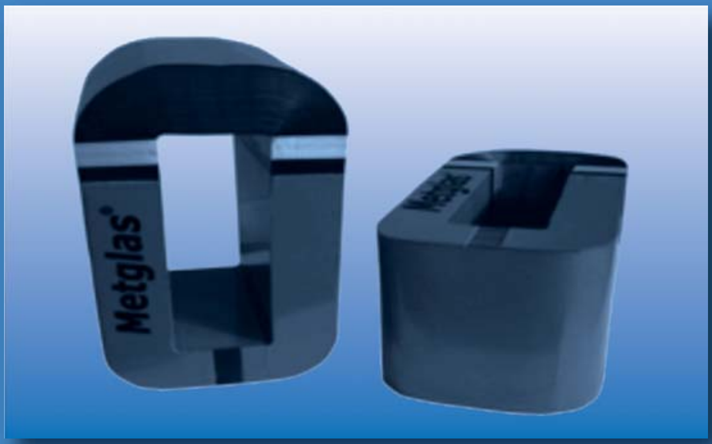
Amorphous Metal Distribution Transformers

Metglas®, Inc.

Lighting the world. Keeping it cool…



www.metglas.com

Distribution Transformer Electrical Steel

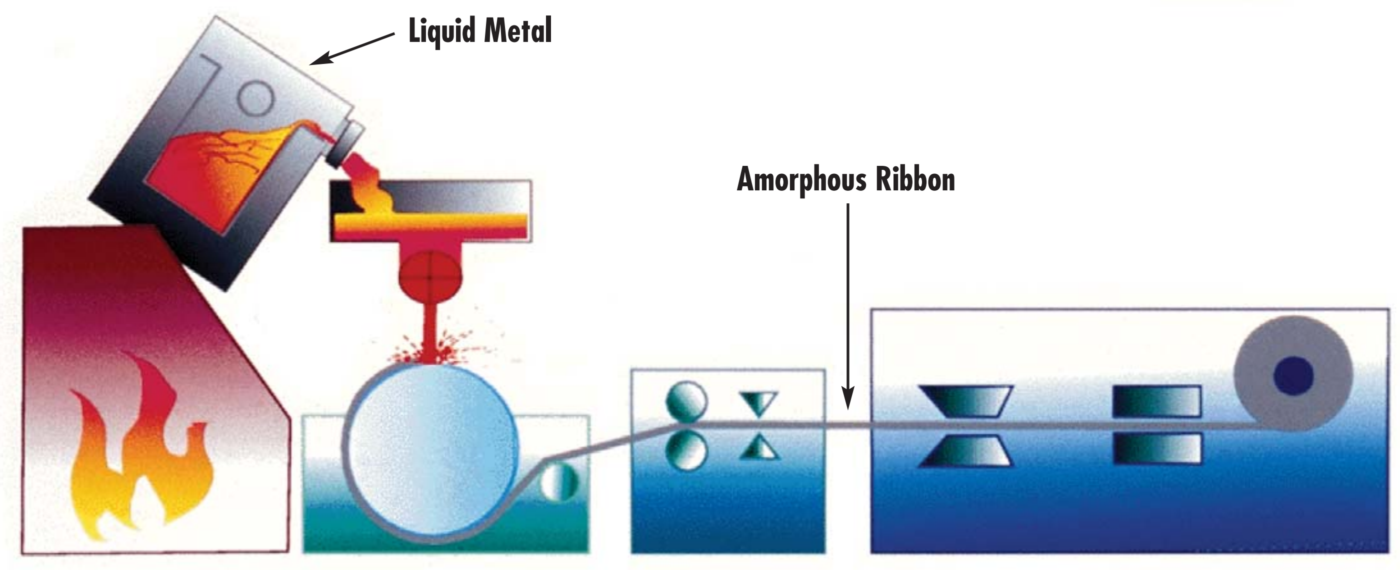
AMORPHOUS ALLOY FOR ENERGY EFFICIENT DISTRIBUTION TRANSFORMERS

Metglas pioneered the development and commercialization of amorphous metals, unique alloys that exhibit a structure in which the metal atoms occur in a random pattern. The grain oriented structure of conventional silicon steel has higher resistance to magnetization and demagnetization than Metglas amorphous.

