

COMPARISON OF kV_p AND PPV MEASUREMENTS BETWEEN A CONSTANT POTENTIAL AND A CLINICAL X-RAY SYSTEM USED FOR CALIBRATION IN MAMMOGRAPHY

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ABSTRACT

The PPV is an electrical quantity that relates the peak voltage with the radiological image contrast, thus having a larger clinical application. By definition, in an X-ray system, the “PPV is a quantity based on the concept that the radiation generated by a high voltage source with an arbitrary wave source produces the same radiographic contrast that the radiation generated by a high voltage source with an equivalent constant potential”. The Instruments Calibration Laboratory (LCI) of IPEN has the mammography qualities established in a constant potential system (industrial X-ray system), and also in a clinical system (mammograph). The objective of this study was to analyze the PPV behavior in these systems, and try to reach calibration conditions that are more similar to the work conditions in hospitals and clinics. For this, it was used an industrial X-ray (constant potential) and a mammography system (high frequency). The first system has a tungsten (W) target, and additional filtration of aluminum (Al) and molybdenum (Mo), and the second one has a Mo target and additional filtration of Mo and rhodium (Rh). A non-invasive measuring system from PTW model Diavolt was used to PPV determination. The voltages used were 25 kV, 28 kV, 30 kV and 35 kV (calibration qualities in mammography, according to the IEC 61267). The Diavolt was placed one meter from the focal spot in the industrial X-ray system, and 60 cm for the clinical system.

1. INTRODUCTION

The PPV (Practical Peak Voltage) is an electrical quantity that relates the peak voltage with the radiological image contrast, thus providing a larger clinical application. The norm that presents the criteria to the PPV use, the intrinsic errors of measurements made by a non-invasive detector, and provides the algorithm for the determination of this quantity is the IEC 61676[1,2].

According to H.M. Kramer, H.J. Selbach and W-J Iles[3], in an X-ray system, the “PPV is a quantity based on the concept that the radiation generated by a high voltage source with an arbitrary wave source produces the same radiographic contrast that the radiation generated by a high voltage source with an equivalent constant potential”. In theory, the PPV depends only on the voltage applied to the X-rays tube, according to the equation 1[1]:

$$\hat{U} = \frac{\sum_{i=1}^n p(U_i) \cdot w(U_i) \cdot U_i}{\sum_{i=1}^n p(U_i) \cdot w(U_i)} \quad (1)$$

in which U_i is the nominal voltage, in kV, and $p(U_i)$ is the probability that the voltage is in the interval of $(U_i - (\Delta U/2), U_i + (\Delta U/2))$ [1,4]. In mammography the nominal voltage is within $20 \text{ kV} < U_i < 50 \text{ kV}$, and the weighting function $w(U_i)$ can be approximated according to the equation 2[1]:

$$w(U_i) = \exp \{ a.U_i^4 + b.U_i^3 + c.U_i^2 + d.U_i + e \} \quad (2)$$

where

$$a = - (2,142352 \text{ E } -06)$$

$$b = + (2,566291 \text{ E } -04)$$

$$c = - (1,968138 \text{ E } -02)$$

$$d = + (8,506836 \text{ E } -01)$$

$$e = - (1,514362 \text{ E } +01)$$

The Instruments Calibration Laboratory (LCI), at the Instituto de Pesquisas Energéticas e Nucleares (IPEN/CNEN), calibrates instruments in radiation protection, radiation therapy and diagnostic radiology levels. In this last is included the mammography ionizing chambers calibration, which qualities are established in two systems: a clinical system (mammograph) and a industrial X-ray system. The first one works at high frequency, and the second has a constant potential.

The objective of this study was to analyze the kVp (Peak Voltage) and PPV behavior in these systems, in order to understand better this quantity and try to reach calibration conditions that are more similar to the work conditions in hospitals and clinics.

2. MATERIALS AND METHODS

In this study was used an industrial X-ray, that works with a constant potential (Figure 1) and a mammography system, working with high frequency (Figure 2). The voltages used in this study were 25 kV, 28 kV, 30 kV and 35 kV (calibration qualities in mammography, according to the IEC 61267)[5].



Figure 1. Industrial System Pantak/Seifert (constant potential)



Figure 2. Clinical system (mammograph), which works with high frequency

A non-invasive voltage meter PTW, Diavolt Universal All-in-one QC Meter model (see Figure 3), which can be used in conventional radiology, CT, fluoroscopy, dental diagnostic and mammography, presenting different target-filtration combination for each one, was used for the determination of PPV. In this study, the option **mammography** was selected.



