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SOME RADIOGRAPHIC QUALITY CONTROL TESTS WITH SPECIFIC IMPORTANCE FOR DEVELOPING COUNTRIES

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Abstract— **The paper describes some QC tests which have specific additional importance for assessment the performance of X-ray radiographic systems in developing (aka LMI) countries. The Beam Quantity (Specific output dose – mGy/mAs) and the linearity of the (mGy/mAs) = F (kV^2) graph are QC parameters indicating also the approaching end of life of an X-ray tube. Dose output and kV dependence on Anode current (mA) QC tests are also indicators for the stability of the hospital electrical power supply system. These QC parameters can be used as providers of useful information for improving the performance of X-ray equipment in developing countries (especially in rural hospitals). The paper could be used as a reference material for lecturing and training Quality Control of X-ray Radiographic equipment.**

Keywords **X-ray Tube and Generator, Diagnostic Radiology Quality Control, QC in Low- and Middle-Income countries, QC in developing countries**

I. INTRODUCTION

Quality Control (QC) of X-ray tube and Generator of Radiographic equipment is an important activity for medical physicists in Diagnostic Radiology. QC tests follow specific protocols and are described by a number of reputable institutions [1, 2, 3]. However, the assessment of results of some QC tests can bring additional information about the functioning of the radiographic equipment, which can be very useful for colleagues in developing countries for planning replacement of the X-ray tube, correcting the electrical supply of the equipment or other (often servicing) procedures. The paper will briefly discuss such QC tests.

II. BEAM QUANTITY AND (mGy/mAs) = F (KV^2) GRAPH

It is well known that X-ray tube output (dose) is linearly related to the mA, time or mAs (hence Dose/mAs should be constant at set kV), and quadratically related to the kV.

The Beam quantity (mGy/mAs) for certain kV (e.g. 80 kV) and measured at certain distance and fixed filtration is a stable parameter, specific for the X-ray equipment (namely for its X-ray tube). This parameter is measured both for Broad Focus (BF) and Fine Focus (FF) of the X-ray tube.

The graph/function plotting mGy/mAs against kV^2 for a relatively new X-ray tube (for different set kV but at fixed mA and time) will produce a relatively straight line [5]. However, if the X-ray tube is exhausted (e.g. one of its focal spots is exhausted), the line will not be straight and most often will bend down at high kV. Fig.1.a and Fig.1.b show such a case for an relatively old X-ray tube (based on the real QC measurements, shown on Table 1).

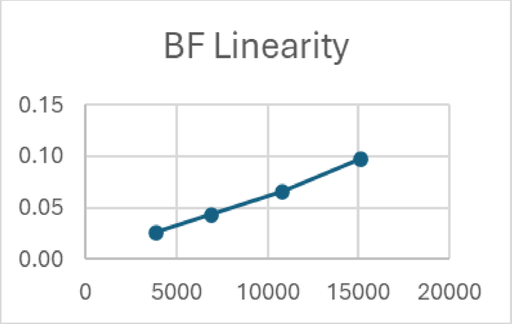

Fig.1.a. (mGy/mAs) = F (kV^2) for Broad Focus

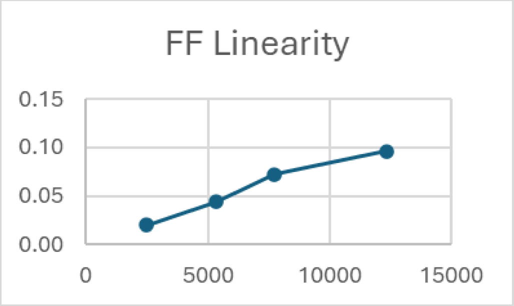

Fig.1.b. (mGy/mAs) = F (kV^2) for Fine Focus

From the two graphs one can see that while the function (mGy/mAs) = F (kV^2) for Broad Focus on Fig.1.a is relatively linear, the same function for Fine Focus on Fig.1.b shows drop at the end of high kV. This drop is an indicator that in this case the Fine Focus has been used very often and it has decreased its specific output (dose/mAs). The reason for this is related mainly to the cracks over the anode surface. The X-ray exposures heat quickly the anode (to temperatures of the order of 2000-3000 ^{0}C), followed by cooling the anode in between exposures. This causes thermal stress of the anode material, and its Tungsten-coated surface starts to crack with time. This way as a result of many exposure (many cycles of heating and cooling) the number of Anode surface cracks and their sizes increases (Fig.2). This leads to the known effect of enlarging the Actual focal spot (hence the measured Effective focal spot)

