[1]Power Quality Considerations for CNC Machines : GROUNDING

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Abstract **- Computer Numerical Control (CNC) machines are used to shape metal parts by milling, boring, cutting, drilling, and grinding. A CNC machine generally consists of a computer-controlled servo-amplifier, servo-motors, spindle motor, and various tooling. The machine can be programmed to shape a part by use of a front control panel. More sophisticated models allow a CAD drawing to be uploaded to the machine. The electronic components within a CNC machine are particularly sensitive to the grounding techniques used in the electrical supply to the machine. Malfunction, degradation, and damage to the electronics can often be traced to problems with the grounding system. Production downtime, product loss, and expensive repair bills result. With the wide-spread use of CNC machines across the world, these problems have become a significant financial concern to many CNC machine users and their electric utility companies.**

This paper begins with a brief explanation of the fundamentals of service and equipment grounding. The basic design of CNC machines is also explained. Based on a survey of several CNC machine representatives, the paper will explore the common grounding techniques recommended by many CNC machine tool builders with particular emphasis on the ground rod problem. In addition, several actual case studies that support the ground rod problem will be described. Finally, a recommended powering and grounding practice is presented to help eliminate power quality related operating problems with CNC machines while maintaining the safety requirements of electrical codes.

Index Terms **– Computer Numerical Control, CNC, power system grounding, ground rod problem, damage.**

I. BUILDING SERVICE GROUNDING

The logical place to begin discussions on grounding is at the electrical utility service entrance. Most machine shops are supplied with a three-phase service classified as a “four-wire grounded” or a “three-wire ungrounded” system. Common voltages of grounded systems are 208Y/120 V and 480Y/277V, and common ungrounded system voltages are 240V delta and 480V delta. Both grounded and ungrounded electrical systems are required to be connected to earth via the building grounding electrode system. This practice is referred to as ***grounding*** or ***earthing*** for safety[1].

In grounded electrical systems, one of the current-carrying conductors (typically the neutral) is solidly grounded to the building grounding electrode system, providing a stable reference to the surroundings

Source: National Geographic

Source:Hitachi Seiki

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(earth). The neutral is also connected to the building's equipment grounding system through the main bonding jumper, which facilitates the operation of over-current protection devices (fuses and circuit breakers), during a ground fault. All conductive (metal) enclosures of the electrical system are also bonded together and to the power system grounding point to keep metal parts at ground potential preventing shock hazards. Fig. 1. shows a typical solidly-grounded building electrical system[1].

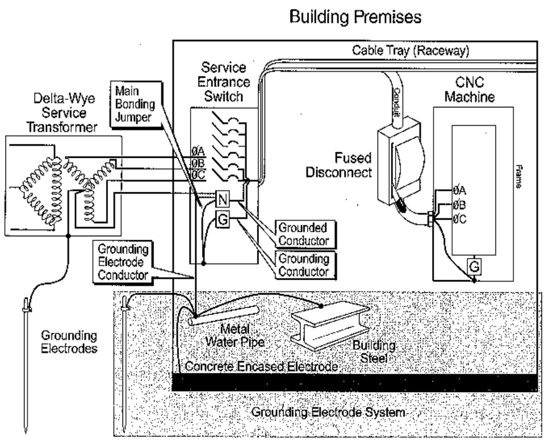

Fig. 1. Typical grounded building service and grounding Electrode System

In an ungrounded electrical system, no circuit conductors are intentionally connected to ground. The advantage of an ungrounded electrical system is that the system can continue to operate with a single ground fault, avoiding production delays. Disadvantages of an ungrounded system are undetected ground faults and uncontrolled voltage build-ups between the insulated electrical power system conductors and various exposed metal parts or equipment enclosures. For many sensitive electronic devices these uncontrolled voltage potentials can be damaging. Hence, unless specified by the manufacturer a CNC machine may not be suited for powering from an ungrounded electrical system. For ungrounded systems a ground fault detector should be used to alert qualified personnel that an inadvertent ground fault has occurred. Fig. 2. shows a typical ungrounded electrical system. Note that exposed metal parts are still bonded to the building grounding electrode system[1].