Figure 3. Non-invasive kVp measurer Diavolt

For mammography, this device has three target-filter combination options, which can be selected on the options menu: Mo/30Mo (molybdenum target and filtration of 30 μmMo), Mo/0.5Al (molybdenum target and filtration of 0.5 mmAl) and Mo/1.5Al (molybdenum target and filtration of 1.5 mmAl). After being irradiated, the Diavolt gives the values of the kVp maximum (kVp max), kVp mean, PPV, exposure time and dose.

The first X radiation system has a tungsten (W) target, and the mammography qualities were established using additional filtration of aluminum (Al) and molybdenum (Mo)[6], and the second has a Mo target and the qualities were established using additional filtration of Mo. The half-value layer (HVL) used to establish these qualities were those presented by the German Primary Standard Dosimetry Laboratory *Physikalisch-Technische Bundesanstalt* (PTB)[7], which calibrated the mammographic reference system of IPEN. For this reason, the

qualities here are called in the same way that PTB does: WAV, for mammography qualities using Al as additional filtration, and WMV, when using Mo as additional filtration. In the clinical system, the nomenclature is the same as the IEC 61267, RQR-M. In the Tables 1 and 2 are shown the characteristics of each established quality in the industrial system, using additional filtration of Al and Mo, respectively, and in Table 3, the characteristics for the clinical system.

Table 1. Radiation qualities established in the industrial system using Mo as additional filtration

Quality code	Nominal Voltage (kV)	Additional Filtration (mmMo)	HVL PTB (mmAl)
WMV 25	25	0.07	0.36
WMV 28	28	0.07	0.37
WMV 30	30	0.07	0.38
WMV 35	35	0.07	0.41

Table 2. Radiation qualities established in the industrial system using Al as additional filtration

Quality code	Nominal Voltage (kV)	Additional Filtration (mmAl)	HVL PTB (mmAl)
WAV 25	25	0.57	0.35
WAV 28	28	0.57	0.40
WAV 30	30	0.58	0.43
WAV 35	35	0.62	0.51

Table 3. Radiation qualities established in the clinical system using Mo as additional filtration

Quality Code	Nominal Voltage (kV)	Additional Filtration (mmMo)	HVL PTB (mmAl)
RQR-M 1	25	0.035	0.29
RQR-M 2	28	0.035	0.32
RQR-M 3	30	0.035	0.33
RQR-M 4	35	0.035	0.37

By the fact that the Diavolt does not have any target-filtration combination option that considers the W target, a special procedure, presented by Corrêa et. al.[8], was made in the first system, to determine which one of these options is the most adequate.

This procedure consists in compare the kVp mean, given by the Diavolt, with the kVp max obtained using the spectrometry, considered a primary method to obtain this value. The kVp mean has been taken for this comparison because it is a mean of all the kVp measured by the Diavolt during a irradiation time [8,9]. For this system, without additional filtration, the best combination option is Mo/1.5Al. When using the additional filtrations the combination option varies depending on the tube voltage.

For the mammography system, the option Mo/30Mo (Mo target and 30 μm of additional filtration) was used, which matches the characteristics of this system, but some tests were also made without the Mo filtration.

The Diavolt was placed 1 m away from the industrial X-ray system focal spot (radiation diagnostic calibration position), shown in Figure 4, and 60 cm away (clinical system), shown in Figure 5.

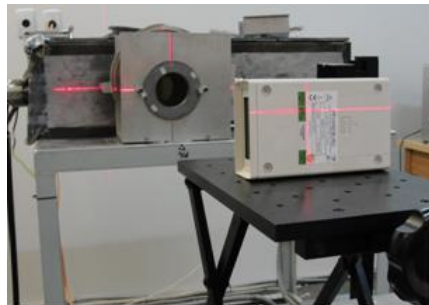


Figure 4. Diavolt placed one meter away from the focal spot (industrial system)



Figure 5. Diavolt placed 60 cm away from the focal spot (mammograph)

Although some previous studies showed that the filtration can change the kVp and PPV values [10], the measurements here were made using the specific filtration for each quality, so it is possible to analyze the system behavior during the calibration procedure.

3. RESULTS AND DISCUSSION

The first thing to be observed in the Table 4 is that it was not possible to obtain the kVp and PPV values for the quality that uses 25 kV and 0.07 mmMo as additional filtration. In this condition the Diavolt did not detect any radiation, probably because the Mo filtration is too thick to this low energy beam.

Table 4. Voltage values for qualities that use Mo, in the industrial system. The option used in Diavolt was Mo/0.5Al for WMV 28 and WMV 30, and Mo/1.5Al for WMV 35.