HOW IS AMORPHOUS FOIL MADE?

Metglas' proprietary rapid-solidification manufacturing process is the key, in which the molten alloy cools at a rate of one million degrees Celsius per second.

MELT SPINNING PROCESS



Metglas Amorphous Metals have a unique non-crystalline structure and possess excellent physical and magnetic properties that combine strength and hardness with flexibility and toughness. Metglas and Metglas products help companies around the globe reduce operating costs, strengthen energy conservation efforts and increase application efficiency.

Our amorphous alloys, Metglas® 2605SA1 and 2605HB1M, can significantly reduce the losses that occur in transformers in comparison with Grain Oriented Electrical Steel (GOES) due to superior soft magnetic characteristics (amorphous structure and thin), which contribute greatly to energy conservation and reducing carbon dioxide emissions.

TOTAL OWNING COST AND PAYBACK FROM USE OF EFFICIENT DISTRIBUTION TRANSFORMERS

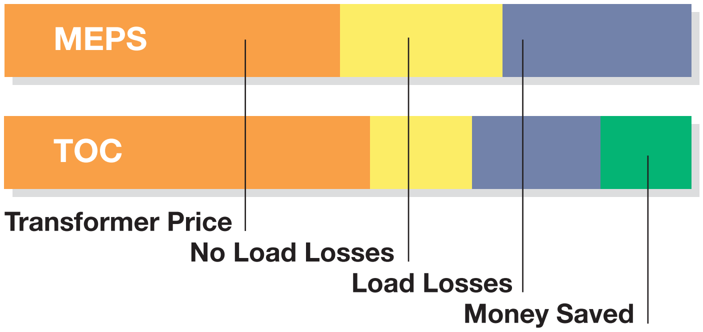
There are several ways to specify distribution transformer Energy Efficiency. The most common methodologies, called Minimum Energy Performance Standards (MEPS), include:

- Efficiency at 50% load (e.g. Australia, USA)
- Maximum 100% load losses and maximum no load losses (e.g. EU, Brazil)
- Maximum losses at 50% and 100% loads (e.g. India)

(See SEAD Distribution Transformers Report Part 1: Comparison of Efficiency Programs December 19, 2013 for a well researched summary)

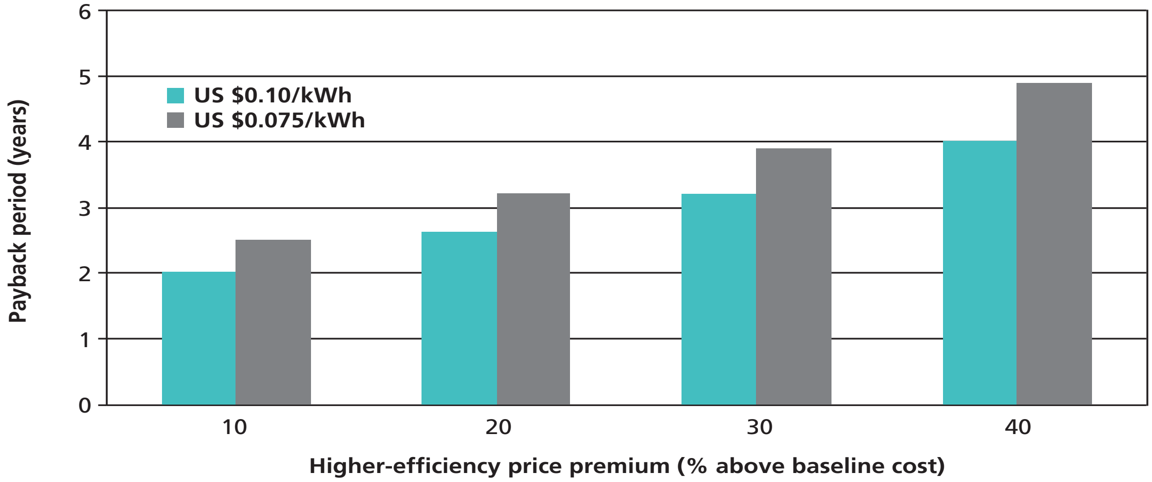
However, many progressive utilities and end users make buying decisions based on total cost of ownership of the transformer over its useful life. These costs include initial cost of the transformer plus the economic cost of the wasted energy. This is the most economically sound method of evaluating different transformer purchase options and is called, among other names, Total Owning Cost (TOC) or Total Cost of Ownership (TCO). Although there are many sources describing methodology of using TOC, as of 2016, both IEEE and IEC are developing updated tools to assist those making buying decisions based on TOC.