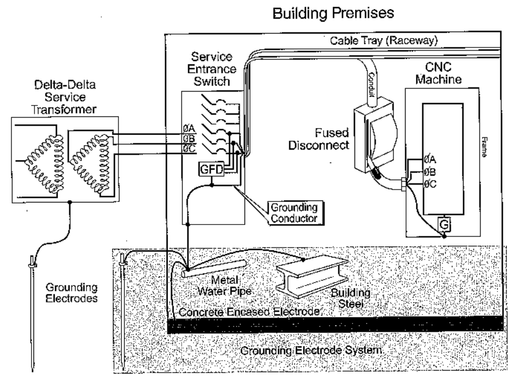

Fig. 2. Ungrounded building service and grounding electrode system

Both grounded and ungrounded building electrical services require a grounding electrode conductor to reference the electrical power system to the building grounding electrode system. The grounding electrode system consists of all available earth electrodes, including building steel, metal water pipes, buried ground rings, and ground rods. The intent of the grounding electrode conductor and grounding electrode system is to provide a low impedance path to earth for lightning surge current and to reference the building electrical system to its surroundings. This minimizes voltage differences between exposed metal parts of the power system including connected equipment and the surrounding parts of the building thus reducing the hazard of electrical shock[1].

II. CNC EQUIPMENT GROUNDING

Besides the grounding electrode system, another fundamental of safety grounding is the equipment ground. The fundamental purpose of equipment grounding is to provide equipment and personnel safety, and the secondary purpose of equipment grounding is to enhance equipment performance by providing a reference for the electronic components. Equipment grounding intends to ***effectively ground*** all non-current-carrying metal parts of the electrical system, including equipment enclosures and raceways.

The proper combination of equipment and system grounding should ensure that a ground fault anywhere in the system would not pose a shock hazard to personnel. In case of a ground fault with a solidly grounded electrical system, the low-impedance equipment-grounding path allows the fault current to flow back to the power source. With sufficient ground fault current, the over-current protection device will trip quickly and clear the ground fault.

According to the NEC, metal raceways, such as conduit, are acceptable means of equipment grounding. Quite often though, especially with sensitive electronic equipment, a conductor is also used to supplement the conduit and further ensure effective grounding. This is usually done because conduit connections can become loose or corroded over time. To maintain a low impedance ground path, the equipment-grounding conductor must always be routed in the same conduit or raceway with its associated power conductors[1].

III. CNC MACHINE COMPONENTS AND SUSCEPTIBILITIES

A CNC machine is typically composed of a controller with appropriate computer program describing the desired part, servo-amplifiers and positioning motors to control relative movement of the part and shaping tools, and spindle motors that actually work to shape the parts. Positioning of the part or the tooling is typically accomplished by turning a screw mechanism and moving a nut in one or more axes. Some machines have five axes, 3-dimensions plus a horizontal and a vertical axis of rotation. See Fig. 3. illustration of a typical CNC machine and controller with 2-dimensions and a horizontal axis of rotation[2].

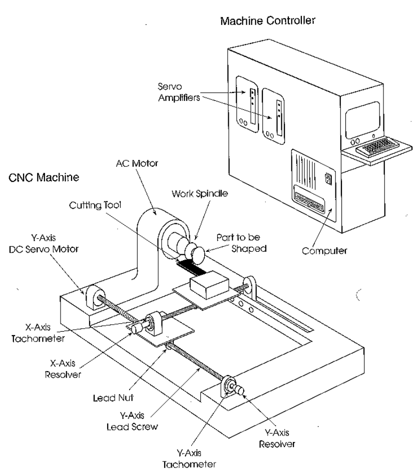

Fig. 3. Illustration of a typical CNC machine and controller

The CNC machine controller contains a computer to provide overall control of the machine. It usually monitors the machined part's position by feedback from the resolvers or encoders to update the program. Movement is accomplished by positioning motors with velocity-based feedback from tachometers to the computer. The speed of the spindle motor is also variable using an adjustable speed drive with either computer or manual control[2].

