

SCANFAX

April 1998

Volume 50, Issue 4



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A publication of the
Institute of Electrical & Electronics Engineers
— Chicago Section —

Alternating Current Induction Motor Design

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Printed By

Town & Country Printers
Columbus, WI

SCANFAX (ISSN #0018-1297) is a monthly publication (except July and August) of the Chicago Section Institute of Electrical and Electronics Engineers, 1919 Swift Dr., Ste. 121, Oak Brook, IL 60521-1502, (800) 898-4333 or (630) 575-8045. It is published by Slack Attack Advertising, 6400 Gisholt Dr., Suite 203, Madison, WI 53713, (608) 222-7630. Printing is by Town & Country Printers, Columbus, WI 53925. For advertising information, contact Slack Attack Advertising.

Subscriptions included in IEEE membership dues; non-member subscriptions: \$25 per year.

Address corrections should be sent to the IEEE office, 1919 Swift Drive, Suite 121, Oak Brook, IL 60521-1502.

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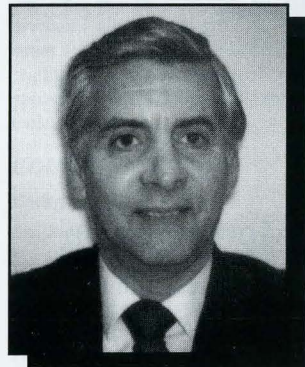
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Irwin C. Smiley, P.E.

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Chairman

First of all, I would again like to thank those businesses that advertise in *SCANFAX* for supporting IEEE. I encourage all members to contact the *SCANFAX* advertisers and thank them for advertising in our publication. Also, please support these fine businesses by giving them a chance to be involved in your projects.

I would also like to thank those who have provided leads for ads. This publication depends on advertising dollars, so please contact Slack Attack Advertising if you have a lead or if you want to buy an ad.

We need feature story topic suggestions. The May issue will feature the Argonne National Laboratory and the June issue covers Education. What would you like to learn more about? The Executive Committee will consider topic ideas as well as existing papers. Please contact our editor, Adrienne Novick at 630-713-4362 with your input.

I was honored to represent the Chicago Section at the IEEE Region 4 meeting at the O'Hare Marriott, February 20-22nd. IEEE president, Dr. Joseph Bordogna, presented an extensive amount of valuable information. I will share some of his points with you here, and will provide more of his information in the next issue of *SCANFAX*.

1. Some sections have combined section business meetings with the technical meetings.

2. Those members who have moved out of the Chicago Section boundary and use their work mailing address can now use their home address and still remain in the Chicago Section. If you or any past IEEE member are in this situation, please call me or IEEE Membership at 800-678-4333, hit "1" and then follow the instructions. Remember to state that you want to remain in the Chicago Section.

3. The IEEE logo has changed and we have incorporated the new look into this issue of *SCANFAX*. The concept is as follows:

- IEEE touches the lives of engineers everywhere.
- IEEE members have advanced the profession, created new knowledge, and developed technologies to benefit humanity.

4. The IEEE vision is: "To advance global prosperity by fostering technological innovation, enabling members' careers and promoting community world-wide."

5. The IEEE mission is: "To promote the engineering process of creating, developing, integrating, sharing and applying knowledge about electro- and information- technologies and sciences for the benefit of humanity and the profession."

The nominations for next term's officers were published in the March issue of *SCANFAX* and the voting ballot is on page 8 of this magazine. Please take the time to vote.

Don't miss the IEEE Chicago Section Annual Awards Banquet on April 25th. Members, students and guests are welcome. This is a great way to meet your fellow engineers!

Finally, I continue to receive calls and positive feedback from members about *SCANFAX*. I am encouraged by the response of our IEEE members. Remember, the quality of this magazine depends on the efforts of our members. We need your help to continue to improve the quality of *SCANFAX*. ■

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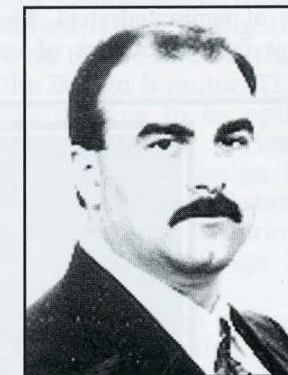


Chicago Section Executive Committee Meeting

April 14, 1998 @ 7:15pm

DeVry, 1221 N. Swift Rd.,
Addison, IL

Alternating Current Induction Motor Design



by Howard W. Penrose
Systems Project Manager
TK Design Technology, Inc.
Carol Stream, Illinois

INTRODUCTION Electric motor systems consume 20% of all energy generated in the United States, 57% of all electrical energy, and 70% of electrical energy consumed by industry. Over 1.1 billion motors, of all types, are presently in use in the United States.

