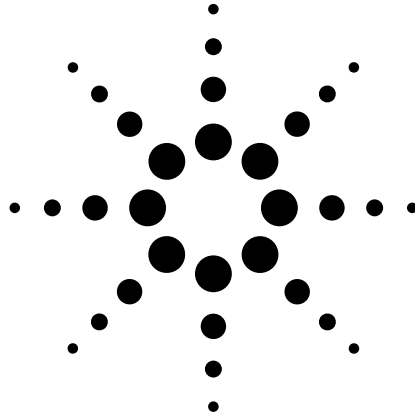


Life and Stability of the Agilent 5DX Sealed X-ray Tube



To produce cross-sectional X-ray images, Agilent's 5DX Automated X-Ray Test systems use a sealed X-ray tube that is designed and built in-house to exacting standards. Since Agilent's 5DX systems are integral to customers' assembly processes, they must operate consistently with minimal downtime. For this reason, Agilent has developed a sealed, ultra-high vacuum X-ray tube that provides stable output throughout a significantly long life. Other X-ray inspection systems use demountable X-ray tubes, that are designed to allow field replacement of tube components to suit diverse applications. However, the poor vacuum levels of demountable tubes adversely affect their stability and reliability, and require the use of simple filament cathodes, which have relatively short lives.

Cathode

The Agilent 5DX sealed X-ray tube uses a dispenser cathode (see Fig.1) which consists of a porous tungsten "sponge" impregnated with barium. To emit electrons, the cathode is heated by a separate tungsten heater. This design results in very reliable and efficient electron emission. It has a life beyond 20,000 hours while providing a small spot size and high current density for high resolution imaging. The typical failure mode involves the gradual depletion of the barium, which can be compensated for to maintain stable operation.

No cathode in any 5DX sealed tube has ever fully depleted in the field, even after years of use. In contrast to sealed tubes, demountable tubes use a filament cathode (see Figure 1).

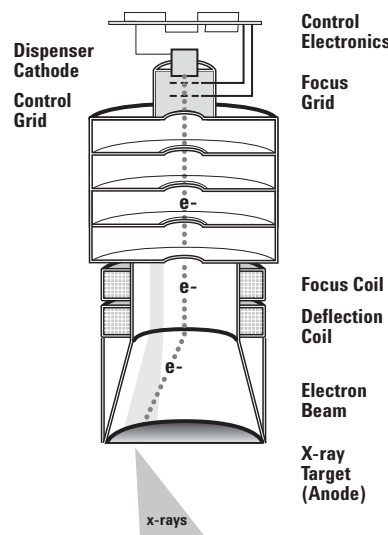
It consists of a thin tungsten wire that is heated to high temperatures by the current flowing through it. While it can also provide a small spot size, a filament cathode only lasts about 400 to 1200 hours. It typically fails by

Agilent 5DX Technical Data

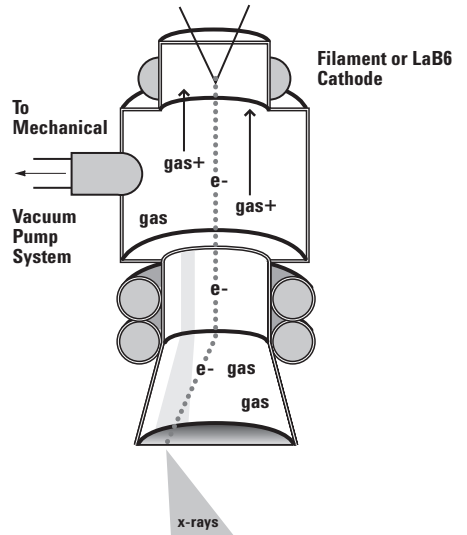
instantly vaporizing, very much like a light bulb failure. As a result, demountable tubes fail unpredictably and frequently, requiring the need for field replacement every 1 to 4 months. Replacing the cathode, including the time required to stabilize the system, takes about 5 to 8 hours when performed by a skilled technician. This leads to significant production downtime over the life of the system.

Figure 1

Agilent 5DX Sealed X-ray Tube



Demountable X-ray Tube



Vacuum Level

In addition to the type of cathode used, the vacuum level in the tube is another major factor affecting tube life and stability. A poor vacuum or "soft" tube contains more gas molecules than a high-vacuum sealed tube. As electrons accelerate from the cathode to the anode, they collide with these gas molecules. In the process, the electrons lose energy and cause the gas to emit secondary electrons. Furthermore, the ionized gas molecules accelerate towards the cathode and strike it with considerable kinetic energy due to their high molecular weight. This further shortens the life of the cathode and may affect the electron beam's quality and the ability to focus and steer it. Consequently, a "soft" tube is less stable and has a greater probability of arcing.

To achieve an ultra-high vacuum, a completed X-ray tube assembly must be baked at a high temperature under hard vacuum for an extended burn-in period. This process substantially removes any gas molecules from surfaces within the assembly. High-quality sealed vacuum devices, such as those used in NASA space missions, military applications and Agilent's 5DX systems, all undergo such a process to ensure that they provide long-term stable operation. Because demountable X-ray tubes cannot be baked, and need to be opened to replace components, they cannot achieve the same high vacuum of sealed tubes.

Comparison of Operating Costs

The operating costs of a typical demountable tube and Agilent's 5DX sealed tube are compared based on three shifts per day, five days a week, resulting in approximately 6000 operating hours per year. The dispenser cathode of the sealed tube is conservatively assumed to have a life of 20,000 hours. Its replacement cost is \$24,500 in parts and 8 hours of labor at \$200/hour. The filament cathode of the demountable tube is assumed to have a life of 1,000 hours. Its replacement cost is \$40 in parts and 6 hours of labor at \$200/hr.

Though the repair costs are similar, the short life of the filament cathode in demountable tubes results in significant production downtime every year. The cost of this down-time far outweighs any savings associated with demountable tubes, particularly if failure occurs during peak production times. Furthermore, another aspect of demountable tubes that is not quantified here is the increased cost of maintaining the vacuum pumps.

Summary

The sealed X-ray tube used in the Agilent 5DX system has significant advantages over demountable tubes used in other inspection systems. Because of their cathode design and ultra-high vacuum level, sealed tubes are more reliable and stable, resulting in higher quality, lower production costs and lower cost of ownership.

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