The onboard computer can be programmed through the unit's front panel or through a communication port where the required data from a CAD drawing program can be downloaded from a remote computer. The CNC machine microprocessor then executes the program, setting up the machine sequence, determining the desired speed and position for machining, etc. When there is physical separation between the CNC machine and its electronic control, certain functions may be sensitive to the machine powering and grounding techniques[2].

Electrically, the AC power is usually converted to several levels of DC for servo systems and computer logic. Fig. 4. shows the AC power sources, functional blocks and interconnections for a typical CNC machine. Also the data link to another area of the factory is likely to have a signal reference ground in that area of the factory's power system. These different reference ground points may increase the CNC machine's sensitivity to power disturbances.

Today's electronically controlled CNC machines require a common signal reference ground for logical circuits to operate reliably. The term, signal reference describes the zero-voltage level used by digital logic circuits. For example, five volts DC above signal reference indicates a logic level "1" and zero volts DC indicates a logic level "0." This signal reference is typically the common of the computer logic power supply, which is connected to the machine's ground plate. The ground plate is bonded to the machine's enclosure, equipment grounding conductor or conduit and, subsequently, to the building grounding electrode system. So the equipment ground establishes the local signal reference both within the CNC machine and for any remotely connected devices.

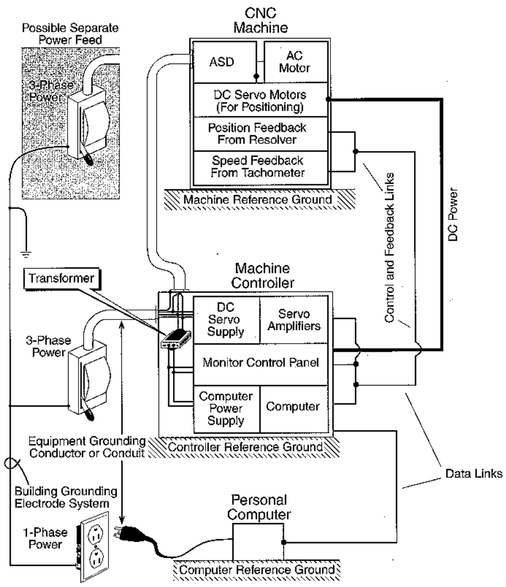

Fig. 4. AC power sources functional blocks and interconnections for a typical CNC Machine

CNC machine upsets that are related to grounding and ground reference are usually attributed to noise or stray currents that find ways into logic circuits. Susceptibility of CNC machines to different sources of noise and stray currents will depend on how the machine is designed and installed. Grounding, bonding, and shielding also play a role in its immunity. For example, certain types of communication circuits are more susceptible to high frequency noise; others are more susceptible to stray ground currents, whereas others (fiber optic) are not susceptible to either.

IV. NOISE SOURCES AND COUPLING MODES

Much of the focus of special grounding recommendations for electronic equipment is based on reducing electrical noise, or any unwanted signal that may affect logic circuits or signal. Sources of electrical noise may be nearby transmitters—both intentional and unintentional—like electric welding arcs or chattering relay contacts. Also, lightning or switching surges may capacitively-couple noise-voltages into sensitive control circuits. A common wiring-related noise source is simply the normal electric currents that inductively couple noise currents into control wires if control and power wiring are run in the same raceway or run close to each other inside the CNC machine. Internal to the CNC machine, contactors, relays, solenoids, and motor drives are a large source of noise and transients, which may also affect the logic circuits[3]. CNC machines that are contained in a single cabinet with good bonding, grounding and shielding should be relatively immune to noise. However CNC machines with remote controllers or data links may be quite susceptible. In these machines two forms of this ground-related noise should be considered. See figure 4. One form is the noise appearing on the input power conductors relative to the equipment ground (typically the enclosure or chassis ground). The other is the noise or difference in potential that appears between the grounds of interconnected equipment. When trying to avoid electrical noise, distancing from the source of noise is usually a great help. Some grounding practices can also help to control the noise relative to ground, but watch out for myths about ground noise problems. Remember that electrical noise or unwanted signals will follow the fundamental principles of electricity, i.e. currents flow only when there is a difference in potential and a completed circuit, and they follow paths of least resistance (reactive impedance in the case of high-frequency signals)[3].

