Properties and Radiographic Effects of Abnormal Voltages Applied to X-ray Tubes

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X線管に加わる異常電圧の性質とその写真効果

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(昭和40年1月29日受付)

単相装置，3相装置，等の変圧器式X線装置では，X線スイッチの閉路時に，正常電圧の2倍に近い異常電圧が発生する事がある．管電圧が高く，管電流が少いほど，この異常電圧の割合は高くなる．異常電圧が発生すると，正常な管電圧の時に比べ．，発生X線の線質が硬くなり線量が増加する．そのために最適撮影条件が変動するので，異常電圧の発生を防止せねばならない．この防止方法ものべる．

Abnormal voltage waveforms of single-phase X-ray units appearing at closing instant of X-ray switch were measured. The ratio of abnormal voltage peak to normal kilovoltage increases when tube-current decreases, tube-voltages increases, and closed phase-angle approaches 90°. This ratio does not exceed two. The abnormal voltage causes harder quality and larger amount of radiation than normal voltage, therefore departure from optimum radiography will occur. The abnormality can be prevented by closing at the phase angle near 0°. On 3-phase units, one phase may be closed at 0° and the other two phases may be closed at 90° immediately after.

§ 1 Introduction

Abnormal voltage sometimes appears when an X-ray switch is closed with single-phase X-ray units as well as 3-phase X-ray units. The peak of the abnormal voltage reaches 1.8 times normal kilovoltage under adverse conditions. This fact has not been noticed since the beginning of low-voltage X-ray radiography. The reason for this may be that old high-voltage unit prats have sufficient margins against electrical breakdown even if abnormal votlage appears, and in addition, abnormal voltage does not appear with such large milliamperage as used in low-kilovoltage radiography. However, abnormal voltage has been noticed since the development of high-voltage such as 125 to 150-kV radiography units. This is because, in high-voltage radiography, small milliamperage began to be used, in addition to the efforts for making smaller high-voltage unit parts.

§ 2 Properties and Preventive Procedures[1)]

Fig. 1 shows waveforms of abnormal voltages to various closed phase-angles with 60 kV, 50 mA of a single-phase unit. In the first half-cycle of all cases, voltage exceeds normal value (broken line),

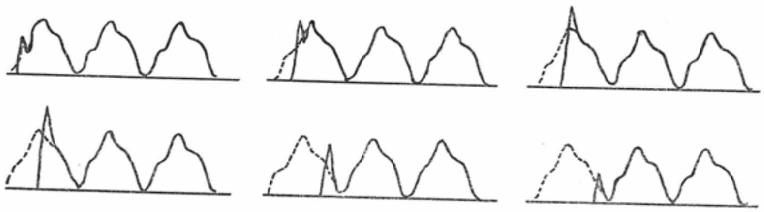

Fig. 1 Abnormal voltage waveforms to various closed phase angles, under 60 kV 50 mA with a single-phase unit: in the first half-cycle, abnormal voltages appear, while after the second half-cycle shows normal waveforms.

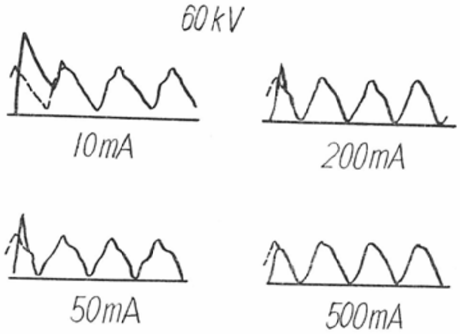

Fig. 2 Abnormal voltage waveforms for various tube-currents.

whereas waveforms after the second half cycle become normal. The abnormal voltage peak is largest, when closed near the peak of the normal voltage, *i.e.* closed phase angle is about 90°. Fig. 2 shows the waveforms closed near 90° with various milliamperges and 60 kV. The lower milliamperage produces the higher abnormal voltage peak. If milliamperage is large enough, abnormal voltage does not appear as shown in the 500 mA waveform curve.