[4]. This reduces the radiographic spatial resolution, but also decreases tube output (dose), as significant part of the accelerated thermal electrons from the Cathode fall inside the cracks and produce there X-ray photons, which are absorbed by the cracks sides/walls (hence increase the temperature of the anode, but with decreased production of X-rays towards the patient). The effect is more prominent with the Fine Focus, as there the heat from the thermal electrons distributes over a smaller area, hence the temperature during the exposure is higher and the FF thermal stress becomes prominent earlier, compared with the BF (at an equal number of X-ray exposures). This way the linearity of (mGy/mAs) = F (kV^2) of an X-ray tube can be seen as an indicator for planning the tube replacement. This is also useful for assessing the status of the tube, when its QC assessment starts at unknown time of its clinical use.

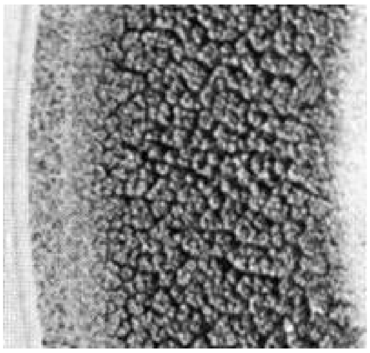

Fig.2 Section of the anode surface of an X-ray tube (rotating anode) showing cracked Anode surface due to thermal stress [4].

If the X-ray tube is QC tested by the Medical Physics Department from its installation – i.e. the Beam Quantity figures (the specific dose output mGy/mAs) are known from the beginning, one can monitor the gradual decrease of this figure (with the years) at specific kV, mAs and distance (focal spot to the dosemeter). From the author's practice, when this parameter drops below 60% from its initial value, replacement of the X-ray tube should be planned.

Depending on the frequency of clinical use of the X-ray equipment, this could be after 5, 10 or more years. This planning is very important for developing countries, where the X-ray tubes are used almost to the end of their life (in many developed countries the X-ray tubes are replaced well before they reach such an exhaustion).

Fig.3 shows the Relative X-ray beam intensity distribution of a new X-ray tube (curve 1) and exhausted X-ray tube (curve 2) [4]. Here can be observed that, additionally to the decreased intensity of curve 2, its pick shifts from the central beam (to the patient) towards the cathode, thus the intensity of the beam towards the Anode drops significantly, what leads to more prominent Heel effect. This effect is difficult to observe in practice [6].

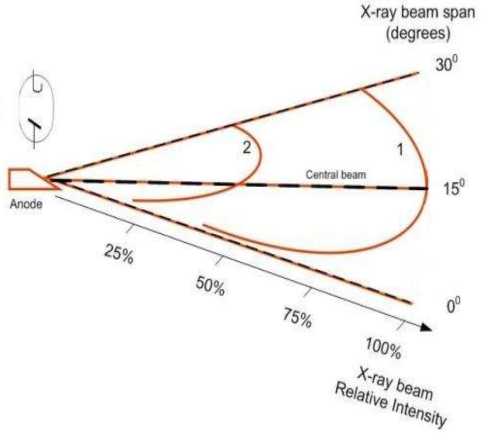

Fig.3 Relative X-ray beam intensity distribution of a new X-ray tube (curve 1) and exhausted X-ray tube (curve 2). Note the significant decrease of intensity towards the anode side (more prominent with exhausted X-ray tube), leading to the well-known Heel effect [4, 6].

