Amorphous Metals in Electric-Power Distribution Applications

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INTRODUCTION

On April 13, 1982, the Duke Power Company energized an experimental pad-mount distribution transformer in Hickory, North Carolina.' The transformer, manufactured by General Electric, provided electric power to a local residence. That same month, the Georgia Power Company installed a similar transformer, made by Westinghouse Electric,[2] atop a utility pole in Athens, Georgia. It supplied electricity for the exterior lights at the Westinghouse Newton Bridge Road plant. These devices shown in Figure 1 were unique among the nearly 40 million distribution transformers in service in the United States because their magnetic cores were made from an Fe-B-Si amorphous-metal alloy. This new material, produced by Allied Signal (formerly Allied Chemical), was capable of magnetizing more efficiently than any electrical steel. By replacing grain-oriented silicon steel in the transformer cores, the amorphous metal reduced the core losses of the transformers by 75%.

Although distribution transformers are relatively efficient devices, often operating at efficiencies as high as 99% at full load, they lose a significant amount of energy in their use. Because of the number of units in service, coupled with the fact that the core material is continuously magnetized and demagnetized at line frequency, transformers account for the largest portion of the energy losses on electric power distribution systems. It is estimated that over 50×10^9 kWh are dissipated annually in the United States in the form of distribution transformer core losses.[3] At today's average electricity generating cost of $0.035/kWh, that energy is worth over $1,500 million.

Currently over 1,250,000 amorphous metal distribution transformers have been installed worldwide, helping electric power utilities improve the efficiency of their transmission and distribution systems. However the application of Fe base amorphous metal to transformers would not be a straightforward substitution for grain-oriented silicon steel. The amorphous metal used in transformers is thinner, harder, and more fragile than the silicon steel it replaces. The amorphous metal transformer must be compatible with the existing power system distribution system and must survive 30 years continuous service.

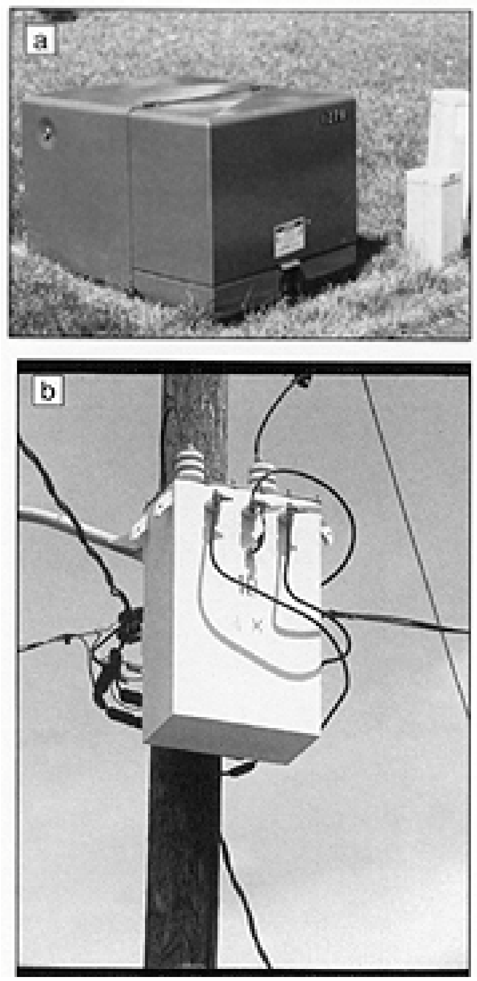

Figure 1. (a) Experimental General electric pad-mount amorphous -metal transformer. (b) Experimental Westinghouse Electric pole-mounted amorphous metal distribution transformer

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These factors necessitated changes to the transformer manufacturing process and mandated both laboratory and field testing before energy savings could be made available at a commercially practical cost and with an acceptable reliability. This article traces the developments leading to the commercialization of amorphous-metal distribution transformers.

The Discovery of Amorphous Metals

Metal alloys typically possess crystalline atomic structures in which individual atoms are arranged in ordered, repeating patterns. Amorphous-metal alloys differ from their crystalline counterparts in that they consist of atoms arranged in near random configurations devoid of long-range order. Although such noncrystalline structures are common in nature, they have normally been associated only with nonmetallic systems. For example, noncrystalline solids can be formed from silicates by continuous cooling from the liquid state. The disordered liquid structure is preserved when the cooling rate is sufficiently great to prevent atoms or molecules from aligning into ordered, crystalline configurations. In silicates, which consist of three-dimensional atomic clusters, the liquid state is viscous. Individual molecules have limited mobility and crystallization proceeds slowly. Only modest cooling rates are required to suppress crystallization entirely.

