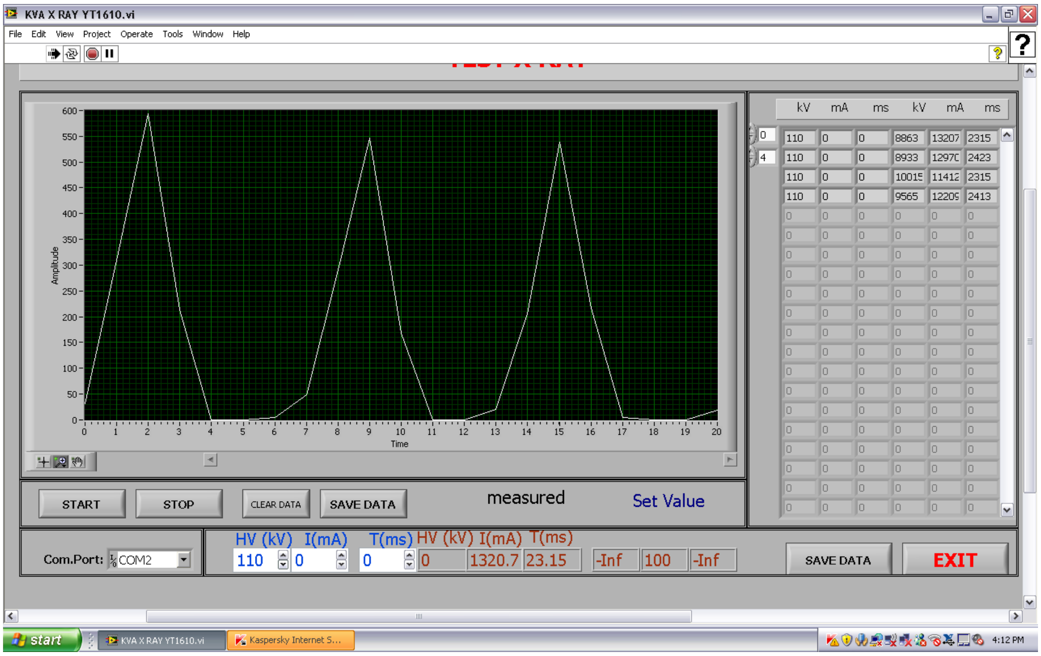

Fig. 6. The high-voltage waveform

IV. RESULTS

As the result, the project team have produced a X-ray Machine Quality Assessment Equipment, with the following specifications as shown in Fig. 7. :

kVp measurements
Range : 50 ÷ 150 kV
Resolution : 0,1 kV
Accuracy : ± 5%

I (mA) measurements
Range : 80 ÷ 500 mA
Resolution : 0,1 mA
Accuracy : ± 5%

Exposure time:
Range : 0 ÷ 6s
Resolution : 0,1 ms
Accuracy : ± 2%

Battery
Type : Lead Acid 6V 3.2 Ah
Operating duration: 24 hr

AC adapter
Input voltage : 100 V ac to 240 V ac
Input frequency: 50/60 Hz
Input current : 0.5 A
Output voltage : 9V

Graphic LCD display: 20 x 4

Interface: RS 232.

Temperature range: 0°C to +50°C

Dimensions: 7 x 20 x25 cm

Weight: 2 kg

Fig. 6. Equipment quality assessment X-ray machine

V. CONCLUSION

The results we achieve through research is equipment quality assessment X-ray machine, which is produced successfully. The Equipment has been surveyed and compared with some devices of the same kind in the world that currently available. Measurement results of our equipment is in the same quality and accuracy level, in comparison to those devices. The overall performance characteristics of the instrument are as follows:

	Range	Accuracy (%)
kVp (kV)	50-140	±5
Current I(mA)	80-500	±5
Exposure time (s)	0-5	±2

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