Usually, the initial cost of a transformer designed for minimum TOC will be higher than one designed to meet minimum efficiency or maximum losses. However, over the life of the transformer, due to the economic value of the wasted energy, a transformer designed to minimize TOC will cost less than one designed using another method.



Many organisations separate the management of the capital expenditure budget from the management of the operations and maintenance budgets. This tends to weaken the economic incentive the procurement manager has to invest in products that minimize service life cost and favours investment in equipment with the lowest price. This focus on lowest price leads to suboptimal investments over the transformer's service life, because operating costs due to losses are significant and yet are undervalued in the procurement transaction. (1)

Payback period for the purchase of high-efficiency amorphous distribution transformers compared to conventional technologies, as a function of electricity price. (2)



(1) Prophet II: The potential for global energy savings from high efficiency distribution transformers; Final report – November 2014, 22; Prepared for the European Copper Institute by Waide Strategic Efficiency Limited and N14 Energy Limited

(2) Ibid. 24 Figure 3-3, source UNEP 2011

ARE YOU BUYING DISTRIBUTION TRANSFORMERS MEETING 2016 US DEPT OF ENERGY EFFICIENCY STANDARD?

COMPARED TO SILICON STEEL CORE TRANSFORMERS, AMORPHOUS CORE TRANSFORMERS WILL HAVE 50% LOWER LOSSES AT 20% LOAD AND 32% LOWER LOSSES AT 30% LOAD (1)

The Energy Efficiency of most distribution transformers purchased in the US are based on the 2016 Dept of Energy Standard. The Standard is based on minimum efficiency at 50% of Nameplate Rated Load (Capacity Factor).

However, the vast majority of residential transformers operate at 20% - 30% Capacity Factor (2)
So transformers with lower no-load losses will be more efficient **under actual operating conditions**. Amorphous Core Transformers have much lower no-load losses than transformers made with traditional electrical steel.

SAVE TONS OF ENERGY (AND CO_2) WITH AMORPHOUS

Annual Energy Savings (kWHr per MVA of Nameplate Capacity)		
	20% Capacity Factor	30% Capacity Factor
Single Phase Distribution	11,258	8,606
Three Phase Distribution	6,935	5,282

(Assumes Size Mix from Table 9.3.3 Chapter 9 of DoE TSD's)

Amorphous metal distribution transformers are key to improving utility economics and enhancing energy conservation efforts worldwide.

Our core focus is efficiency.

Ask your suppliers to quote transformers made with Metglas® Core Steel.

(1) Estimate based on Metglas Transformer Optimization Model
(2) APPA / NRECA Letter to EPA 27th February 2015 – Attachment A – 1st page

ARE YOU BUYING DISTRIBUTION TRANSFORMERS MEETING EUROPEAN UNION ECODESIGN REQUIREMENTS?

METGLAS® Amorphous Metal Core Distribution Transformers (AMDTs) ARE MORE EFFICIENT AND HAVE LOWER OPERATING COSTS

Under the Commission Regulation (EU)[1] that establishes EcoDesign requirements for transformers, each transformer installed must operate with energy losses below both maximum No-Load Loss (NLL) and maximum Load Loss (LL) levels.

Due to amorphous metal core material having a random atomic structure and being thin, AMDTs **MUST** have lower NLL than those called out in the regulations.

Therefore, amorphous core transformers will naturally have

- **Higher Efficiency**
- **Less Wasted Energy**

under normal Tier 1 operating conditions than a traditional silicon steel transformer.