By contrast, liquid metal alloys are characterized by low viscosity and high diffusivity, partly because they consist of loosely bonded atoms rather than bulky clusters or molecules. The individual atoms in a liquid metal alloy can move about freely. On cooling, atomic rearrangement and crystallization occur rapidly, suggesting that extraordinary cooling rates would be necessary to bypass crystallization.

The first observation of metallic alloys with noncrystalline atomic structures was made in 1950 at the National Bureau of Standards.[4] A. Brenner reported that amorphous Ni-P alloy films could be produced by electrodeposition. Although amorphous Ni-P is widely used as a hard-surfacing material, Brenner's startling observation of the amorphous structure has gone relatively unnoticed.

The discovery of amorphous metals is generally credited to P. Duwez, who in 1960 produced amorphous samples by rapid quenching an $AU_{75}Si_{25}$ alloy from the liquid state. [5] Duwez used a pressurized gas gun to propel small droplets of the molten alloy onto a polished copper plate. On impact, each droplet deformed into a thin film. Intimate contact with the highly conductive copper plate allowed the molten film to cool rapidly and solid1ify into flake or "splat" form. Ironically, this discovery came as a surprise. Duwez adopted the rapid solidification, "splat quenching" process to study solid solubility and phase separation in crystalline metal-alloy systems.

H. Cohen and D. Turnbull suggested that the formation of the amorphous $AU_{75}Si_{25}$ structure was related to the presence of a deep eutectic in the Au-Si alloy system near 25 at.'% Si coupled with the rapid solidification rate achieved in Duwez's experiment.[6] The incorporation of 25% Si into molten Au reduces the melting point of Au from 1336 K to about 970 K .[7] Thus the molten AU75Si,, alloy could cool to a relatively low temperature without solidifying. At the reduced temperature, atomic diffusion would proceed slowly, permitting the alloy to solidify without crystallization. The association of amorphous-metal formation with both rapid solidification rates and eutectic compositions has formed the basis for virtually all subsequent studies of this material form.

In the early 1970s, H.S. Chen and D.E. Polk at AlliedSignal conducted the most exhaustive Study of amorphous-metal formation.[8] This work defined alloy compositions that-on rapid solidification formed stable, amorphous structures. The alloys were described by the general formula $M_{70-90}\ Y_{10-30}\ Z_{0.1-15}$,"'here *M is* one or more transition metals, Y is a nonmetallic element (such as B, P, or Q, and Z is a metalloid (such as Si, Al, or Ge). Virtually all amorphous-metal products manufactured follow this basic recipe.

Rapid Solidification Process Development

Physical metallurgical principles teach that the structure, processing, and properties of a material are intimately linked. Duwez's pioneering experiments in 1960 probed the limits of two of these dimensions: structure and processing. The formation of an amorphous structure in metallic alloys is made possible only at select compositions and through the use of extraordinary processing techniques. The rapid solidification method employed by Duwez yielded cooling at rates of approximately 10^5 K/s at the instant of solidification. Within the splat-quenched sample, the solidification interface traveled at speeds approaching 100 mm/s. By comparison, continuously cast slabs of steel experience cooling rates of only about 1-10 K/s and exhibit solidification interface velocities of about 1-10 mm/s.

These extremes highlight a fundamental limitation of rapid solidification processing. To achieve cooling rates of 10^5 K/s, at least one dimension of the quenched material must be small so that heat can be efficiently extracted. Typically, the small dimension of the rapidly solidified material is 25-50µ tm. To facilitate heat extraction, the material must also be in contact with a highly conductive medium.

In Duwez's case, the quenched sample was in the shape of a flattened droplet, and the highly conductive medium was a copper plate. Subsequent studies of amorphous metal attempted to produce larger samples, either as multiple droplets or as elongated splats. The conductive medium also took on a variety of shapes such as an inclined plane, a piston and anvil, twin pistons, and counter-rotating rollers. Ultimately, these efforts led to the production of continuous, amorphous metal filaments via a process known as chill block melt spinning. Modeled after the work of E.M. Lang," who in 1871 produced solder wire by casting a stream of molten alloy onto the outer surface of a rotating drum, chill-block melt spinning has taken on many forms. In each case, a stream of molten metal is directed at a moving substrate. The stream forms a "puddle" on impact with the surface of the moving substrate, and the puddle serves as a local reservoir from which a filament or ribbon is continuously formed and chilled as shown iii Figure 2.