Failing to replace an exhausted X-ray tube can lead to X-ray tube arcing, what may lead to fault exposures (hence

Table 1. Real parameters from QC test of an X-ray tube for assessment of (mGy/mAs) = F (kV^2) graph linearity

Focus	set kV	set mA	set msec	set mAs	meas kV	meas mGy	mGy/mAs	(meas kV)2
BF	60	200	100	20	62	0.51	0.03	3844
BF	80	200	100	20	83	0.86	0.04	6889
BF	100	200	100	20	104	1.31	0.07	10816
BF	120	200	100	20	123	1.95	0.10	15129
FF	50	100	200	20	50	0.40	0.02	2500
FF	70	100	200	20	73	0.88	0.04	5329
FF	90	100	200	20	88	1.45	0.07	7744
FF	110	100	200	20	111	1.92	0.10	12321

repetition of exposures and increased patient dose) and further to X-ray equipment failure, what will be associated with significant cost [6, 7].

III. DOSE OUTPUT AND KV DEPENDENCE ON ANODE CURRENT

The dependence of the X-ray tube output (dose) and kV on the Anode current (mA) of the exposure is a parameter related with QC testing of the X-ray Generator. However, this parameter is closely related to the main electrical power circuit of the hospital (it is very prominent in smaller, often rural, hospitals in developing countries [8]).

This effect is really prominent at high mA. We shall demonstrate the effect with a small indicative example (calculation with round figures), which gives an estimate of this dependence, in order to support its understanding.

Each X-ray equipment is connected to the main electrical power circuit of the hospital. Hence between the X-ray equipment and the main transformer of the hospital there are long cables and electrical connections, which have their specific electrical resistance (ohmage). Let us take the following indicative example:

-The X-ray Generator of an X-ray equipment has a High Voltage step-up transformer with transformer ratio 1:500;

-The electrical mains supply the X-ray equipment with 200 Volts (thus the X-ray equipment could produce max 100 kV: 200x500 = 100,000V)

-If this equipment produces a heavy exposure (e.g. in the area of the pelvis) with parameters: 100kV and 100mA (0.1 Amperes Anode current), the required electrical power for this exposure will be of the order of 100,000x0.1 = 10,000 Watts (in this indicative example we do not take into consideration the length of the exposure and the effective voltage);

-This way during the exposure of 100kV and 100mA, the X-ray equipment will consume 10kW from the electrical power circuit of the hospital;

-These 10kW (at 200 V) will require 50 Amperes electrical current entering the X-ray Generator (200x50=10,000);

-These 50A will be delivered by the main power supply of the hospital (its main transformer) and will pass through long hospital cables before coming to the X-ray equipment;

-If we assume that the electrical resistance of these cables is of the order of 0.2 Ohms (what is almost ideal parameter in a small hospital), then this 50A will produce a voltage drop over the cables of the order of 10 Volts (50x0.2=10V). In a rural hospital with high electrical ohmage of the power cables (and their connections) the voltage drop in this example could be twice as much. Similarly, significant voltage drop can be associated with mobile X-ray equipment, where the resistance of the plug connection should also be considered;

-This means that while at the very first moment of the exposure (the first milliseconds) the X-ray Generator will receive 200V, then during the next moment it will receive 200-10=190V;

-After the High Voltage transformer these 190V will supply the X-ray tube with 95kV (190x500=95,000), instead of the required 100kV;

-This way the exposure in this indicative example will just begin with the set parameters of 100kV and 100mA, but will continue with 95kV and 100mA;

-Thus, due to the drop of voltage over the cables of the hospital, the resulting X-ray exposure will be with reduced kV (affecting the image contrast) and reduced dose. The higher is the Anode current (mA) required during the exposure, the more prominent will be this voltage drop in the electrical power supply (in small hospitals one can even observe short dimming of the room lamps light during a heavy X-ray exposure).

