Generators, cine pulse systems, and x-ray tubes for coronary cineangiography

Thure Holm, M.L.

Lund, Sweden

X-ray generator

A modern x-ray generator consists of a 3-phase transformer, a 12-pulse rectifying circuit, and an electronic contactor on the high-tension side. The generated tube potential (kV) is monitored and automatically maintained at an exact preset value. The tube potential is free from ripple and the cine pulses are essentially square waves. Full operating potential can be reached in less than 0.2 msec. The repetition rate of the contactor is at least 200 pulses/sec.

The practical working range is 50 to 120 kV and tube currents higher than 800 mamp are not needed. Thus, the power requirements are never more than 100 kW.

Due to the image intensifier lag, exposure times shorter than 1.5 msec should be avoided. Exposure times shorter than 2 msec are in fact not needed to avoid motion blur in coronary cineangiography. Exposure times longer than 10 msec are not accepted by cine cameras at a frame rate of 50 fr/sec or more. The Arritechno camera will not permit more than 6.3 msec exposures at 60 fr/sec due to its 149° shutter-open phase. A suitable exposure time is about 3.2 msec and this can be used up to a maximum of 120 fr/sec.

The most common generator programming in the past 20 years was based on constant tube potential (kV) and variable tube current (mamp) during exposure. This is a slow reacting system and is no longer recommended due to underutilization of the x-ray loadability. (The tube load may vary from 25% to 100% during a routine examination.) It is better to use a generator program that utilizes constant tube current (mamp) and rapidly variable tube potential (kV). This mode of operation permits an x-ray tube load in the range of 75% to 100%. A still superior system uses constant load (kW) in which the tube potential always is kept as low as possible and the tube current is adjusted over a small range to maintain the constant load. This system may be set at a constant load of 100%. It also has a wider working range than the other two systems and can handle twice the patient thickness range in a single program setting compared to a constant current system.

X-ray tube

The choice of a suitable x-ray tube is affected by imaging geometry, peak tube load per examination, average tube load per hour, and image intensifier performance. The old rule of thumb for ideal imaging geometry implies that the source-image-distance (SID) should be five times the object diameter, that the object should be as close to the image detector as possible, and that the nominal value of the focal spot should be 1/1000 of the SID. Application of this rule to coronary angiography will give an SID of 90 to 120 cm and a nominal focal spot size of 0.9 to 1.2 mm.

Analysis of the imaging conditions shows that any focal spot smaller than 1.5 mm (nominal value), used with an SID of 100 cm and a magnification of 1.25 times, has a better MTF than a 9″ CsI image intensifier.

Studies of load characteristics of available high power x-ray tubes indicate, however, that sufficiently powerful tubes are available with 1 to 1.2 mm focal spots. Exposure conditions for two such tubes (Philips SRM 35 100 and SRO 25 50) are given in the *Table*.

Standard power specification for x-ray tubes relate to short single exposures and relatively long cooling intervals. An x-ray tube used in coronary cineangiography must be specified for its actual working conditions. It must be capable of handling 10-second-long sequences of many and short high-intensity exposures during 15% to 25% of this time (see table: effective exposure time). The load requirements must be established for each practical combination of frame rate, exposure time per frame, and total time for the cine sequence. The *Table*

Table. Exposure conditions

Exposure time per frame			Effective exposure time	Tube load in cinefluorography			
				SRM 12°	100 mm	SRO 15°	90 mm
50 fr/sec	63 fr/sec	80 fr/sec	during 10 sec	100 kW 1.2 mm	35 kW 0.6 mm	50 kW 1.0 mm	25 kW 0.6 mm
2.0 msec	...	...	1.0 sec	62 kW	31 kW	43 kW	22 kW
2.5	2.0 msec	...	1.25	55	28	39	20
3.2	2.5	2.0 msec	1.6	50	27	34	18
4.0	3.2	2.5	2.0	41	22	30	16.5
5.0	4.0	3.2	2.5	35	20	27	15
6.3	5.0	4.0	3.2	30	17	23	13

shows that the tube load usually is 30 to 50 kW. This is maintained at constant level when the tube is used with a modern constant load cine pulse generator. If the generator uses a fixed mamp setting and variable kV, the load requirements will be about 25% larger. The consequence of choosing a tube with insufficient loadability is that the tube potential must be increased, resulting in reduced image contrast.

The loadability of an x-ray tube depends upon how the problems related to heat distribution and heat emission have been solved. The actual target area must be large even though the projected focal spot must be small. This is solved by choosing an x-ray tube with smallest possible anode angle and a large diameter of the rotating anode. A 9-inch image intensifier requires an anode angle of not less than 8° to avoid the anode heel effect at an SID or 100 mm. A laminated anode has the best combination of good heat conductivity and large heat storage capacity. The surface of a laminated anode consists of an alloy of 90% tungsten and 10% rhenium, which has a high melting point and large cracking resistance. The base consists of molybdenum, which has good heat conductivity and large heat storage capacity. A thick graphite backing will further increase the heat storage capacity and improve the heat emission. Any type of black surface of the anode will increase the heat emission. Water cooling leads the heat away from the tube housing and may double the possible heat load over longer periods. Anodes with radial slits have higher resistance to cracking due to thermal tensions.