Two common and historically important variations of chill-block melt spinning are free-jet melt spinning and planar flow casting. In the free-jet process, molten metal is ejected under pressure from a cylindrical nozzle to form a free jet. Using this process, the first commercial amorphous metal-in the form of continuous ribbon 1.7-mm wide and 50I-tm thick-was manufactured bv Allied Chemical in 1971" However it soon became apparent that the free-jet process would be limited to the production of narrow ribbons (up to -5-mm wide). Attempts to increase ribbon width by increasing the size of the cylindrical jet or by using a rectangular jet all met failure.

Figure 2(a) Chill block melt spinning by free-jet casting. (b) Free Jet Cast amorphous metal ribbon.

On impact with the surface of the moving substrate, large cylindrical jets produced nonuniform puddles and hence nonuniform ribbon shapes. Driven by the high surface tension and low viscosity of molten metal, rectangular jets tended to destabilize and deform prior to contact with the substrate. They too yielded nonuniform ribbon.

The use of amorphous metal in electric power applications would clearly have been limited if only narrow-width ribbons were available. The critical problems limiting cast ribbon dimensions were resolved with the development of planar flow casting by M. Narasimhan." In this variation of chill-block melt spinning, shown in Figure 3, molten metal is forced through a slotted nozzle in close proximity (-0.5 mm) to the surface of the moving substrate. The melt puddle is simultaneously in contact with the nozzle and the substrate and is thereby constrained in a stable, rectangular shape. While the flow of molten metal through the nozzle is controlled by pressure, it is also dependent on nozzle-substrate gap. Using planar flow casting, amorphous metal ribbon widths up to 300 mm have been reported, and widths up to 210 mm are commercially available. [12,13]

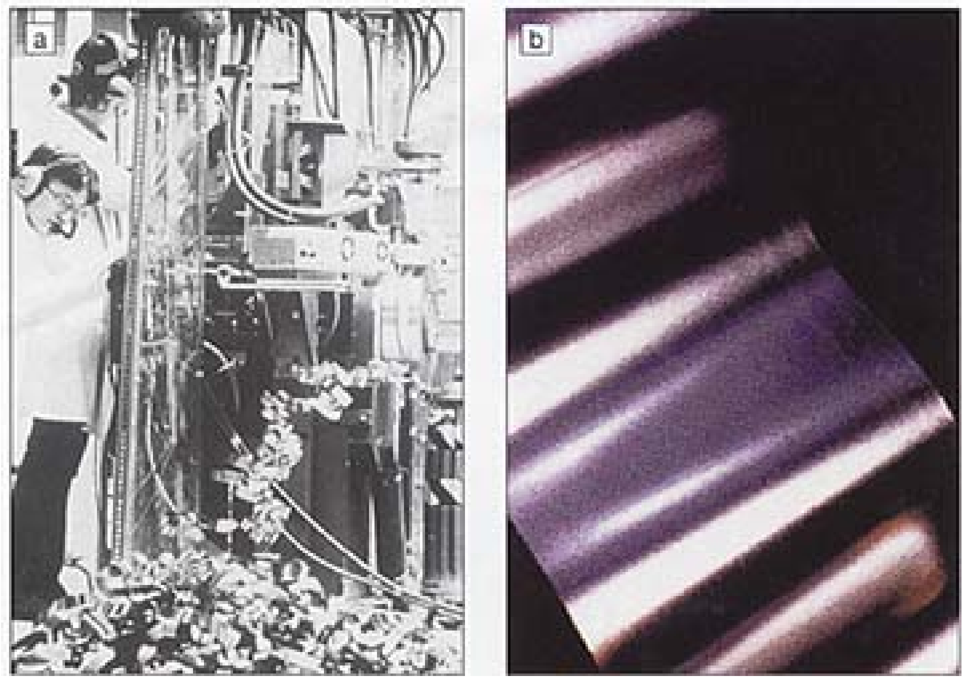

Figure 3(a) Chill-block melt spinning by planar-flow casting. (b) Planar-flow-cast amorphous-metal ribbon (170-mm width)

Alloy Development for Electric-Power Applications

All early studies of amorphous metal involved alloy systems based on precious metals such as Au and Pd. However in 1967, Duwez produced an amorphous $Fe_{80}P_{13}C_7$ alloy. [14] This development was significant in two contexts. It indicated that amorphous metals could be made with common, inexpensive, metallic constituents (Fe in this case). It also demonstrated that ferromagnetism could exist in amorphous materials, a concept that had been postulated only seven years earlier.[15]