Quality code	Nominal Voltage (kV)	Additional Filtration (mmMo)	kVp mean (kV)	kVp max (kV)	PPV (kV)
WMV 25	25	0.07	***	***	***
WMV 28	28	0.07	29.1 ± 1.7	30.3 ± 1.7	27.5 ± 1.7
WMV 30	30	0.07	33.0 ± 1.9	34.3 ± 1.9	31.3 ± 1.7
WMV 35	35	0.07	36.8 ± 2.3	37.8 ± 2.3	35.5 ± 2.5

In Table 4, the variation between the kVp mean, measured using the Diavolt, and the system nominal voltage was of 3.9 % for the WMV 28 quality, 10 % for WMV 30 and 5.1 % for WMV 35. It is important to highlight that these values are being compared with the nominal voltage. When compared with the values obtained from the spectrometry this variation is lower (maximum of 5.5 %, for the WMV 30 quality)[10].

The results for the qualities that use Al are shown in the Table 5. In this case it was possible to make measurements in all qualities.

Table 5. Voltage values for qualities that use Al, in the industrial system. The option used in Diavolt was Mo/1.5Al for all qualities.

Quality code	Nominal Voltage (kV)	Additional Filtration (mmAl)	kVp mean (kV)	kVp max (kV)	PPV (kV)
WAV 25	25	0.57	27.1 ± 1.7	27.6 ± 1.5	26.6 ± 1.5
WAV 28	28	0.57	30.1 ± 1.8	30.6 ± 1.8	29.7 ± 1.9
WAV 30	30	0.58	32.2 ± 1.8	32.7 ± 1.8	31.7 ± 1.9
WAV 35	35	0.62	37.3 ± 2.2	37.9 ± 2.3	36.7 ± 2.3

In this case, the variation between kVp mean and the nominal voltage was from 6.6 % (WAV 35) to 8.4 % (WAV 25). When compared with the spectrometry values, this variation is from 2.9 % (WAV 35) to 3.2 % (WAV 25) [10].

For the clinical system, that has a Mo anode, and 0.035mmMo as additional filtration, the options used was Mo/30Mo, and the results are shown in the Table 6. Due to technical difficulties it was not possible to make the spectrometry of this system, so there was no way to find out if this option is the best to be used here.

Table 6. Voltage values for qualities that use Mo, in the clinical system. The option used in Diavolt was Mo/30Mo for all qualities.

Quality code	Nominal Voltage (kV)	Additional Filtration (mmMo)	kVp mean (kV)	kVp max (kV)	PPV (kV)
RQR-M 1	25	0.035	25.5 ± 1.5	25.7 ± 1.5	25.2 ± 1.5
RQR-M 2	28	0.035	28.2 ± 1.6	28.4 ± 1.6	28.1 ± 1.6
RQR-M 3	30	0.035	30.3 ± 1.6	30.5 ± 1.6	30.2 ± 1.6
RQR-M 4	35	0.035	35.6 ± 1.7	35.8 ± 1.7	35.5 ± 1.7

The variation between the kVp mean obtained in this system and the nominal voltage is much lower than that obtained in the industrial system; from 0.7 % (RQR-M 2) to 2 % (RQR-M 1). Probably this has happened because the Diavolt has an option for the target-filter combination that matches exactly with this system.

4. CONCLUSIONS

It is possible to note a difference between the kVp and PPV values obtained in the industrial and clinical system. For the kVp, this difference was from 3.4 % (WMV 35 and RQR-M 4) to 8.9 % (WMV 30 and RQR-M 3), and from 4.8 % (WAV 35 and RQR-M 4) to 6.7 % (WAV 28 and RQR-M 2). For the PPV, the difference was from almost zero (WMV 35 and RQR-M 4) to 3.6 % (WMV 30 and RQR-M 3), and from 3.4 % (WAV 35 and RQR-M 4) to 5.7 % (WAV 28 and RQR-M 2). It is difficult to affirm if this difference is because the characteristics of the systems, or due to the Diavolt limitations.

In the clinical system, which has a Mo target and filtration, the Diavolt Mo/30Mo option presented consistent results, giving values that did not exceed 2 % between the kVp mean measured and the X-ray system nominal voltage. The same happened for the PPV.

The results show different values for the kVp and PPV between two systems that have the same new mammography qualities established, although they have different values for the HVL. It is interesting to observe how the additional filtration changes the energy of the

radiation beam, and how it is important to use a non-invasive voltage meter specific for different kinds of systems.

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