THE BENEFITS OF A ECODESIGN TIER 1 AMORPHOUS CORE TRANSFORMER

Europe Losses Designations (CENELEC) Tier 1			Amorphous (AMDT)	Efficiency at 20% Load[2]	
kVA	No-Load Losses (W)	Load Losses (W)	No-Load Losses (W)	GOES	AMDT
	A_0	C_k	A_0–55%	A_0; C_k	A_0–55%; C_k
400	430	4600	194	99.69%	99.81%

AMDT **MUST** be 99.81% Efficient at 20% Load and at C_k Load Losses due to lower No-load Losses;
Grain Oriented Electrial Steel (GOES) unit would be 99.69% Efficient at 20% Load for $A_O C_k$

A TIER 1 AMDT WILL HAVE 38% LESS WASTED ENERGY THAN A TIER 1 TRANSFORMER MADE WITH GOES (20% LOAD)

If all Tier 1 transformers in the EU were to be amorphous, energy savings (reduced generation) would be more than 5,000 kWHr/Year per MVA of Nameplate Distribution Capacity.

If 30,000 MVA of industrial – distribution transformers are installed in a given year, purchase of 100% AMDT would reduce annual CO_2 emission by **57,000** Tons.

(1) COMMISSION REGULATIONS (EU) No 548/2014 of 21 May 2014 (Table 1.1)
(2) VITO's 2010 LOT 2: Distribution and power transformer Draft Chapter 6 – Improvement Potential (Table 27) assumes that EU Distributions Transformer Load Factors are in the 10% to 25% Range, and Industrial Transformers are Loaded at 10% to 60%.

ECONOMIC AND ENVIRONMENTAL BENEFITS OF HIGHLY EFFICIENT DISTRIBUTION TRANSFORMERS

Lawrence Berkeley National Laboratory's Environmental Energy Technologies Division issued a report in October 2013 entitled *"Energy Efficiency Potential for Distribution Transformers in the APEC Economies."*

According to the report, Transmission and Distribution (T&D) losses in electricity networks in Asia-Pacific Economic Cooperation (APEC) member economies range between 2.8% and 15.6% of final energy consumption (IEA). Because approximately one-third of T&D losses take place in distribution transformers, there is significant potential to save energy and reduce costs and carbon emissions through an increase in distribution transformer efficiency.

The report estimated the Energy Savings, CO_2 emission reduction and Economic Benefit over fifteen (15) years in APEC countries assuming that, starting in 2016, energy efficient distribution transformers were installed where they could be justified economically.

In the vast majority of the cases studied, "Max Tech" (EL4) from the US Dept of Energy 2013 rulemaking was determined to be economically justified and the below table shows the impact of a 100% shift to these energy efficient transformers in those cases. "Max Tech" is synonymous with Amorphous Metal Core transformers (AMDTs).

Therefore, the below table shows the benefits of widespread adoption of AMDTs.

Summary Results for all APEC Economies Under the MEPS Scenario

	ANNUAL IMPACTS				CUMULATIVE IMPACTS		
	National Distribution Losses	Energy Savings	% Red.	CO_2 Emission Savings	Energy Savings	CO_2 Emission Savings	Net Financial Benefits
	2030 GWh	2030 GWh	2030 %	2030 Million Tons	2016-2030 TWh	2016-2030 Million Tons	Total Million USD
Australia	9,402	2,759	29%	2.3	21.5	18.1	1,982
Brunei*	63	19	30%	0.0	0.1	0.1	43
Canada	10,058	1,464	15%	0.3	11.4	2.1	463
Chile	3,254	1,248	38%	0.5	9.2	3.8	724
Hong Kong	586	95	16%	0.1	0.7	0.5	15
Indonesia*	7,913	2,361	30%	1.7	14.9	10.6	1,634
Japan	15,492	2,558	17%	1.1	20.5	8.6	1,330
Malaysia	4,516	1,957	43%	1.4	14.7	10.7	2,320
Mexico	6,295	1,434	23%	0.7	10.8	4.9	833
New Zealand	455	153	34%	0.0	1.2	0.2	152
Papua New Guinea*	156	47	30%	0.0	0.3	0.2	65
Peru	1,646	392	24%	0.1	2.7	0.8	130
Philippines*	2,230	665	30%	0.3	4.5	2.2	619
Russia*	22,031	6,574	30%	4.2	47.2	30.1	3,184
Singapore	814	243	30%	0.1	1.8	0.9	180
South Korea	7,354	1,325	18%	0.7	10.0	5.4	514
Taipei*	4,562	1,183	26%	0.9	8.9	6.9	214
Thailand	4,980	1,491	30%	0.8	10.3	5.3	1,066
United States	51,117	3,138	6%	1.6	24.8	12.9	2,604
Vietnam	4,008	1,107	28%	0.5	6.9	3.0	460
TOTAL	**156,932**	**30,212**	**19%**	**17**	**222**	**127**	**18,532**