The first amorphous metal offered for commercial sale, METGLAS®* 2826 ($Fe_{40}Ni_{4O}P_{14}$B6), was selected on the basis of modest raw-materials cost (Fe and Ni being the principle constituents), relative ease of fabrication (low liquidus temperature ~1240 K), and attractive mechanical properties (tensile strength >1.9 GPa and hardness ~7.35 GPa). When Allied Chemical advertised the availability of this material in 1973, few laboratories in the world could produce more than minute quantities of amorphous metal. As a result, amorphous $Fe_{40}Ni_{4O}P_{14}$B6 was widely studied. The soft ferromagnetic properties of this material were first recognized at the University of Pennsylvania[16] and optimized, through stress relief and magnetic annealing, at General Electric.[17] Annealed, amorphous $Fe_{40}Ni_{4O}P_{14}$B6 exhibited extraordinary magnetic properties, magnetizing with a coercive force (H_c as low as 0.8 A/m. However its relatively low saturation induction (B_{sat} = 0.8 T) and Curie temperature (T_c = 537 K) would limit its use to low-power, high-frequency applications.

The development of amorphous magnetic materials for electric power distribution applications focused instead on Fe-base alloys. In effect, researchers attempted to create amorphous-metal analogues to electrical steel, which combines high saturation induction, preferred magnetic anisotropy, and efficient magnetization with low raw-materials cost. Table I compares the key characteristics of grain oriented silicon steel with those of several Fe-rich amorphous-metal alloy compositions. The Fe-base amorphous-metal alloys retained the ease of magnetization observed in amorphous $Fe_{40}Ni_{4O}P_{14}$B6 while offering higher saturation induction and improved thermal stability (as evidenced by higher Curie temperatures) at lower raw-materials cost.

The Fe-base alloys listed in Table I represent distinct families of amorphous metal compositions, each optimizing an independent parameter. $Fe_{80}P_{13}C_7$ offers the lowest raw materials cost (by using P and C as the primary nonmetals). Fes,)B,() and $Fe_{86}B_8$,C_6 attempt to increase saturation induction (by replacing P and C with B, and by increasing the Fe content, respectively). $Fe_{80}B_{11}Si_9$, displays the best thermal stability (as illustrated by its high Curie temperature). Of these parameters, the latter proved to be most critical. Inadequate thermal stability could limit the production and use of amorphous metals in numerous ways. A molten metal stream could partially crystallize during amorphous metal formation by rapid solidification. Amorphous-metal ribbon could

*METGLAS is a registered trademark of AlliedSignal, Inc.

Table I: Key Charteristics of Electrical Steel and Fe-Based Amorphous Metals. [13, 18-22]

	Saturation Induction B_{sat} (T)	Curie Temperature T_c (K)	Coercive Force H_c (A/m)	Core Loss @ 60 Hz, 1.4 T CL (W/kg)	Reference
Grain Oriented, 3.2 wt% silicon steel (m-2)	2.01	1019	24	0.7	18
Amorphous $Fe_{80}P_{13}C_7$	1.4	587	5	-	19, 20
Amorphous $Fe_{80}B_{20}$	1.6	647	3	0.3	21
Amorphous $Fe_{86}B_8C_6$	1.75	<600	4	0.4 (est)	22
Amorphous $Fe_{80}B_{11}Si_9$	1.59	665	2	0.2	13

recrystallize during annealing of bulk magnetic components. Annealed magnetic components could lose their magnetic anisotropy during temperature excursions in service. In each case, the magnetic properties of the amorphous metal and the performance of amorphousmetal magnetic component would suffer.

As a result, the amorphous alloy commonly used in power magnetic applications is $Fe_{80}B_{11}Si_9$ It offers a saturation induction of 1.59 T, satisfactory thermal stability and reasonable raw-materials cost. Although the saturation induction is only 80%, of that of grain-oriented silicon steel, amorphous $Fe_{80}B_{11}Si_9$ has a usable operating induction of 1.4 T. When magnetized to 1.4 T at 60 Hz, the amorphous metal generates only 30% of the core loss of the M-2 grade of grain-oriented silicon steel.