The properties of the abnormal voltage were characterized from electrical circuit theory by the author. The theoretical results coincided with experimental results. According to the theory, the rate of abnormal voltage peak to normal kilovoltage increases with an incremental resistance, $\Delta V/\Delta I$, of the voltage-current characteristics of X-ray tube but does not exceed twice the normal kilovoltage. Therefore, the lower mA as well as the higher normal kV produces the higher abnormal peak (see 10, 50, 200 mA curves in Fig. 2). If $\Delta V/\Delta I$ is less than a value $\sqrt{L/C}$, abnormal voltage does not appear (Fig. 2, 500 mA), where L, C is inductance and capacity of the equivalent electric circuit viewed from the high-voltage terminals. The abnormal voltage is electric free oscillations. The frequency of the oscillation approaches the well known value, $1/2\pi\ \sqrt{LC}$, as $\Delta V/\Delta I$ increases. The initial amplitude of the oscillation is the instantaneous voltage of the normal voltage waveform, therefore abnormal voltage does not appear when the closed phase-angle is near 0°, and the high abnormal peak appears when the angle is near 90° (Fig. 1). With three-phase units, abnormal voltages having the same properties appear as they do in single-phase units.

Using the phase-adjuster and maintaining the closed phase angle near 0°, abnormal voltage generation can be prevented with single-phase units. With 3-phase units, if all of the three phases are closed simultaneously, abnormal voltage can exceed normal voltage, in the phase showing the highest instantaneous voltage. For the prevention, it is simply suggested to close each phase at its 0°, but it requires a 120°-retardation. Our new method is to close one phase at 0° and close the other two phases at 90° immediately after. At the second closing, the two phase-voltages are half the normal phase voltage peak therefore abnormal voltage can not exceed normal kilovoltage.

Against the electrical breakdown of high-voltage parts, the abnormal voltage should be prevented when kilovoltage setting is more than the half of kilovoltage rating of a unit, since abnormal peak does not exceed twice the normal kilovoltage.

§ 3 Radiographic Effects

At the abnormal voltage peak, tube current becomes maximum according to the voltage-current property of X-ray tubes as shown in Fig. 3. Therefore, it is feared that a harder and larger quality of

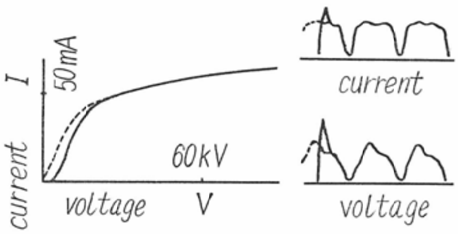

Fig. 3 Abnormal voltage and corresponding tube current waveforms (right side), in addition to a voltage-current characteristic curve of an X-ray tube (left side), when normal waveform (broken line) is 60 kV, 50 mA; Current-peak instant coincides with abnormal voltage peak instant.

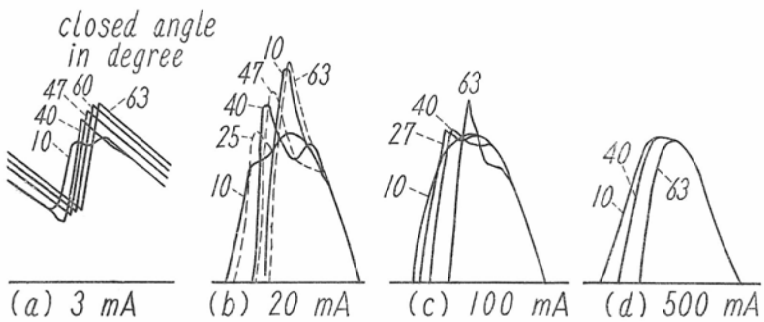

Fig. 4 Abnormal voltage waveforms and their factors utilized in experiments: These waveforms were generated in every half-cycle of the electric source by connecting arc-rectifiers instead of an X-ray switch.

abnormal origin radiation will be generated than normal waveform radiation. This causes a change in optimum kilovoltage and milliampere-seconds for radiography. These facts were confirmed experimentally as follows:

In order to generate the abnormal voltages in every half cycle of the electric source, arc-rectifires were connected to a single-phase unit instead of an X-ray switch. Experiments were conducted utilizing the waveform factors shown in Fig. 4. Where, primary voltage and filament voltage were kept constant