Induction motors were invented by Nikola Tesla in 1888 while he was a college student. In the present day, induction motors consume between 90-95 percent of the motor energy used in industry.

In this article we are going to discuss:

- The purpose of induction motors
- Induction motor construction
- Operating principles
- NEMA designs
- Design E motor discussion
- Motor insulation
- Inverter duty motor construction

The Purpose of Induction Motors

Contrary to popular belief, induction motors consume very little electrical energy. Instead, they convert electrical energy to mechanical torque (energy). Interestingly enough, the only component more efficient than the motor, in a motor system, is the transformer.

The mechanical torque developed by the electric motor is transferred, via coupling system, to the load.

The electrical energy that is consumed by electric motors is accounted for in the losses. There are two basic types of losses, Constant and variable, all of which develop heat (Figure 1):

Core losses — A combination of eddy - current and hysteresis losses within the stator core. Accounts for 15-25 percent of the overall losses.

Friction and Windage losses — Mechanical losses which occur due to air movement and bearings. Accounts for 5-15 percent of the overall losses.

About the Author: Howard W. Penrose is a Systems Project Manager for TK Design Technology, Inc. in Carol Stream, Illinois. He is consulted by the Canadian Electrical Association (CEA) and US Department of Energy (US DOE) in matters of energy efficient motor systems and repair. Mr. Penrose conducts training, develops programs, and consults in energy efficient motor systems, maintenance systems, repair, operations, testing and sampling, marketing, and safety. He is presently the treasurer of Chicago Section, vice chair of Fox Valley Subsection, and chair of both PELS and DEIS. He may be contacted via e-mail at h.penrose@ieee.org, or in care of TK Design Technology, Inc., 250 Kehoe St. Suite 200, Carol Stream, IL 60188, ph. 630 681-9302.

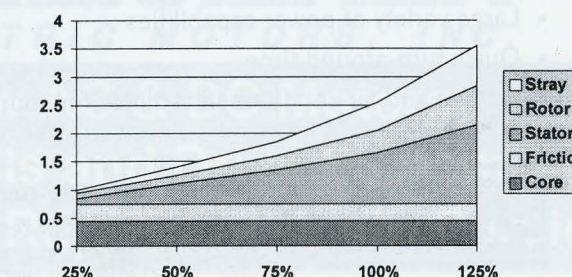
Stator losses — The I^2R (resistance) losses within the stator windings. Accounts for 25-40 percent of the overall losses.

Rotor losses — The I^2R losses within the rotor windings. Accounts for 15-25 percent of the overall losses.

Stray Load losses — All other losses not accounted for — Accounts for 10-20 percent of the overall losses.

Continued on page 4.

Figure 1: Losses vs. Load



Induction Motor Construction

An induction motor consists of three basic components:

1. **Stator:** Houses the stator core and windings. The stator core consists of many layers of laminated steel, which is used as a medium for developing magnetic fields. The windings consist of three sets of coils separated 120 degrees electrical.

2. **Rotor:** Also constructed of many layers of laminated steel. The rotor windings consist of bars of copper or alu-

minum alloy shorted, at either end, with shorting rings.

3. **Endshields:** Support the bearings which center the rotor within the stator.

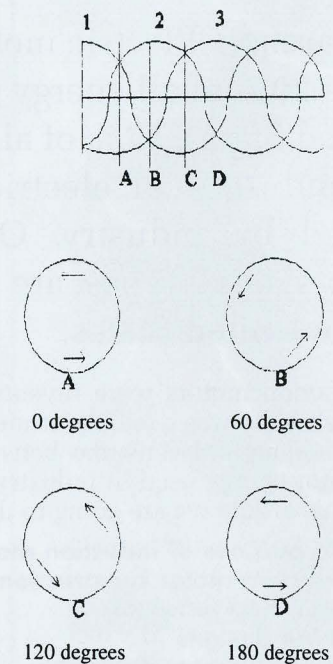
Operating Principles:

The basic principle of operation is for a rotating magnetic field to act upon a rotor winding in order to develop mechanical torque.