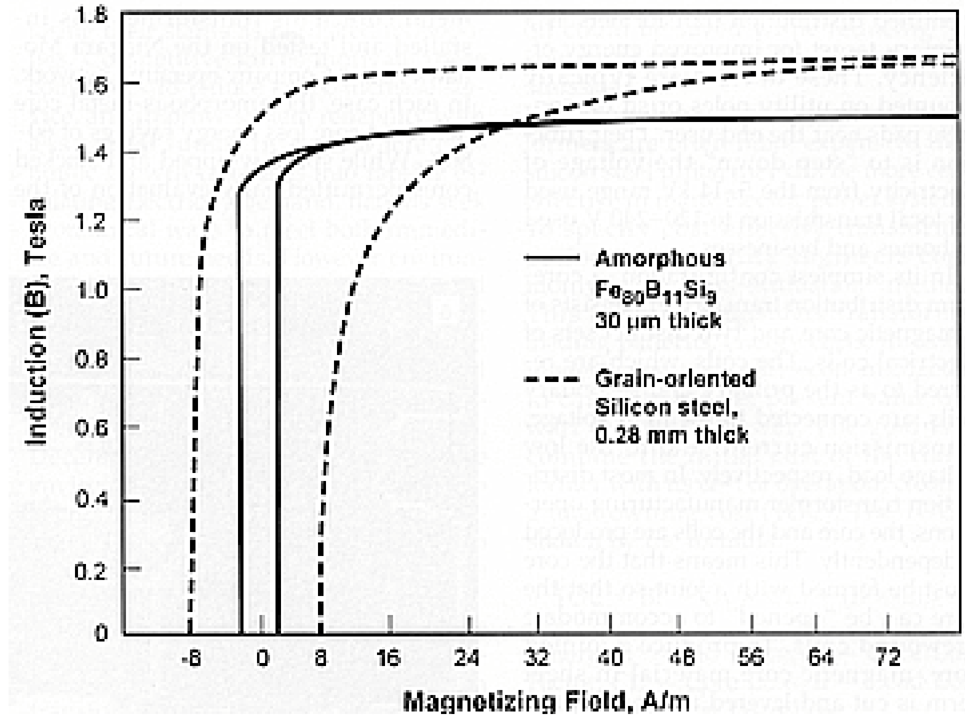

Figure 4. B-H characteristics of amorphous $Fe_{80}B_{11}Si_9$ and grain-oriented silicon steel

Engineering Magnetic Properties and Thermal Stability

The engineering magnetic properties of a ferromagnetic material are in part related to the ease of magnetization through domain-wall motion. In crystalline metals such as grain-oriented silicon steel, structural features of comparable size to domain walls, such as dislocations and grain boundaries, can impede domain-wall motion.[23] Amorphous metals magnetize more easily than crystalline metals because they lack such features. The ease of magnetization in a material is reflected by the relationship between the magnetic induction *(B)* and the applied magnetic field *(H). B-H* loops of amorphous $Fe_{8O}B_{11}Si_9$ and grain-oriented silicon steel are illustrated in Figure 4. The narrowness of the *B-H* loop for the amorphous metal, the high permeability *(B/H),* and the low hysteresis component of magnetic losses (as measured by the area within the *B-H* loop) indicate the relative ease of magnetization.

The eddy-current component of magnetic losses is also minimized in amorphous metals. The atomic disorder and high solute content (metalloid and nonmetal components) of amorphous metals limit the mean-free path of electrons, resulting in electrical resistivity two to three tirnes those of crystalline alloys.[24] The thin gauge of amorphous metal, typically 25 µm compared to -200,µm for grain-oriented silicon steel, further increases the total electrical resistance. High electrical resistance in the magnetic component suppresses eddy currents produced by domain-wall motion, minimizing the eddy-current portion of the magnetic losses.

The relative efficiencies of amorphous-metal and grain-oriented silicon steel distribution transformers are illustrated in the infrared photographs of Figure 5. These images compare transformer corecoil assemblies heated by core loss.[25]

Infrared analysis indicates that the grain--oriented silicon-steel unit reaches an average temperature of 332 K (59°C). Comparable operation of the more efficient amorphous-metal core results in a smaller temperature rise to 304 K (31°C).

Analysis of the stability of the magnetic properties of Fe-base amorphous metals has been an important facet in their qualification for use in electric power distribution systems. Devices such as distribution transformers are expected to perform reliably for periods up to 30 years. While it is impractical to test material properties in actual service over such extended periods, accelerated aging tests have been used to predict long-term performance.

