I.9. THE HIGH VOLTAGE DIVIDER – A TOOL FOR COMPARISON OF MEASUREMENT EQUIPMENT IN DIAGNOSTIC RADIOLOGY

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Abstract

The high voltage divider (HVD) is designed for control and analysis of the characteristics of the X-ray generator. The low voltage analogous signals produced by the divider are proportional to the high voltage (kVp) applied to the x-ray tube by a ratio 1:1000 or 1:10000 and can be measured with external test devices like storage oscilloscope (or digital multimeter). The exposure duration and the wave form may be visualized, too.

Apart of this invasive way the high voltage also may be measured non-invasively by means of appropriate devices as well as indirectly through calculations. Since the invasive method of measurement with the high voltage divider is distinguished by a high accuracy, it may be utilized as an effective tool for calibration of different devices and for comparison of the measurement methods.

Key words: x-ray generator, invasive measurements, high voltage divider, noninvasive methods, comparative analysis

Fundamentals:

In order to ensure the quality in the radiological diagnostics the parameter stability (in the limits of admissible deviations) for the single parts of the x-ray equipment (reproducibility, consistency) is of primary importance, especially that of the high voltage generator. For the purposes of calibration and analysis of the x-ray generators various devices for invasive and noninvasive measurements may be utilized.

The main component of the apparatus for invasive measurements represents a set of megaohm resistors (high voltage divider), connected between the generator and the X-ray tube unit. In this manner a low level voltage results proportional to the applied kVp's. This low voltage may be measured by an external read out device like oscilloscope or digital multimeter. Besides it, the exposure duration and the high voltage fronts are displayed, too. The analog output provides visualization of the signal waves form on the oscilloscope display as well as digital read out of the measured values.

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Features:

A series of certain requirements [1] have to be met by the equipment under consideration:

1. Capability for measurement of anode to cathode, anode to ground and cathode to ground kV
2. Anode to cathode measurement range of 20 to 150 kV
3. Anode current range of 0.1 mA to 2 A
4. Filament current range of 0 to 6 A
5. Exposure time range of 1 ms to 8 s
6. Accuracy for kVp - ± 1%
7. Frequency compensation from 0 to 100 kHz
8. Range of mAs from 0.1 to 999 mAs with an accuracy of ± 1%
9. Calibration should be traceable to national standard.

The equipment also includes high voltage cables and insulation oils and greases. The quality of the high voltage connecting cable is essential for the accuracy of the procedure. The cables must be provided with appropriate standard HV connectors. They should be durable and should possess possible low specific capacity. The diverse capacitance effects in the HV cables may lead to distortion of the faster pulses and by this, to an inaccurate operation of the high voltage generator. In particular, high frequency generators with microprocessor control and capacitance compensation of the connecting cable are concerned.

The recommended cable length is maximum 1.5 m with straight termination. They have to be solated for operation voltages at least 75 kV to ground.

Method

For the measurements it is very important to utilize an external test device (oscilloscope or digital voltmeter) with input impedance corresponding to the output impedance of the high voltage divider. Otherwise essential differences between the read high voltage values and the real ones will emerge. In practice the divider resistors have some stray capacitance across them and also to the walls of the container. In order to frequency compensate the divider, these capacitances have to be reduced and the entire dividers network – compensated. For it the following equation should be met

$$R1 \times C1 = R2 \times C2,$$

Where R1 is the high voltage resistor set, C1 – its compensating capacitor, and R2, C2 – the viewing (readout) resistor and capacitor.

It is very important for the oscilloscope to be two-channel type, a storage one and in its analogous part with a horizontal bandwidth ≥ 2 MHz (3 dB), rise time ≤ 5 ns. Furthermore, it should enable one of the channels to be inverted, range of the vertical sensitivity of -2 mV/cm to 5 V/cm, amplitude accuracy ≤ ± 2%, and for the digital a range ≥ 20-50 MHz sampling rate, vertical resolution ≥ 8 bit. The memory is in those cases needed when pulses or very short exposures should be detected. It is recommended for the digital voltmeter to have high dc input impedance (10 MΩ) and a response time of less than 2 s. The accuracy of the test device should be at least ± 2% of the reading for all ranges.

The test configuration was as follows: the invasive (HVD) and the non-invasive instruments were placed in an appropriate way in the radiation beam. Three exposures at least were performed for each kVp-value set on the control panel (reproducibility). For a given value the average of the readings have been calculated for every device.

Specificity

Diverse reasons may cause inadequacies between the readout values of the invasive test system and the noninvasive measurement device. The invasive method of measurement is a direct one and is not affected by the filtration of the x-ray radiation, while the readings of non-invasive measured device depend on the quality of the x-ray beams (HVL), the construction and the built-in software. These discrepancies are of critical importance for the mammography equipment where an error of 1 kVp will result in an inferior image quality.

As a handicap in the application of the invasive method are the relatively huge dimensions and weight of the container and the complimentary HV cables and accessories – coaxial cables, oils and greases, connectors and adaptors and others. The operation with the invasive HV divider requires staff well experienced in work with a storage oscilloscope, x-ray machines and high voltages. The interconnecting of the HV divider to the x-ray equipment itself is not a simple procedure. In some cases it rather yields challenge to the operator and should be executed in close collaboration with the service personnel of the x-ray equipment. During the preparation and the measurement mistakes may be easily done in connecting and adjusting the test devices as well as in the interpretation of the obtained results.