The stator windings of an induction motor are evenly distributed by 120 degrees electrical. As the three phase current enters the windings, it

creates a rotating magnetic field within the air gap (the space between the rotor and stator laminations). The speed that the fields travel around the stator is known as synchronous speed (N_s). As the magnetic field revolves, it cuts the conductors of the rotor winding and generates a current within that winding. This creates a field which interacts with the air gap field producing a torque. Consequently, the motor starts rotating at a speed $N < N_s$ in the direction of the rotating field.

Figure 2: Rotating Magnetic Field



The speed of the rotating magnetic field can be determined as:

$$N_s = (120 * f) / p \text{ eq. 1}$$

Where N_s is the synchronous speed, f is the line frequency, and p is the number of poles found as:

$$p = (\text{\# of groups of coils}) / 3 \text{ eq. 2}$$

The number of poles is normally expressed as an even number.

Table 1: Synchronous Speeds

# of poles	Synch. Speed
2	3600
4	1800

The actual output speed of the rotor is related to the synchronous speed via the slip, or percent slip:

$$s = (N_s - N) / N_s \text{ eq. 3}$$

$$\%s = s * 100 \text{ eq. 4}$$

Torque

By varying the resistance within the rotor bars of a squirrel cage rotor, you can vary the amount of torque developed. By increasing rotor resistance, torque and slip are increased. Decreasing rotor resistance decreases torque and slip.

Motor horsepower is a relation of motor output speed and torque (expressed in lb-ft):

$$HP = (RPM * Torque) / 5250 \text{ eq. 5}$$

The operating torques of an electric motor are defined as (Ref. NEMA MG 1-1993, Part 1, p.12):

Full Load Torque: The full load torque of a motor is the torque necessary to produce its rated horsepower at full-load speed. In pounds at a foot radius, it is equal to the hp times 5250 divided by the full-load speed.

Locked Rotor Torque: The locked-rotor torque of a motor is the minimum torque which will develop at rest for all angular positions of the rotor, with rated voltage applied at rated frequency.

Pull-Up Torque: The pull-up torque of an alternating current motor is the minimum torque developed by the motor during the period of acceleration from rest to the speed at which breakdown torque occurs. For motors which do not have a definite breakdown torque, the pull-up torque is the minimum torque developed up to rated speed.

Breakdown Torque: The breakdown torque of a motor is the maximum torque which it will develop with rated voltage applied at rated frequency, without an abrupt drop in speed.

NEMA Motor Design Classifications

NEMA defines, in NEMA MG 1-1993, four motor designs dependant upon motor torque during various operating stages:

1. **Design A:** Has a high starting current (not restricted), variable locked-rotor torque, high break down torque, and less than 5% slip.

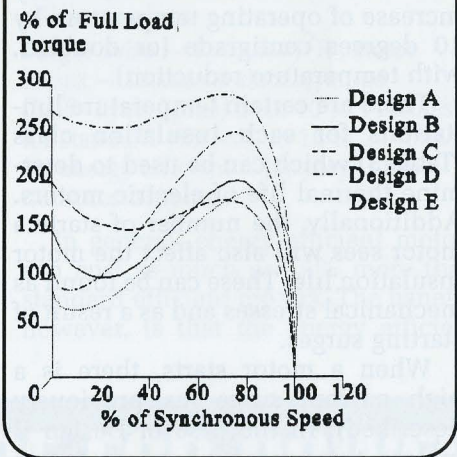
2. **Design B:** Known as "general purpose" motors, have medium start-

ing currents (500-800% of full load nameplate), a medium locked rotor torque, a medium breakdown torque, and less than 5% slip.

3. **Design C:** Has a medium starting current, high locked rotor torque (200 - 250% of full load), low breakdown torque (190-200% of full load), and less than 5% slip.

4. **Design D:** Has a medium starting current, the highest locked rotor torque (275% of full load), no defined breakdown torque, and greater than 5% slip.

Figure 3: Motor Torque Curves



Design A and B motors are characterized by relatively low rotor winding resistance. They are typically used in compressors, pumps, fans, grinders, machine tools, etc.

Design C motors are characterized with dual sets of rotor windings. A high resistive rotor winding, on the outer, to introduce a high starting torque, and a low resistive winding, on the inner to allow for a medium

breakdown torque. They are typically used on loaded conveyers, pulverizers, piston pumps, etc.