Aging processes in crystalline metals can be described by simple structural rearrangements of atoms. These processes can be modeled with a single activation energy. In amorphous metals however, atomic motions are more complex and may vary from site to site. Therefore models based on single activation energies are not applicable. Therefore an "activation-energy spectrum" (AES) model, originally developed to describe the aging behavior of oxide glasses, has been adapted to describe the aging behavior of amorphous metals.[26]

The Fe-base amorphous alloys used in transformer core applications survive ac-celerated aging tests at 543 K (270°C) for up to 30 days. Based on this observation, the AES model predicts a transformer core life of over 1,000 years at a temperature of 398 K (125°C). By comparison, the continuous service temperature of a transformer core is typically 353-373 K (80-1000°C). Results from actual field tests of amorphous alloy transformer cores are in keeping with the AES model.[27-28]

Amorphous-Metal Transformer Technology

Recent years have brought major changes to the global electric power in-dustry. Starting with the oil embargo of 1973, perceived energy shortages and rapidly escalating energy prices stimu-lated interest in energy conservation. Al-though both the supply and price of energy stabilized in the 1980s, power companies, especially those with high electricity generating costs, continued to invest in energy saving measures. Dur-ing this era, highly efficient transformers caught the interest of electric utilities.

In the United States, the Electric Power Research Institute (EPRI) provided much of the guidance, as well as the initial funding, for the development of amorphous metal transformers.

The institute identified distribution transformers as a primary target for improved energy efficiency. These devices are typically mounted on utility poles or sit on concrete pads near the end user. Their function is to "step down" the voltage of electricity from the 5-14 kV range used for local transmission to 120-240 V used in homes and businesses.

In its simplest configuration, a coreform distribution transformer consists of a magnetic core and two distinct sets of electrical coils. The coils, which are referred to as the primary and secondary coils, are connected to the high voltage, transmission current, and to the low voltage load, respectively. In most distribution transformer manufacturing operations, the core and the coils are produced independently. This means that the core must be formed with a joint so that the core can be "opened" to accommodate prewound coils. To produce a jointed core, magnetic core material in sheet form is cut and layered around a mandrel. Although the overall core shape is a closed loop, each layer of the core contains a gap. After annealing the core to relieve residual stresses from the assembly process, each layer of the gapped core is "opened" to a "U' shape. The layers of the gapped core are then threaded into the prewound primary and secondary coils and reassembled into the original, "closed" core shape.

Although this technique has been fully adapted to grain-oriented silicon steel, it was not immediately applicable to thin, hard amorphous metal. The sheer number of layers of thin amorphous-metal ribbon in the finished core coupled with excessive wear to the blades used to cut the hard amorphous metal forced alternate approaches to transformer design. The earliest amorphous-metal transformers contained simple, continuous, spiralwrapped cores. With no gaps or joints in the core, it was necessary to assemble the primary and secondary coils by winding insulated wire through the center and around the legs of the "closed" core. AlliedSignal used the spiral-wrapped core design to produce the first large (15 kVA) amorphous-metal transformer in 1979 for the Massachusetts Institute of Technology Solar Photovoltaic/Thermal Residence Experiment at the University of Texas at Arlington .[29] General Electric and Westinghouse Electric used similar techniques to produce numerous fractional kVA units as well as their first experimental distribution transformer . On a larger scale, Westinghouse Electric produced a 500-kVA, three-phase transformer containing a stacked amorphous metal core. This transformer was installed and tested on the Niagara Mohawk Power Company operating network. In each case, the amorphous-metal core delivered core loss energy savings of 60 -80'%. While spiral-wrapped and stacked cores permitted early evaluation of the performance of amorphous-metal transformers, the approaches of winding the coil about a finisher core or cutting and stacking thousands of amorphous-rnetal laminations did not prove commercially feasible.