On the other hand, an excellent feature of the invasive method consists in the very high rate of information accuracy. A huge amount of information is received with regard to the amplitude and form of the high voltage pulses, the exposure time, the rise time (fronts). The latter have as sequence a soft radiation, to which the non-invasive measuring instruments do not respond precisely enough. It is possible also to uncover certain problems in defect or seemingly good operating x-ray generators – a corona in the HV tract if higher voltages are applied, a blow in a rectifying element, asymmetry in the anode and cathode voltages, etc.

For the reasons cited above the instruments for non-invasive measurement of the x-ray machine parameters are utilized for the routine quality control. Due to its high precision, the HV divider is applied mainly for calibration of noninvasive kVp-meters

Comparative analysis

Recently a great number of devices for non-invasive measurement and control of the radiological equipment parameters from various manufacturers have been imported. In a pilot study a series of measurements have been accomplished on different types of x-ray generators in some diagnostic imaging departments. The aim was to compare the readings from the non-invasive instrument to those of the invasive set and the subsequent analysis of the obtained results.

The utilized apparatus encompassed the high voltage divider set [2], an oscilloscope (Fluke 199), non-invasive kVp-meters and the respective interface and accessories. The measurements were performed on four X-ray generators: one HF and three 6-pulse.

The following Table 1 shows how the data were processed (as an example only one X-ray unit is presented here). Values of kVp measured simultaneously with High Voltage Divider (HVD) and three other instruments on a radiography unit, their mean value, standard deviation and value of the ratio of HVD mean value to the instrument mean value, k, are given.

			HVD	Instrument No. 3		Instrument No. 4		Instrument No. 5	
			кVp	кVp	k	кVp	k	кVp	k
RADIOGRAPHY UNIT No. 4	**total filtration > 2 mm Al**	**1**	53.6	51.3	**1.04**	51.6	**1.04**	51.78	**1.04**
		2	54.0	51.8		52.2		51.65	
		3	54.0	51.9		52.2		51.78	
		Mean =	**53.9**	**51.7**		**52.0**		**51.7**	
		St.Dev =	**± 0.2**	**± 0.3**		**± 0.3**		**± 0.1**	
		1	72.0	68.1	**1.06**	67.9	**1.07**	67.76	**1.06**
		2	72.0	68.2		67.7		67.89	
		3	72.8	68.1		67.8		67.98	
		Mean =	**72.3**	**68.1**		**67.8**		**67.9**	
		St.Dev =	**± 0.5**	**± 0.1**		**± 0.1**		**± 0.1**	
		1	89.6	84.0	**1.07**	82.0	**1.10**	83.69	**1.07**
		2	90.4	83.8		81.9		83.94	
		3	89.6	84.2		81.9		84.18	
		Mean =	**89.9**	**84.0**		**81.9**		**83.9**	
		St.Dev =	**± 0.5**	**± 0.2**		**± 0.1**		**± 0.3**	
		1	113.0	108.5	**1.06**	105.4	**1.08**	105.0	**1.08**
		2	114.0	105.8		103.9		105.3	
		3	113.0	107.7		104.3		105.3	
		Mean =	**113.3**	**107.3**		**104.5**		**105.2**	
		St.Dev =	**± 0.6**	**± 1.3**		**± 0.8**		**± 0.2**	
			50 ÷ 115	$\bar{k}$ =	**1.06**	$\bar{k}$ =	**1.07**	$\bar{k}$ =	**1.06**
				St.Dev =	**± 0.01**	**St.Dev =**	**± 0.03**	**St.Dev =**	**± 0.02**

Table 1 - Results from the measurements on one radiographic machine

It could be seen that sometimes the standard deviation of HV divider readings is greater than the standard deviation of readings of noninvasive kVp-meter. As the standard deviation includes the repeatability of the X-ray generator, an explanation of this could be that the HV divider, due to its higher accuracy, measures the small differences in X-generator's kVp output, while the non-invasive test device do not react to them.

HVD κVp	$\bar{\bar{k}}$ INSTRUMENT No. 1	2	3	4	5
50 ÷ 115	**1.00 ± 0.01**	**0.99 ± 0.01**	**1.06 ± 0.01**	**1.07 ± 0.02**	**1.06 ± 0.02**

Table 2 – The "calibration factors" $\bar{\bar{k}}$ - ($\bar{k}$ averaged out on the radiographic units used)

It is seen that the "calibration factors" determined by us of two kVp-meters are close to 1.00. The values for the other three have to be taken in consideration when these kVp-meters are used for quality control measurements.

Conclusions

The calibration of the diverse kVp- and other measuring instruments outside the country is very expensive and time consuming as well as risky enough. Also restrictions are imposed on the calibration time (duration). Hence, if equipped with a modern X-ray generator (reproducible and reliable operation) and the available invasive measurement set, the Secondary Standard Dosimetry Laboratory could effectively serve (function) to calibrate the non-invasive measurement devices throughout the country. In the mean time, the measurements will continue to enrich the experience, to increase the number of instruments covered (tested and compared), and by this to obtain a greater rate of statistical adequacy (truthfulness) of the results.

References:

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