

Keysight Technologies

Automated X-Ray Inspection System

Sealed X-Ray Tube

Technical Overview

To produce cross-sectional X-ray images, Keysight’s Automated X-Ray Inspection (AXI) systems use a sealed X-ray tube that is designed and built in-house to exacting standards. The AXI systems are integral to customers’ assembly processes; they must operate consistently with minimal downtime.

For this reason, Keysight 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 Keysight AXI sealed X-ray tube uses a dispenser cathode (see Figure 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 AXI 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 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.

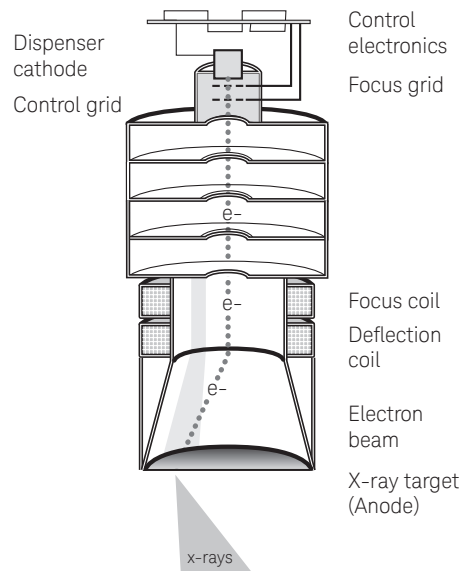
Vacuum Level

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 AXI 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.

Keysight AXI sealed X-ray tube



Demountable X-ray tube

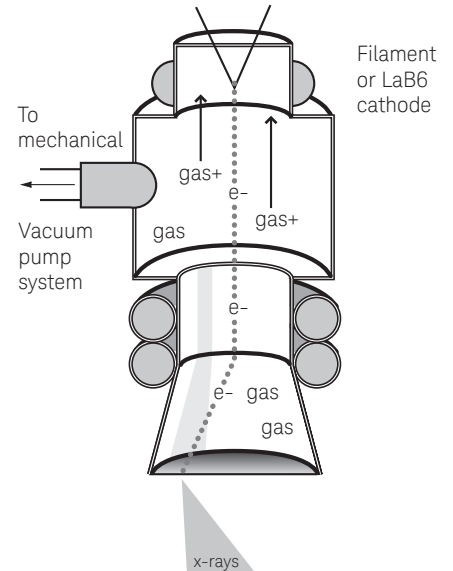


Figure 1.

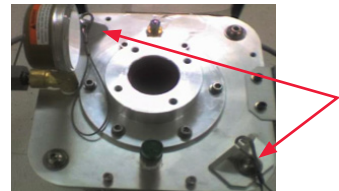
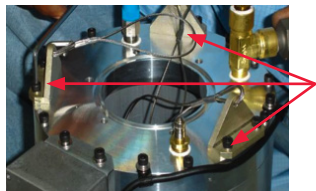
New Improved X-Ray Tube Housing

Keysight has improved the current X-ray tube housing design to enable the following benefits:

1. To increase the supply chain capability
2. Ability to ship the new improved x-ray tube with improved housing under 'Non-Dangerous Good' classification.
3. The weight is lighter at 32 kg compared to the current design which is 48 kg.
4. Transportation cost is less.
5. Materials cost for the new improved x-ray tube housing is lower and easily available.
6. Materials availability turn-around time is shorter.

Comparing the current and new improved X-ray tube housing:

Current X-ray tube housing	New improved X-ray tube housing
<ol style="list-style-type: none"> 1. The materials are made of stainless steel for the top plate and bottom plate. 2. The pressure vessel is made of extruded aluminum. 	<ol style="list-style-type: none"> 1. The bottom plate, top plate and pressure vessel is made of aluminum. 2. The pressure vessel rods are also made of aluminum.
<ol style="list-style-type: none"> 1. The top plate is round. 2. There are three lifting support brackets. 3. The plate thickness is 25.4 mm. 4. The diameter of the top plate is 203.2 mm. 	<ol style="list-style-type: none"> 1. The top plate is square. 2. There are only two lifting support brackets instead of three. 3. The plate thickness is 19.05 mm.
<ol style="list-style-type: none"> 1. The SF6 gas in the tube is pressurized at 63 psi. 	<ol style="list-style-type: none"> 1. The SF6 gas in the tube is pressurized at 26 psi.



Current X-ray tube housing	New improved X-ray tube housing
<ol style="list-style-type: none"> The wall thickness of the pressure vessel is 12.44 mm. The length of the pressure vessel is 495 mm and the total tube length is 102 cm. There are no support rods for this X-ray tube. 	<ol style="list-style-type: none"> The wall thickness of the pressure vessel is 3.18 mm. The length of the pressure vessel is 507.7 mm and the total tube length is 102 cm. There are four support rods for this X-ray tube. The diameter of each rod is 19.98 mm The length of each rod is 507.60 mm
<ol style="list-style-type: none"> The base plate length is 254 mm. The base plate has no outer groove on the top. The thickness of the plate is 23.23 mm. 	<ol style="list-style-type: none"> The base plate length is 247.65 mm The base plate has an outer groove that is 195.83 mm in length. The overall thickness of the plate is 19.05 mm. The groove thickness is 6.65 mm.
<ol style="list-style-type: none"> The tube has a standard L-shaped bracket. 	<ol style="list-style-type: none"> This tube has an improved design VACION pump bracket mounting.
<ol style="list-style-type: none"> It is supported by two screws on the top plate only. 	<ol style="list-style-type: none"> It is also supported by two screws on the top plate.

Comparison of Operating Costs

The operating costs of a typical demountable tube and 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 \$28,500 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 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.

X-Ray Tube Parts List

Part#	Description in custom invoice/oracle	Specification				
		Pressure vessel (Pressure of SF6)/psi	High resolution	Standard resolution	New tube	Refurbished tube
E7200-89009	RSTRD E7200-80009 x-ray tube	62		√		√
E7200-89059	RSTRD E7200-80059 hi resolution x-ray assy	62	√			√
E7200-89066	Zero pressure vessel standard res x-ray tube exch	26		√		√
E7200-89067	Zero pressure vessel hi res x-ray tube exch	26	√			√
N7210-80066	Zero pressure vessel standard res x-ray tube	26		√	√	
N7210-80067	Zero pressure vessel hi res x-ray tube	26	√		√	

Glossary

Hi Resolution	High resolution
Standard Res	Standard resolution
HI RES	High resolution
Zero Pressure Vessel	Denotes 26 psi

Note: The maximum operating voltage and current for all the tubes are 165 KV and 105 micro Amps.

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