The Electric Power Research Institute,

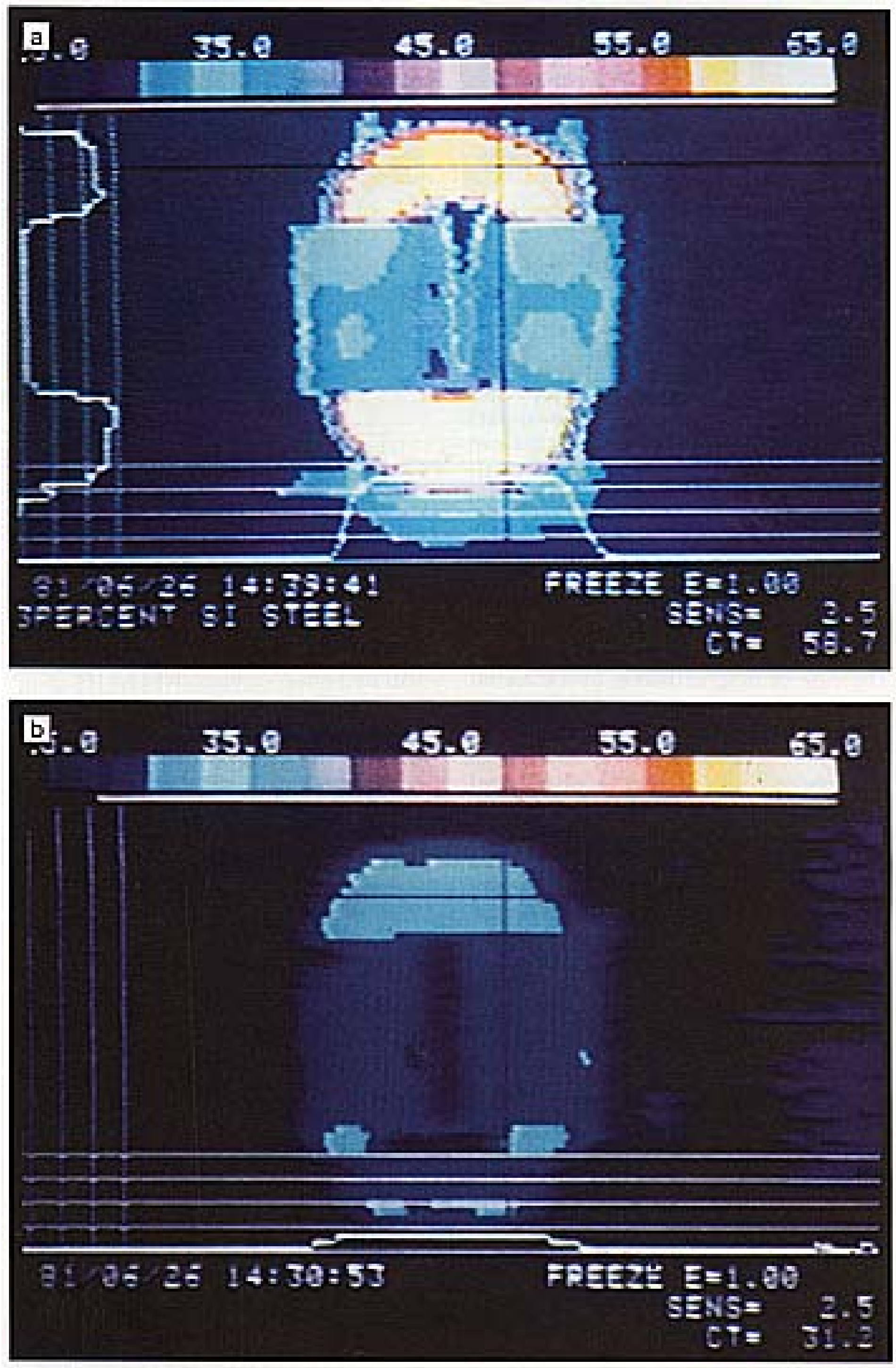

Figure5 . Infrared photographs of (a) grain-oriented steel and (b) amorphous-metal distribution transformer core-coil assemblies.

The Empire State Electric Energy Research Corporation, General Electric, and AlliedSignal in 1983 embarked on a project to bridge this gap. The participants would evaluate transformer design and manufacturing options, and construct and field-test prototype transformers. By 1985 the EPRI-led effort would produce 25 25-kVA pad-mounted transformers and 1,000 25-kVA polemounted transformers that were installed by 90 utilities across the United States. The performance of these amorphousmetal transformers is compared to the performance of grain-oriented silicon steel units in Table 11. Although slightly heavier, the amorphous-metal transformers operated with 70% lower core loss, 60% lower exciting current, and a smaller temperature rise than their silicon steel counterparts. Five years of documented field testing indicated that the amorphous metal transformers were reliable and operated with stable, low core loss.[27] The results of these field tests were consistent with independently conducted accelerated aging tests.

In the course of the EPRI-led program, several technologies were developed which allowed amorphous metal to be used in transformer manufacturing in a manner similar to silicon steel. To simulate the thickness of a silicon steel sheet, a process referred to as "pre-spooling" produced multiple layered packages of amorphous metal ribbon.[30] Multiple coils of single-layer thickness amorphous-metal ribbon were simultaneously unwound and combined to form a strip of multiple-layer thickness.

