How Long will my X-Ray Tube Last?

Summary

A frequent question posed on a manufacturer of x-ray tubes is "how long should I expect this x-ray tube to function?" Unfortunately the best answer is "that depends". While this is an unsatisfactory answer, one can examine the main failure modes in an effort to predict this otherwise elusive answer. This application note sets out to explore the modes of failure of an x-ray tube and provides the reader with the information necessary to estimate the expected life of an x-ray tube.

Modes of Failure

Heat

The most frequent mode of failure of an x-ray tube is the failure to adequately dissipate the heat generated during normal operation. It is well known that 99%+ of the kinetic energy imparted on the electron beam is lost in the form of heat at the anode target. Thus, a 50W x-ray tube will produce roughly 49.8W of energy in the form of heat just through the conversion process. Add to this the thermal energy produced by the helical tungsten filament and one can readily see that heat dissipation is a major factor. The failure mechanism, with respect to the x-ray tube itself, due to inadequate cooling can take on two forms; the first is simple sublimation of the anode target material. In converting the anode target material directly from a solid to a gas (sublimation), the resulting vapour rapidly degrades the internal ultra-high vacuum necessary for proper operation. This loss of ultra-high vacuum results in a failure of the x-ray tube to withstand the high voltage gap between the cathode electron source (helical tungsten filament) and the target anode. The x-ray tube begins to short circuit, or arc, which in turn liberates more gas, which in turn further degrades the internal vacuum, which finally results in an x-ray tube which no longer functions. The second failure mode due to improper heat dissipation is the liberation of damaging ions. If the x-ray tube anode is allowed to surpass the vapour pressure point of the target material, than a liberation of ions occur. In turn these liberated ions are attracted back toward the helical tungsten filament and begin to erode the filament through an ion scrubbing process. This can result in a premature failure of the filament, which manifests itself as a broken filament, or open circuit. Prevention of both of these failure modes is made possible by ensuring that the x-ray tube is not allowed to overheat. This means careful monitoring of the cooling circuit with fault protection in the event of a cooling system failure. Oxford Instruments now offers integrated thermal protection in its packaged x-ray tubes to prevent this type of failure.

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Filament Evaporation

The process of producing electrons necessary in the production of x-rays in an x-ray tube begins by heating a tungsten wire. When heated to approximately 2000 degrees C, tungsten is a copious emitter of electrons. From this point several trade-offs in design become factors, which must be considered. The resulting design of a modern x-ray tube seeks to balance the relationship between performance and filament longevity. Of importance to those users seeking a small x-ray focal spot, the relationship between a smaller wire filament and a small focal spot is well established[1]. Thus, one would prefer a smaller filament where possible. With this in mind a typical filament "driver" circuit must be able to control the current to the filament quite carefully. This is due to the important relationship between filament current and actual temperature of the filament wire itself. By example, the series 5000 x-ray tube requires more than 1.5 amps current at 2 volts to achieve the required filament temperature necessary for electron emission. However above 1.7 amps the filament enters a very high region of evaporation, and by 1.75 amps the filament reaches its melting point, which results in an open filament. Therefore careful control of the filament circuit is essential to a long lived x-ray tube, and most x-ray tube power supplies have this tightly designed circuit which prevents the filament from exceeding its maximum allowable current. It is essential that the user of an x-ray tube understand what is the maximum allowable filament current and that the chosen x-ray tube power supply has the capability for setting a filament current limit. Again a very frequent mode of failure is a filament which has been allowed to exceed its maximum allowable filament current. The best course of action is to purchase your power supply from Oxford Instruments. In doing so you are guaranteed that the power supply has been matched to the x-ray tube and that it has a properly functioning filament current limit circuit.

Assuming that the user has taken consideration to design an integration which adequately cools and protects the x-ray tube from overheating and has chosen a power supply which properly protects the filament, the remaining issue to examine is the end of life of the helical tungsten filament itself. As mentioned above, the process of producing electrons from the filament requires heating the helical tungsten filament. In doing so a natural process of evaporation occurs such that after a number of hours of normal operation, the filament thins to the point of failure. The rate of evaporation, and thus the total number of hours required to thin the filament to the point of failure is a function of the chosen operating conditions. As can be seen in figure one, the filament current required to heat to achieve a given x-ray beam current differs depending upon the required applied high voltage. Therefore, to determine the anticipated life of a helical tungsten filament, one must estimate the average filament current employed throughout its life. Once estimated, the rate of evaporation can be used to estimate the normal filament life, (figure two). By example, if the user normally operates the x-ray tube at 40kV, and 1.0 mA, this requires a

[1] Note: This argument applies only to small focal spots when utilizing a tungsten wire filament. In the case of microfocus x-ray tubes a dispenser cathode is typically employed.

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filament current of approximately 1.60 A. Using the chart in figure 2, this translates to approximately 40,000 hours of expected life.