Design D motors are characterized by high resistance rotor windings. They are typically used on cranes, punch presses, etc.

Design E Motor Discussion

The design E motor was specified to meet and international standard promulgated by the International Electrotechnical Commission (IEC). IEC has a standard which is slightly less restrictive on torque and starting current than the Design B motor. The standard allows designs to be optimized for higher efficiency. It was decided to create a new Design E motor which meets both the IEC standard and also an efficiency criterion greater than the standard Design B energy efficient motors.

For most moderate to high utilization application normally calling for a Design A or B motor, the Design E motor should be a better choice. One should be aware of slight performance differences.

Although the NEMA standard allows the same slip (up to 5%) for Designs A, B, and E motors, the range of actual slip of Design E motors is likely to be lower for Designs A and B.

There are a number of considerations which must be observed with Design E motors:

Good efficiency — as much as 2 points above Design B energy efficient.

Less Slip — Design E motors operate closer to synchronous speed.

Lower Starting Torque — May not start "stiff" loads.

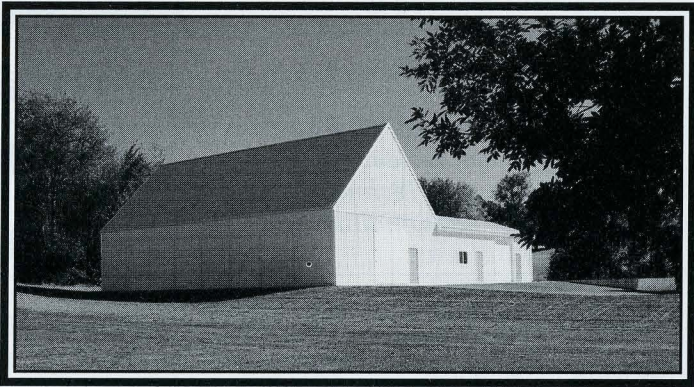
High Inrush — As much as 10 times nameplate full load amps.

Continued on page 6.

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Availability — Presently low as the standard has just passed.

Starter Availability — Control manufacturers do not have an approved starter developed at this time.

National Electric Code — Has no allowance for higher starting amps. Design E motors will require changes to NEC allowances for wire size and feed transformers.

Limited Applications — Low starting torque limits applications to pumps, blowers, and loads not requiring torque to accelerate load up to speed.

Heavier Power Source Required — High amperage and low accelerating torque mean longer starting time and related voltage drops. May cause nuisance tripping of starter of collapse of SCR field with soft starters.

Electric Motor Insulation:

With all this discussion about motor operation, losses, torque curves, and inrush, it is only fitting to review the thermal properties of electrical insulation. In general, when an electric motor operates, it develops heat as a by-product. It is necessary for the insulation that prevents current from going to ground, or conductors to short, to withstand these operating temperatures, as well as mechanical stresses, for a reasonable motor life.

Table 2:
Maximum Temperatures of Common Insulation Classes

Insulation Class	Temperature °C
A	105
B	130
F	155
H	180

Insulation life can be determined as the length of time at temperature. On average, the thermal life of motor insulation is halved for every increase of operating temperature by 10 degrees centigrade (or doubled, with temperature reduction).

There are certain temperature limitations for each insulation class (Table 3) which can be used to determine thermal life of electric motors. Additionally, the number of starts a motor sees will also affect the motor insulation life. These can be found as mechanical stresses and as a result of starting surges.

When a motor starts, there is a high current surge (as previously described). In the case of Design B motors, this averages between 500 to 800% of the nameplate current. There is also a tremendous amount of heat developed within the rotor as

Table 3:
Temperature Limitations

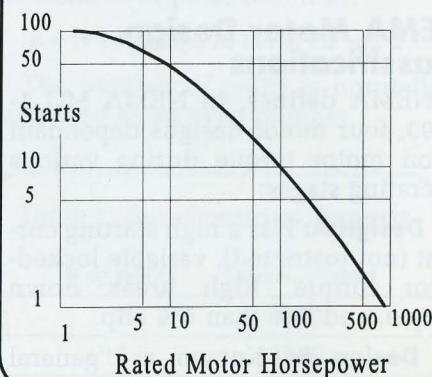
Service Factor	Insulation Temperature	Class B	Class F
1.0/1.15	Ambient	40C 104F	40C 104F
1	Allowable Rise	80C 176F	105C 221F
1	Operating Limit	120C 248F	145C 293F
1.15	Allowable Rise	90C 194F	115C 239F
1.15	Operating Limit	130C 266F	155C 311F

the rotor current and frequency is, initially, very high. This heat also develops within the stator windings.