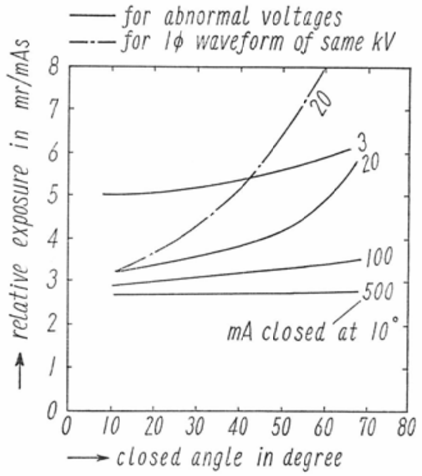

Fig. 5. Relative exposure at a 1.8-m F.C.D. produced by abnormal voltage waveforms (full lines), compared with those produced by single-phase waveforms of the same kilovoltages (broken lines of 20 mA).

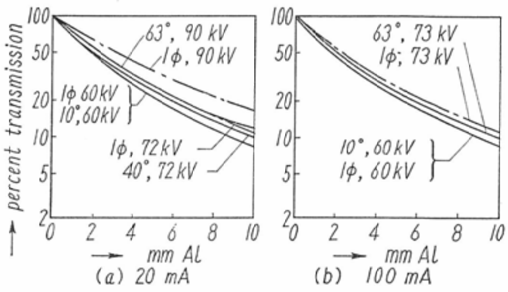

Fig. 6 Absorption curves measured with abnormal voltage radiation (full lines), compared with those with single-phase waveforms of the same kilovoltages (broken lines).

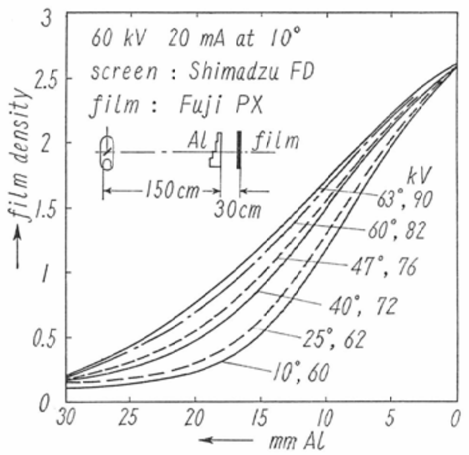

Fig. 7 The deviations of radiographic effects due to abnormal voltage generation.

while the closed angle was varied, and 60 kV was chosen as the kilovoltage when abnormal voltage did not occur, *i.e.*, the closed angle was small.

Fig. 5 and Fig. 6 show relative exposure at a 1.8-m F.C.D. and absorption curves, being compared with those produced by single-phase waveforms of the same kilovoltages (broken line) respectively. In those figures, indicated milliamperages show the values when the closed angle is 10°, while indicated kilovoltages are the abnormal voltage peaks. Actual milliamperage closed at a larger angle is smaller because filament voltage is kept constant. The abnormal voltage has higher peak voltage so that it produces a larger amount of and harder quality of radiation than steady voltage does, but less and softer than single-phase voltage with the same kilovoltage does. The reason for this may be that abnormal voltages were sharper at their peaks than steady voltage was.

Fig. 7 shows the density of radiographs of aluminium steps made with 20 mA radiation with various closed angles. As the closed angle changed from 10° to 63°, tube voltage peak increases from 60 to 90 kV, the gradient becomes 1/1.5, with a density difference of 0.65 at 15-mm aluminium. Therefore, when exposure time is short, such as one or two electric source cycles, the effects of abnormality can not be ignored.

Thus we have confirmed that the abnormal voltage causes a departure from optimum exposure-factors[2] of radiographs.

Conclusions

According to the facts mentioned above, we can conclude regarding the necessity for prevention of the abnormality, that: When operating with high kilovoltages *i.e.*, more than half the kilovoltage rating of a unit, the abnormal voltage should be prevented so that the break down of high-voltage unit parts does not occur. Whereas, even if operating with less than half of the kilovoltage-rating, abnormal voltage should be prevented so that a departure from optimum radiography does not occur.

References

1) Kanamori, H.: Analysis of High-Voltage Waveforms in X-ray Units: II Abnormal Voltages, Journal of the Franklin Institute, **279** (1965) 246～253.

2) Kanamori, H.: Optimum Density and Density Range of Radiographs, Japanese Jour. of Applied Physics, **3** (1964) 286～294.