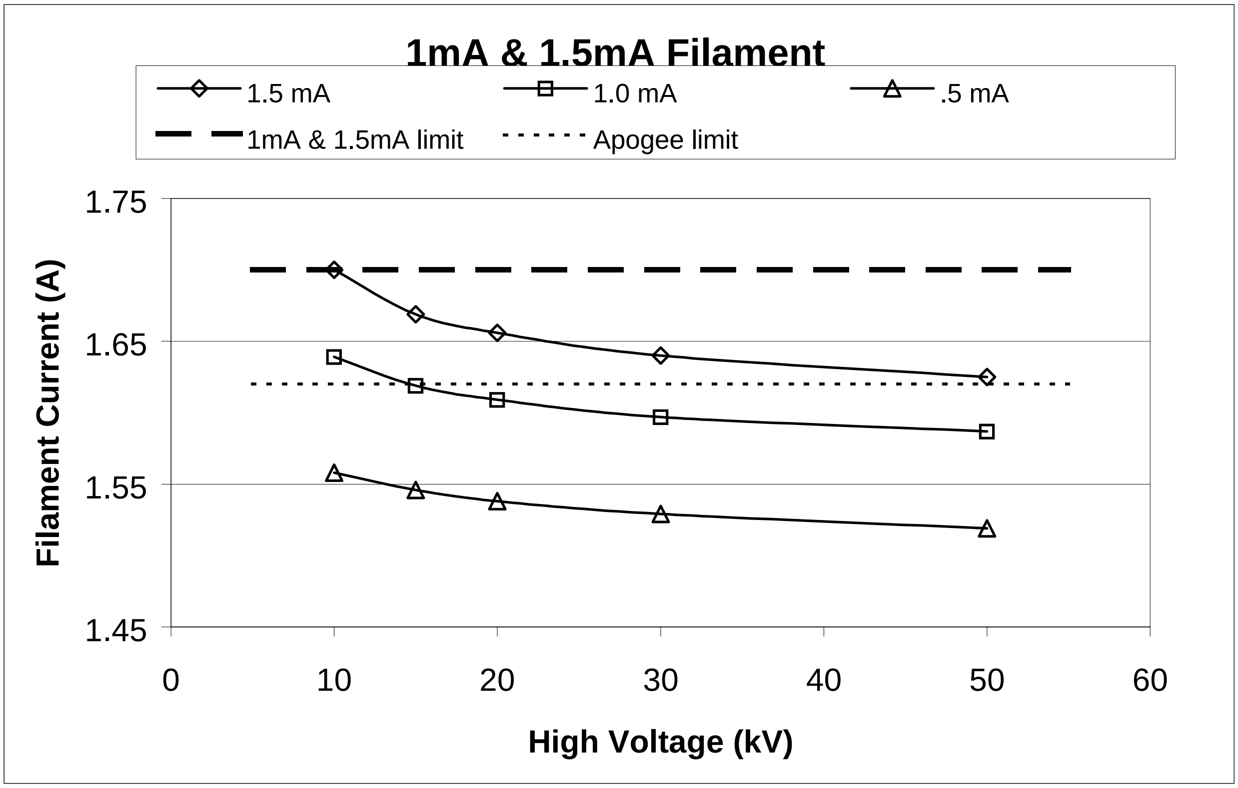

Fig 1: Filament current required for the series 5000 x-ray tube from Oxford Instruments

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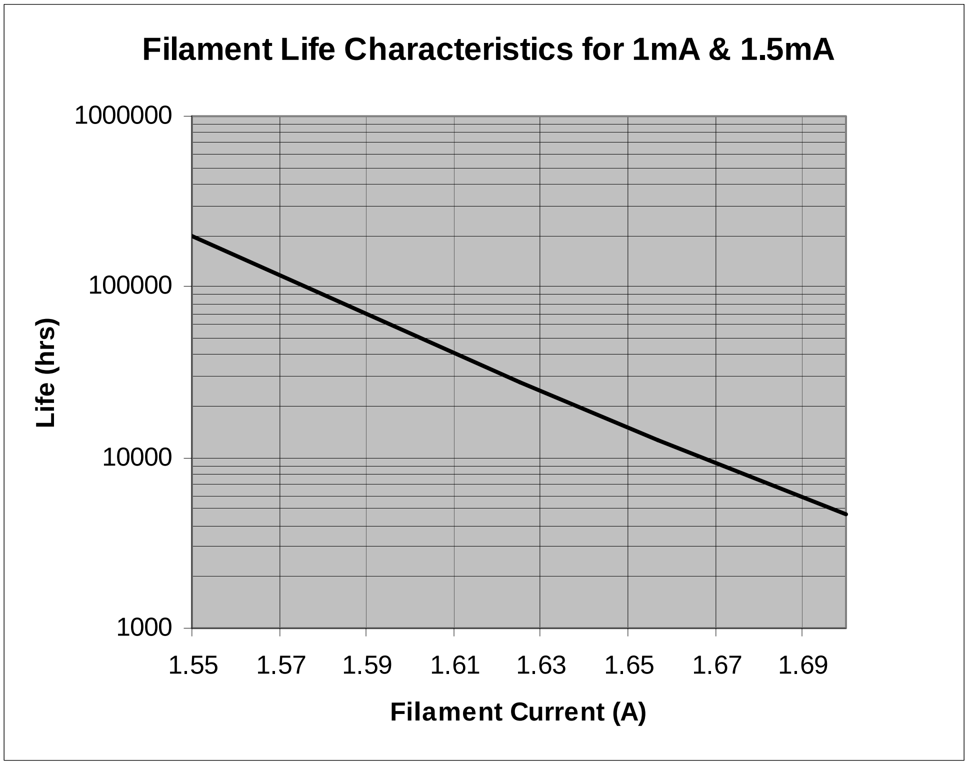

Fig 2: Filament life for the series 5000 x-ray tube from Oxford Instruments

Conclusions

As can be seen, if an x-ray tube is properly cooled and essential filament circuit protection is provided, the remaining issue, which governs x-ray tube life, is the evaporation of the tungsten filament. The rate of evaporation is a function of the operating conditions but under most circumstance is several 10's of thousands of hours.

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