In addition to the heat developed due to startup, there is one major mechanical stress during startup. As the surge occurs in the windings, they flex inwards towards the rotor. This causes stress to the insulation at the points on the windings that flex (usually at the point where the windings leave the slots).

Both of these mean there are a limited number of starts per hour (Figure 4). These limits are general, the motor manufacturer must be contacted (or it will be in their literature) for actual number of allowable starts per hour. This table also assumes a Design B motor driving a low inertia drive at rated voltage and frequency. Stress on the motor can be reduced, increasing the number of starts per hour, when using some type of "soft start" mechanism (autotransformer, part-winding, electronic soft-start, etc.).

Figure 4:
Allowable Number of Starts Per Hour



SPECIAL MOTORS

Energy Efficient Motors

The Energy Policy Act of 1992 (EPACT) directs manufacturers to manufacture only energy efficient motors beyond October 24, 1997 for the following:

- General Purpose
- Design B
- Foot Mounted
- Horizontal Mounted
- T-Frame
- 1 to 200 hp
- 3600, 1800, and 1200 RPM
- Special and definite purpose motor exemption

To meet NEMA MG1-1993 table 12.10 efficiency values, the method for testing for these efficiency values must be traceable back to IEEE Std. 112 Test type B.

Energy efficient motors are really just better motors, when all things are considered. In general, they use about 30% more lamination steel, 20% more copper, and 10% more aluminum. The new lamination steel has about a third of the losses than

the steel that is commonly used in standard efficient motors.

As a result of fewer losses in the energy efficient motors, there is less heat generated. On average, the temperature rise is reduced by 10 degrees centigrade, which has the added benefit of increasing insulation life. However, there are several ways in which the higher efficiency is obtained which has some adverse effects:

Longer rotor and core stacks — narrows the rotor — Reduces air friction, but also decreases power factor of the motor (more core steel to energize — kVAR).

Smaller fans — reduces air friction — the temperature rise returns to standard efficient values.

Larger wire — Reduces I^2R , stator losses — Increases starting surge (half-cycle spike) from 10 to 14 times, for standard efficient, to 16 to 20 times, for energy efficient. This may cause nuisance tripping.

In general, energy efficient motors can cost as much as 15% more than standard efficient motors. The benefit, however, is that the energy efficient

motor can pay for itself when compared to a standard efficient motor.

$$\$ = 0.746 * hp * L * C * T (100/Es - 100/Ee)$$

where hp = motor hp, L = load, C = \$/kWh, T = number of hours per year, Es = Standard efficient value, and Ee = Energy efficient value Eq. 5

Inverter Duty Motors

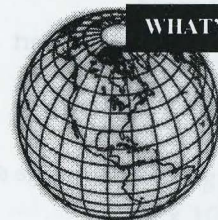
Inverter duty motors are specially designed to withstand the new challenges presented by the use of inverters. There are a number of ways to designate motors "inverter duty," however, several things must exist as a minimum:

Class F insulation — to withstand the higher heat generated by non-sinusoidal current from the drive.

Phase insulation — Insulation between phases is a must to avoid "flashover" between phases from current surges.

Layered Conductors — To reduce turn to turn potential between conductors.

Continued on page 8.



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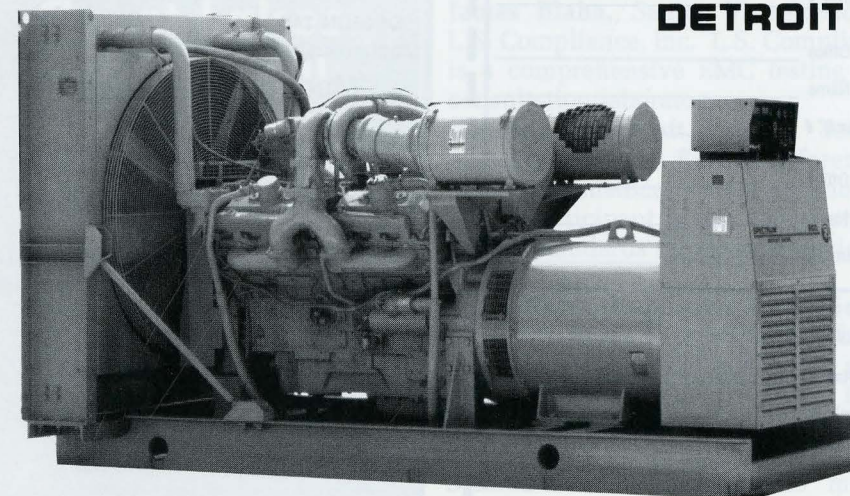
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ter withstand standing waves which occur due to the faster rise times in modern inverter technology.