* Results for this country are subject to a sizeable uncertainty

The report concludes that distribution transformer efficiency improvements are achievable in APEC economies and would save significant energy and reduce CO_2 emissions at a net negative cost. On average, electricity distribution losses in the APEC region can be reduced by 19 percent in 2030. As a result of this reduced energy consumption, annual CO_2 emissions would be reduced by 17 million tons (Mt) in 2030. Overall, between 2016 and 2030, more than 127 Mt of CO_2 emissions would be avoided. The net present value of the financial benefits of the programs that would achieve the above savings is estimated at about 18.5 billion USD.

AMORPHOUS METAL DISTRIBUTION TRANSFORMERS FOR WIND FARMS

Natural Partner for Wind Turbines

Many wind farm owners are taking advantage of AMDTs to increase plant output and profitability, while reducing environmental impact.

The AMDT Advantage for Wind Farms

- No load loss (NLL) or core loss up to 70% lower than GOES
- Substantially lower operating costs
- Lower draw from grid when not generating
- Increased contribution to Renewable Portfolio Standards (RPS)
- Lower losses = higher profits
- Optimal solution regardless of energy cost or capacity factor

METGLAS® 2605SA1 & 2605HB1M MAGNETIC ALLOY

APPLICATIONS:

- Distribution, industrial and commercial transformers
- Motors
- High frequency inductors
- Current transformers
- Devices requiring high permeability and low loss at low frequencies

BENEFITS:

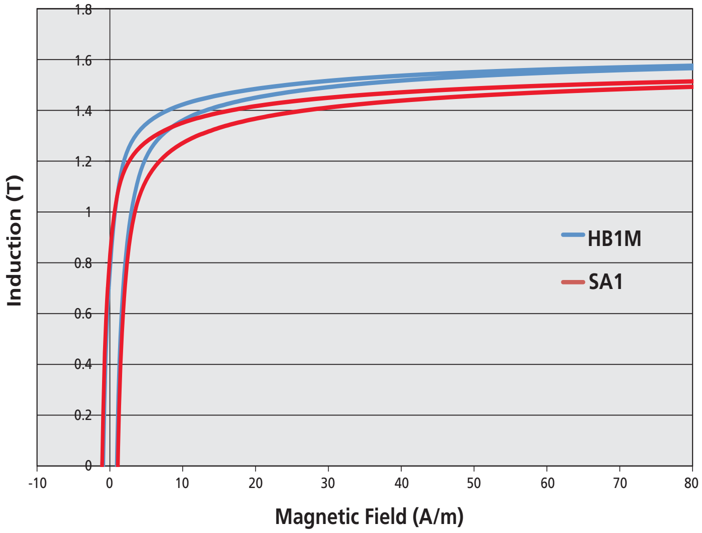
- Extremely low core loss , 35% of M3-Grade GOES core loss in finished cores
- High permeability gives low Exciting Current
- Over thirty (30) years of experience of AMDTs in the field using technology developed in the 1980s by Metglas business
- Well established processes to manufacture AMDTs that can meet global utility requirements
- Multiple grades to allow for design optimization
- Compared to other amorphous ribbon, relatively low temperature anneal allows for high ductility ribbon and easy core making and core-coil assembly