Older X-ray equipment (often used in developing countries) have specific Compensatory System, which estimates the expected voltage drop and compensates this voltage drop. This System is between the electrical power supply and the High Voltage transformer (usually using autotransformer). It has variable transformer ratio and usually increases the voltage from the mains to compensate the voltage drop during the exposure. Thus, it provides the High Voltage transformer of the X-ray Generator with specific higher voltage, which compensates the expected voltage drop. Contemporary medium-frequency X-ray Generators use varying frequency of the current through the High Voltage transformer to keep the set kV correct. In any case the voltage drop effect always exists and the correct functioning of the Compensatory System has to be tested

During QC this effect should be tested with high Anode current (as per the maximal clinical requirements) – usually of the order of several hundred mA. Observing the kV waveform could show the effect (and its correction).

The Compensatory system is adjusted regularly by the X-ray service engineers, and if over-adjusted, one could even measure higher kV than the set ones during the exposure. Anyhow, if the dependence of the kV and Dose output from the mA is found during QC tests to be significant, the service engineers should be informed, and they shall decide to either correct the Compensatory System or repair the respective part of the electrical power supply of the hospital (for this X-ray equipment).

Table 2 shows a real QC measurements for assessment Dose output dependence (DOD) and kV dependence (kVD) on the Anode current (mA) of an old X-ray equipment (BF). From Table 2 data one could calculate the % of DOD as:

DOD=100*(stdev of mGy/mAs)/(average of mGy/mAs)

The result is 12% DOD, what is too high (up to 10% can be accepted).

In a similar way one can calculate the % of kVD as:
kVD = 100*average (error/real value) for all 4 meas.
(e.g. from the measured 83, 83, 85, 90 kV the error from the set 80kV is 3, 3, 5, 10 kV, hence in the last measurement at 500mA we have 10/80 = 12.5% error).

The overall kVD in this case is 6.5% what is also unacceptable (up to 5% can be accepted). Both DOD and kVD show that this old X-ray equipment does not function well, it has been overcompensated, perhaps electrical cables ohmage is too high, and all this should be corrected.

In newer X-ray equipment the often-used modern Automatic Exposure Control (AEC) system will correct the drop of dose (usually by some prolongation of the time of the exposure). Considering the image contrast - the Window technique of the digital radiography systems could correct it relatively well (visually). Despite this, the effect of Anode current dependence will always influence the exposure, especially in small hospitals. Its assessment can be an useful indicator for the need of improvement of the electrical power supply circuit of the hospital, or need of adjusting the Compensatory System, what is important for the correct functioning of the X-ray equipment.

IV. CONCLUSION

In the past the above QC tests were performed regularly in developed countries. However, with the time the importance of these decreased. This was due to various factors such as:

-Hospital-Manufacturer Contracts, which require replacement the X-ray equipment (or X-ray tube) well before its expected end of life;

-Improving quality of the Hospital electrical power supply;

-Automatization of the new digital Radiographic X-ray systems, etc.

However, the effects, explained above, continue to exist and they affect the performance of X-ray equipment (especially in developing countries and surely in rural hospitals). Due to this reason the additional information from these QC tests will have to be taken into account in such places.

The assessment of the QC parameters described above formed part of the 1998-published e-learning EMERALD training materials (where the tests are explained in detail) [5].

The explanation of the above effects are also included in the EMITEL e-Encyclopedia of Medical Physics [4] and the author has lectured these at numerous venues and occasions. The paper here, with its examples, can form part of the explanations of the rationale for some QC tests, especially in developing countries - aka Low-and-Middle Income (LMI) countries.

V. FURTHER READING

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Table 2. Real parameters from QC test of an X-ray tube for assessment of Dose output and kV dependence on mA

Focus	set kV	set mA	set msec	mAs	meas kV	meas mGy	mGy/mAs
BF	80	25	100	2.5	83	0.16	0.0640
BF	80	200	100	20	83	0.96	0.0480
BF	80	300	100	30	85	1.72	0.0574
BF	80	500	100	50	90	2.65	0.0530