Caution: Some manufacturers may only de-rate motors. This is done by reducing the motor by (about) 25%. Therefore, a 10 hp motor may be rated as a 7.5 hp motor.

It should be noted, also, that an inverter application does not always require an inverter duty motor. The old motor or an energy efficient motor may be sufficient for the application. ■

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- You may vote for only one candidate for each office.

BALLOT INSTRUCTIONS:

- Enter your name, membership number, and mailing address in the space provided.
- After voting, sign the ballot on the line at the bottom.
- Ballots **must be mailed** to the IEEE Business Office, Attn: Section Secretary, 1919 Swift Dr., Ste. 121, Oak Brook, IL 60521-1502. Please mark "Ballot" on the envelope.
- Ballots **must be postmarked by April 20th.**

Ballots must be postmarked by April 20th.

Chicago Section Nominations 1998-1999

OFFICERS:

- Chairman** ☐ Sam Peach
Vice Chairman ☐ Howard Penrose
Treasurer ☐ Ed Bogus
Secretary ☐ Pat Murphy

COMMITTEES:

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Conference ☐ Judy Gemperline
Finance ☐ Chuck Nochumson
Government Activities ☐ Bert Orszula
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Program ☐ Weider Yu
Publications OPEN
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Calendar of Events

DATE	EVENT
April 3, 1998	Engineering in Medicine and Biology Society 22ND ANNUAL GREAT LAKES BIOMEDICAL CONFERENCE: EMC, FDA & COMPLIANCE TESTING FOR MEDICAL DEVICES
April 14, 1998	Chicago Section EXECUTIVE COMMITTEE MEETING
April 22, 1998	Computer Society and Fox Valley Subsection THE NATURE OF THE NATURE OF ORDER: TOWARD AN AESTHETICS-BASED THEORY OF DESIGN
April 22, 1998	IAS/IES Joint Meeting with PES APPLICATION CONSIDERATIONS FOR MEDIUM VOLTAGE VARIABLE FREQUENCY DRIVES
April 25, 1998	IEEE Chicago Section ANNUAL AWARDS BANQUET
May 13, 1998	IAS/IES STAND-BY, CO-GENERATION, AND PEAK SHAVING POWER APPLICATIONS

ENGINEERING IN MEDICINE AND BIOLOGY SOCIETY

22nd Annual Great Lakes Biomedical Conference

"EMC, FDA & compliance testing for medical devices"

Friday,
April 3, 1998

Speakers:

Suzanne Parisian, M.D., President, Medical Device Assistance, Inc. Former Chief Medical Officer in the Office of Device Evaluation, Center for Devices and Radiological Health, FDA.
James Blaha, Senior Vice-President, L.S. Compliance, Inc. L.S. Compliance is a comprehensive EMC testing and consultation laboratory.
Donald J. Sherratt, Intertek Testing Services, one of Europe's foremost experts in medical device technology and a participant in the development of new standards for medical devices.

PROGRAM: (beginning at 8:45am)

Session I: EMC: A review of the background on EMI, EMC and testing standards, the medical products EMC requirements, and European directives and laws.

Session II: A discussion of the "maze" of AFDA, designed for engineering professionals seeking insight into FDA terms such as valid scientific evidence and substantial equivalence.

Session III: An overview of the steps required for device certification, test-

ing, and inspection; the benefit of utilizing a global testing, the diverse categories of products that require testing; and employment opportunities in product testing, inspection and certification services.

Session IV: Round Table Discussion.

Place:

Golden Rondelle Theater, S.C. Johnson Wax, Racine, Wisconsin. **Directions:** 194 north to Hwy. 20. East to 14th St. Right on 14th about mile to theater.