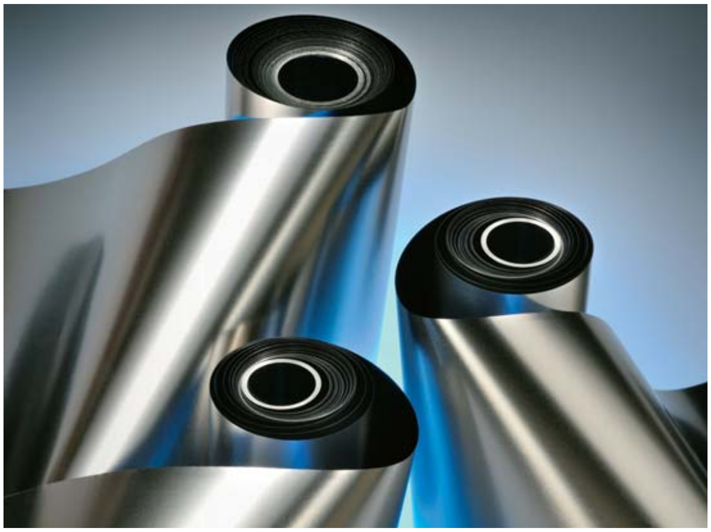
Metglas® Amorphous Transformer cores are manufactured from low loss **Metglas® 2605SA1** and **Metglas® 2605HB1M** transformer core alloys. These low loss, high permeability alloys have excellent performance for single and three phase commercial, industrial and distribution transformer applications.

1. Alloys and the Specification

Alloy	Average Lamination Factor (%)	Thickness (µm)	Standard Available Widths (mm)	Bs (T)	Tc (°C)	Tx (°C)
2605SA1	0.87	23.5	142.2 170.2 213.4	1.56	395	510
2605HB1M	0.88	25		1.63	364	489

*The numbers in the above table are not guaranteed





2. General Properties and Characteristics

Electromagnetic

Alloy	Saturation Induction (T)	Electrical Resistivity (µΩm)	Magnetostriction ($x10^{-6}$)	Curie Temperature (°C)
2605SA1	1.56	1.3	27	395
2605HB1M	1.63	1.2	27	364

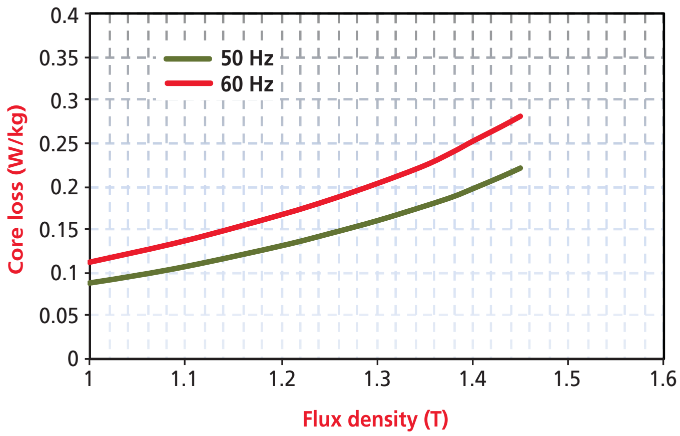
*The numbers in the above table are not guaranteed

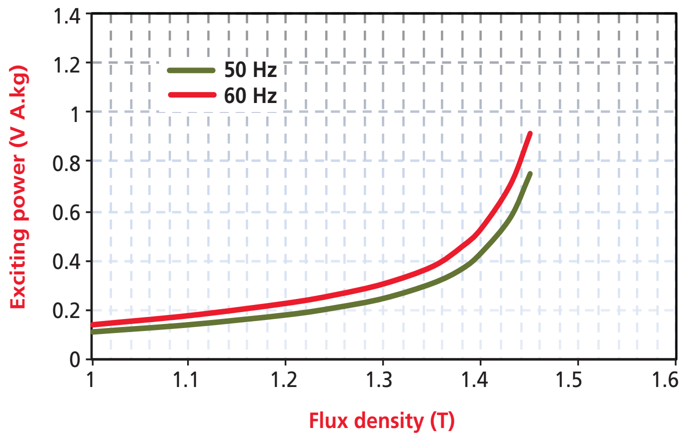
Physical

Alloy	Density (g/cm^3)	Crystallization Temperature (°C)	Tensile Strength (N/mm^2)	Young's Modulus (GPa)	Vickers Hardness Hv-50 g load
2605SA1	7.18	510	2,000	110	900
2605HB1M	7.33	489	2,100	120	900

