SINGLE CRYSTAL X-RAY DIFFRACTION

Electrical power requirements and cost of ownership for high-intensity X-ray sources

White Paper 528

Introduction

Given today's soaring energy prices and the possibility of looming shortages in some areas many firms and universities are implementing new policies and guidelines to reduce electrical usage. Some institutes are also offering special funding to facilitate upgrades to more energy-efficient instrumentation. Significant energy savings can be achieved in the X-ray laboratory without sacrificing performance by upgrading from an energy-intensive rotating anode source to a modern microfocus source like the IμS DIAMOND II.

The new IμS DIAMOND II is the latest member of the air-cooled IμS family which exploits an innovativenew diamond anode and a novel high-brightness cathode to achieve a remarkable intensity of up to 1.1×10^{11} X-rays/mm^2-sec. The performance is thus competitive with typical rotating anode sources whilereducing energy consumption by an order of magnitude.

Figure 1
The new IμS DIAMOND II exploits improved hybrid diamond anode together with a novel high-brightness cathode to achieve anX-ray intensity equal to typical rotating anode sources but with anorder of magnitude lower power consumption.

Total electrical power requirements for rotating anode and microfocus sources

The power rating of an X-ray source typically refers to the electron beam power focused on the anode. For example, a typical 1200 W rotating anode deposits 1200 W of electron beam power onto the anode. However, the electron beam power does not represent the total electrical cost of running the source as several other components require additional electrical power.

In particular, the high-voltage generator for the rotating anode will not be 100% efficient so a 1200 W generator will typically require about 1300 W of electrical power. The rotating anode also requires an electric motor to spin the anode which typically requires about 900 W of electrical power. Rotating anodes must be actively pumped by a turbomolecular pump to maintain the required base vacuum level and the pump typically will draw about 600 W of electrical power. The anode is water cooled and the cooler typically requires about 2.8 kW of electrical power for the pump and compressor. Finally, waste heat

from the high voltage generator, anode motor, and water cooler will be exhausted into the room air and must be removed by the air conditioning (HVAC). This requires about 1100 W assuming a typical HVAC efficiency (EER=8.5). Therefore, the total electrical power required to operate a typical 1200 W rotating anode is about 6750 W as shown below in Table 1.

Similarly, in a microfocus source, the high voltage generator that drives the source is not 100% efficient and thus an 80 W electron beam typically requires about 100 W of electricity from the wall. In addition, the cathode heater typically requires about 30 W, and for an air-cooled source, the cooling fans require a few watts of power. Thus, the 80 W microfocus source typically requires about 135 W of electrical power to operate. Finally, the 135 W of power used by the source will be exhausted as heat into the room which must be removed by the air conditioning (HVAC) system which also requires electrical power. For a typical HVAC system, this would require 30 W of electrical power to remove 135 W of waste heat. Therefore, the total electrical bill for running an 80 W microfocus source is about 165 W (as shown in Table1 below).

	Rotating anode Electrical power consumption (W)	Microfocus tube Electrical power consumption (W)
HV generator	1300	100
Filament heater	50	30
Turbomolecular vacuum pump	600	0**
Anode rotation motor	900	0**
Anode cooling	2800	5
HVAC*	1100	30
Total	6750	165

Table 1
The electrical power consumption for rotating anode and a diamond anode microfocus sources. The 1200 W rotating anode requires about 5500 W additional electrical power for the filament heater, anode motor, vacuum pump, water chiller, and HVAC while the 80 W microfocus source requires an additional 85 W for the filament heater, fans, and HVAC.

* Assumed HVAC efficiency EER=8.5.

** Not required for sealed microfocus tube.

Electrical costs to run a rotating anode source and a microfocus source for a year

Table 2 below shows the current electricity prices for several countries and the associated costs to run a rotating anode and microfocus source for one year (assuming full-time, full-power operation).

With today's electricity pricing it would cost up to 40,000 € in Germany to pay for the electricity to run a 1.2 kW rotating anode for a year. In comparison, the 80 W diamond microfocus source would require only 1000 €.

Country	Electricity cost (€/MW-h)	Rotating anode Annual electrical cost (€)	Microfocus tube Annual electrical cost (€)
Germany	699	39,900	1069
Italy	543	30,900	830
France	492	28,000	753
Switzerland	488	27,800	746
Sweden	190	10,800	285

Table 2
The cost to run a typical rotating anode (1.2 kW) and a microfocus source (80 W) for one year (full power, 24/7). Electrical costs as per August 2022 (Ref. Statistica.com).

The projected 10-year total cost of ownership of rotating anode and microfocus sources

Current electrical prices are at historical highs and prices over the near term remain uncertain. However, most observers predict that in the mid to longer term that energy prices will moderate. So, what is the projected cost of energy for the rotating anode and microfocus source over 10 years based on current cost projections? Figure 2 shows one projection of average electricity costs in Europe through 2050.

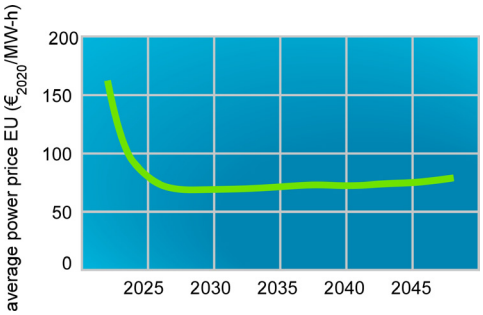

Figure 2
Projected electrical pricing in Europe through 2050 (EU Energy Outlook 2050, April 2022, https://energycentral.com).

Based on these projected prices we can calculate the 10-year cost of electricity for rotating anode and microfocus sources as shown in Table 3. Over 10 years the microfocus tube is projected to save nearly 70,000 € in electrical costs.

In addition to electrical costs, the other major component of the total costs of ownership is the maintenance costs. Rotating anodes require period routine replacements of the anode, filaments, rotary seals, and brushes. Such maintenance typically costs between 10,000-20,000 € per annum. In addition, it is usual that the turbomolecular vacuum pump will need to be replaced during 10 years of operation at a cost of about 8,000 €.

The IμS DIAMOND II microfocus source will typically require only one tube replacement over 10 years of operation at a cost of about 25,000 €. Therefore, the microfocus source can save almost 150,000 € in the total cost of ownership over 10 years compared to a rotating anode.

Table 3
Over 10 years a rotating anode will cost on the order of 175,000 € to operate, with about 75,000 € for electrical power and about 120,000 € for routine maintenance (anode, filament, seal, and brush exchange). In contrast, over 10 years the microfocus source will cost only about 27,000 € to operate with 2000 € for electricity and 25,000 € for maintenance.

	Rotating anode source	Microfocus source
10-year electrical costs (€)*	74,800	2,000
10-year maintenance costs (€)**	120,000	25,000
The total cost of ownership (€)	175,000	27,000

*Projected European average electricity price as per EU Energy Outlook 2050
**RAG: Anode refurbishment, filament, ferrofluidic seal, and carbon brush exchange. Microfocus: one tube replacement

Conclusions

The latest IμS DIAMOND II diamond anode microfocus source produces an X-ray intensity equal to a typical 1.2 kW rotating anode generator. However, the lower power consumption and reduced maintenance saves typically on the order of 150,000 € in the total cost of ownership over 10 years.

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