Registration:

Registration (at door) includes chicken with tarragon luncheon.
IEEE Member\$60
Non-Member\$80
Student\$35

For more information:

See the conference web page at <http://www.msos.edu/~gassert/index.htm> or contact John D. Gassert, (414) 277-7167, Email:Gassert@msos.edu or Ricardo J. Soto, (414) 260-3086 fax-(414) 260-3077.

COMPUTER
SOCIETY
AND
FOX VALLEY
SUBSECTION

The Nature
of the Nature
of Order:
Toward an
Aesthetics-
Based Theory
of Design

Wednesday,
April 22, 1998

EVENING MEETING

James O. Coplien, Lucent Technologies

About the topic:

The software pattern discipline, now a standard for object-oriented software development, took its cues from a famous building architect named Christopher Alexander. Yet Alexander himself maintains that there is a major step beyond software patterns that has proven successful in Alexander's architectural work. Alexander's new paradigm focuses on the development process and on geometry-based aesthetics. He will describe this paradigm in a forthcoming book called "The Nature of Order."

We welcome back one of our favorite speakers, Jim Coplien (Cope), who has been exploring with Alexander the ramifications of what the Nature of Order holds for software. Also, their research has led to some curious topics including functional and applicative programming, parallelism, and even Turkish carpets.

Cope's talk will relate the current work of Alexander to what we understand of good system development, as well as to art, beauty, and the nature of the world around us.

About the speaker:

Jim Coplien is a Distinguished Member of Technical Staff in the Software Production Research Department at Lucent Bell Laboratories in Naperville.

He is a found member and Member Emeritus of the Hillside Group, which has nurtured and sponsored the pattern discipline of software. His book "Advanced C++ Programming Styles and Idioms" is widely acknowledged as one of the foundations of the software pattern discipline, and he has worked as co-editor on two volumes in the Software Pattern Series. Jim was program chair of OOPSLA '96 and remains an active leader in the object-oriented community. He currently conducts research in organizations and process, in software architecture, and multi-paradigm design.

Location:

Lucent Technologies, 200 N. Naperville Rd., Naperville, IL 60566.

Directions: Lucent Technologies is located at the northwest of Warrenville and Naperville Roads. When you enter the building, company security will provide you with a visitor's badge and direct you to the meeting place.

Time:

Networking social: 7:00pm.

Presentation: 7:30pm.

Presentation is free.

For reservations:

Call the IEEE Business Office at 1-800-898-IEEE.

IAS/IES

JOINT MEETING
WITH PES

Application
Considerations
for Medium
Voltage Variable
Frequency
Drives

Wednesday,
April 22, 1998

IAS/IES

Stand-by,
Co-generation,
and Peak
Shaving Power
Applications

Wednesday,
May 13, 1998

IAS/IES DINNER MEETINGS

Gene Pledger, Director of Pacific Operations, Adjustable Speed Drive Division of Ansaldo Ross Hill

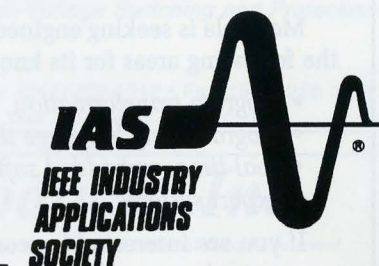
About the topic:

An excellent complement to the March dinner presentation on low voltage VFD's, the April dinner presentation will concentrate on medium voltage variable speed drive applications, their effect on sources and loads, and specific application considerations that differ from low voltage drive applications.

About the speaker:

Mr. Gene Pledger received his B.E.E. degree in Electrical Engineering from the Georgia Institute of Technology with academic honors. After serving his country in the United States Air Force, Gene Worked for AT&T and various consulting engineers as a design engineer and Chief Engineer. He then joined Westinghouse, supervising the design and development of solid state power conditioning equipment includ-

ing variable frequency drives and uninterruptible power systems. He also managed the activities of the Systems Engineering Department in the design and fabrication of solid state power conditioning systems for the Garrett Corporation. He currently is responsible for the application of large variable speed drives for Ansaldo Ross Hill. Gene is a PE, an IEEE member and holds numerous patents.