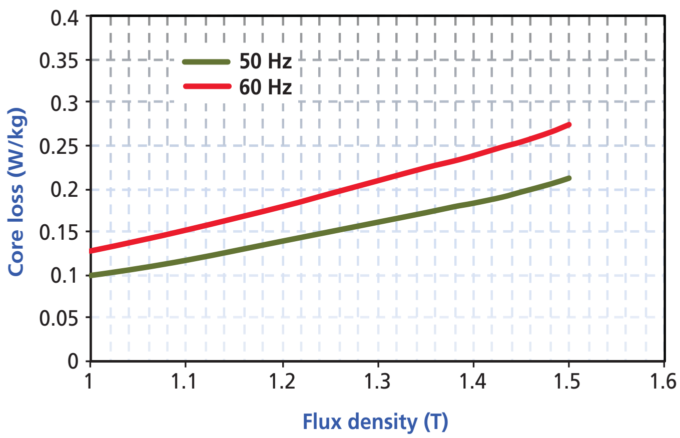
*The numbers in the above table are not guaranteed

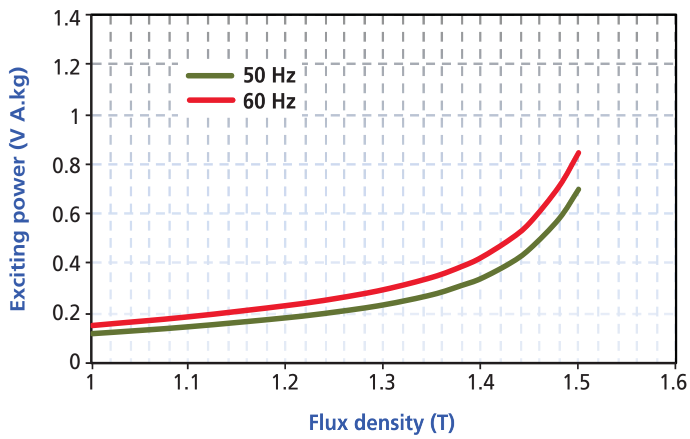
2605SA1 Alloy (142.2 mm) magnetic characteristics for amorphous core





2605HB1M Alloy (142.2 mm) magnetic characteristics for amorphous core





Above numbers depend on core production process and are not guaranteed

Lighting the world. Keeping it cool with Amorphous Metal Distribution Transformers (AMDTs)

Metglas AMDTs can significantly reduce the impact on our global environment.

Metglas® amorphous alloys are earth-friendly, high technology materials for distribution transformers that can reduce no-load loss (standby electricity) in distribution transformers to about one-third the level compared to those using grain-oriented electrical steel. Worldwide use of amorphous metal-based transformers, therefore, will help us reduce fossil-fuel dependency and create a cleaner environment with higher air quality.

Over 4 Million AMDTs Sold Around the World

Based on Hitachi Metals/Metglas®, Inc. sales through 2015

METGLAS COMPANY HISTORY

1970s Product Development - Corporate R&D

- 1973 - Discovery of Metglas® Amorphous Alloy Announced (AlliedSignal)
- 1978 - Transformer Core Alloy Developed & Introduced
- 1979 - Pilot Continuous Casting Line – AlliedSignal Headquarters, Morristown, NJ (USA)

1980s Process Development - Strategic Business Unit

- 1982 - Installed First Commercial Transformers in USA
- 1989 - Commenced Production of Transformer Core Alloy – Conway, SC (USA)

1990s Commercial Operation for Metglas Alloys

- Mid 1990s – 6-8% of distribution transformers bought in USA utilized Metglas
- 1999 - AlliedSignal buys Honeywell - takes Honeywell name

2000s Commercial Development / Increase of Capacity

- 2003 – Purchase of Metglas by Hitachi Metals Ltd (Japan) from Honeywell
- 2010 – Hitachi Metals increases global capacity to 100k MT/yr

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