The layered package produced by pre-spooling helped to address many of the differences between amorphous metal and silicon steel. The thick package was easier to handle than individual ribbons and required less stringent control o blade clearance during the cutting process. The edges of the cut packages could be trimmed to produce clean, uniform joints. Lengths of the cut packages could be wound into a gapped transformer which could be field annealed and equipped with primary and secondary coils in a manner similar to that used in silicon steel transformers." 12 Currently most amorphous-metal distributor transformers are designed and constructed using technology similar to that defined in the EPRI-led program.

Environmental and Economic Impact

In the United States and many western countries, electric power companies are losing their status as regulated monopolies. Competitive forces motivate these companies to reduce costs, increase service, and improve system reliability with less capital funds. In Asia, where economic growth translates into rapidly escalating electricity demand, nations seek economical ways to meet both immediate and future needs. However environmental concerns must be considered along with market pressures on the cost and supply of electric power. The Third Conference of the Parties of the United Nations Framework Convention on Climate Change, held in Kyoto, Japan, December 1-10, 1997, emphasized these environmental concerns with respect to energy conservation and harmful emissions. The conference adopted the Kyoto Protocol, an agreement to cut greenhouse gas emissions by 5% from 1990 levels.

Improvements to the efficiency of the electric-power system, such as that offered by amorphous-metal distribution transformers, help to achieve these goals. Based on 1990 electric-power usage and the U.S. Environmental Protection Agency estimates of fuel requirements and harmful gas emission associated with electric power generation, Table III calculates the potential benefits associated with amorphous metal distribution transformers. In the United States alone, the energy equivalent of over 70 million barrels of oil could be saved while reducing the volume of harmful $C0_2$, NO_x, and $S0_2$ emissions.

Although amorphous-metal transformers are often more expensive than silicon steel units, they can be more cost-effective in many electric power systems. To specify cost-effective transformer performance, utility engineers commonly use a "loss-evaluation" method. This approach considers transformer loading patterns, energy costs, inflation, interest rates, and other economic factors to calculate the net present value of a watt of electric power. The goal is to combine the initial cost of the transformer with its cost of operation, creating a total owning cost (TOC). The TOC is shown by the formula:

$$\mathbf{TOC = BP + (A \times CL) + (B \times LL) \quad (1)}$$

where BP Bid Price, A = Core Loss Factor, CL Core Loss, B = Load Loss Factor, and LL = Load Loss.

Table IV shows how this technique can be used to determine the lowest TOC option." In the scenario described in the table, the amorphous-metal transformer can command a 15% price premium and still deliver a 3% reduction in TOC. Where energy costs are sufficiently high, amorphous metal transformers make economic as well as environmental sense.

Table II: Performance Comparison of Amorphous-Metal and Grain-Oriented Silicon-Steel Transformers.

Specification	Amorphous Metal	Grain-Oriented Silicon Steel
Core (no-load) Loss (W)	15.4	57
Coil (load) Loss (W)	328	314
Exciting Current (%)	0.14	0.36
Temperature rise (K)	48	57
Audible Noise (dB)	33	40
TIF 100% / 110% (IT/kVA)	2/10	5/25
Short Circuit Test	40 times	40 times
Weight (kg)	200	184

*Telephone interference factor at load

Table III: Environmental Impact of Amorphous-Metal Transformers.

Benefit	USA	Europe	Japan	China	India
Energy Savings (billion kWh)	40	25	11	9	2
Oil (million barrels)	70	45	20	15	4
CO_2 (million tons)	35	20	10	12	3
NO_x (thousand tons)	110	70	30	90	22
SO_2 (thousand tons)	260	160	75	210	52

Table IV: Economic Comparison of Amorphous-Metal and Grain-Oriented Silicon-Steel Transformers

Distribution Transformer 60 Hz, 500 kVA (15 kV/480 -277 v)	Amorphous - Metal Core	Grain-Oriented Silicon Steel Core
1.Core Loss (W)	230	610
2.Core Loss Factor ($/W)	$5.50	$5.50
3.Load Loss (W)	3192	3153
4.Load Loss Factor ($/W)	$1.50	$1.50
5.Efficiency (%)	99.6	99.4
6.Bid Price	$11,500	$10,000
7.Core Loss Value	$1,265	$3,355
8.Load Loss Value	$4,788	$4,730
9.Total Owning Cost	$17,558	$18,085

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