About the dinner meeting format:

Each dinner meeting features an informative presentation on an electrical or electronic application topic of interest to the members of the organization, as submitted to the Executive Board. The topics are presented by industry professionals as application experts in that chosen field. The presentations are followed by open forum discussions on the topic. The dinner meetings start with an information social hour where individuals can socialize with fellow industry professionals followed by the dinner and the presentation.

Location:

Como Inn, 564 N. Milwaukee Ave, Chicago, IL

Directions: The Como Inn is located on Milwaukee Avenue just off the expressway on the east side of 90/94.

Time:

Social: 5:30pm.

Dinner: 6:00pm.

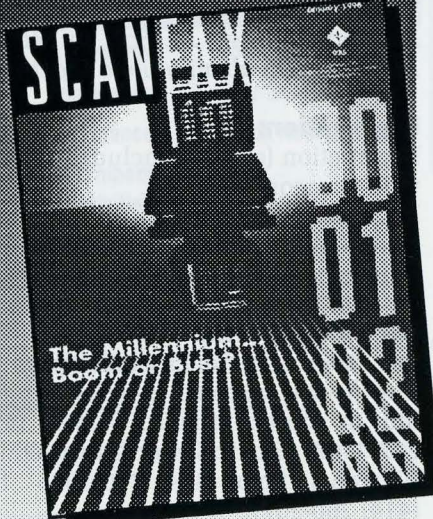
Presentation: 7:00pm.

For reservations:

Cost: \$20 includes the presentation and your choice of chicken or pasta for dinner. Please call the IEEE Business Office at (800) 898-IEEE or (630) 575-8045 with your entree preference.

NOTE: Attendance at IEEE Technical Meetings is acceptable as one PDH (Professional Development Hour) per meeting, where continuing education is required for renewal of the P.E. licenses.

NOTE: Elections for the IEEE, IAS/IES Executive Board will take place in June. We encourage all interested parties to contact the IEEE Business Office for details.



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IEEE Chicago Section ANNUAL AWARDS BANQUET

Saturday, April 25, 1998

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AWARDS

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University
Student Chapter
Awards

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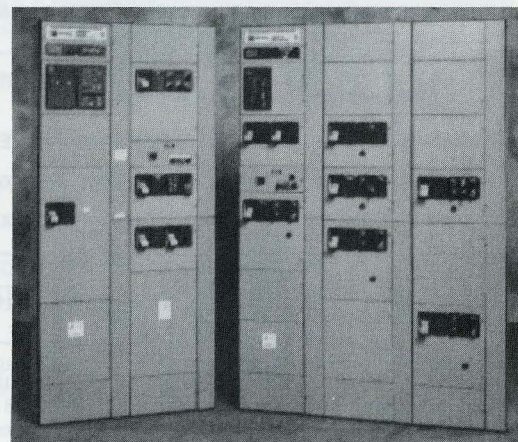
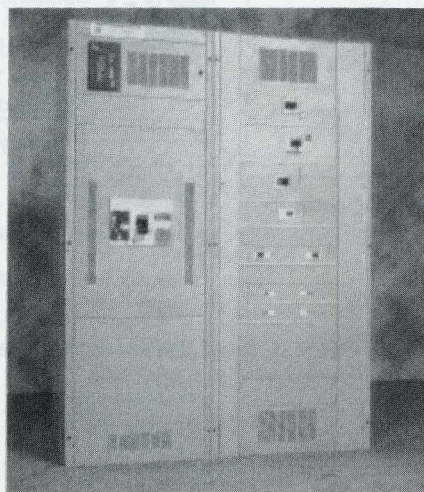
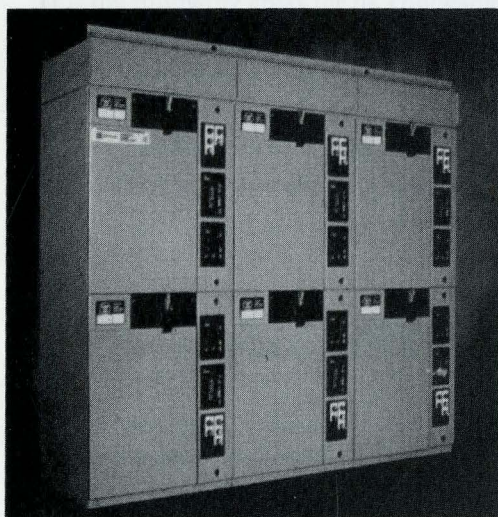


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