V. THE GROUND ROD PROBLEM

To combat the problem of unwanted electrical noise on the equipment grounding system, many CNC machine tool builders require or recommend that a ground rod be driven into the earth at each CNC machine and connected to the CNC machine's frame via the ground plate. Fig. 5. shows a typical installation. Some CNC machine tool builders will void the warranty if the ground rod is disconnected. Many CNC machine tool builders feel that the building's equipment grounding system is "noisy" because of nearby equipment in the facility such as welders, wire EDM machines, and motor drives. The supposed purpose of the ground rod is to carry away or eliminate this unwanted electrical noise from the CNC machine's data signals. Apparently, these CNC machine tool builders believe the ground rod provides a low impedance path for this noise to flow. The recommended impedance of this path ranges from no more than 5 ohms to no more than 100 ohms. These CNC machine tool builders feel that the building's equipment grounding system does not provide a reliable, low impedance path to earth. CNC machine tool builders that have recommended installing a ground rod to eliminate unexplained operating problems report that the problems go away more often than not. In addition, some feel that the ground rod provides lightning protection. On the contrary, other CNC machine tool builders do not recommend a ground rod at the CNC machine because of lightning problems[4][5].

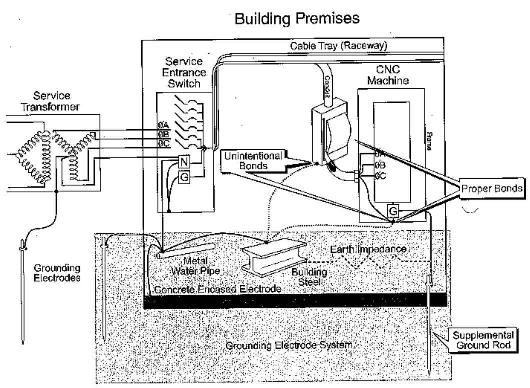

Fig. 5. Supplemental ground rod properly installed may invite stray ground currents

Obviously, CNC machine tool builders and service technicians recommend many confusing and conflicting grounding techniques. Quite often, these techniques, implemented to help correct operating problems believed to be caused by electrical noise, can actually lead to more severe problems such as damage during lightning storms. Of particular concern is the practice of driving a ground rod directly at the CNC machine and connecting that ground rod to the CNC machine's ground plate. The presence of this ground rod creates a ground loop with the earth. The ground loop is a conductive path for current to flow between the grounding electrode system at the main service switch through the conduit/equipment grounding conductor to the CNC machine's ground plate, then through the ground rod at the CNC machine and back to the grounding electrode system through the earth. Current will flow in this path when a voltage difference develops between the two earth connections. Current flowing through the earth, such as that during a lightning strike or utility ground fault, can create an extremely large voltage difference.

The presence of the ground rod also creates a path to earth, which allows lightning current and utility fault current to travel on the conduit/equipment grounding conductor. When lightning strikes a facility, the lightning current flows into the earth at the main service switch (grounding electrode system) and also travels along the conduit/equipment grounding conductor through the CNC machine and into the ground rod driven in the earth[4].

Fig. 6. shows how utility fault current flowing through the earth can flow up the CNC machine's ground rod, travels along the conduit/equipment grounding conductor, onto the utility neutral and back to the source (the utility substation). The presence of these large currents can result in malfunction, degradation, and damage to the electronic components within the CNC machine[4].

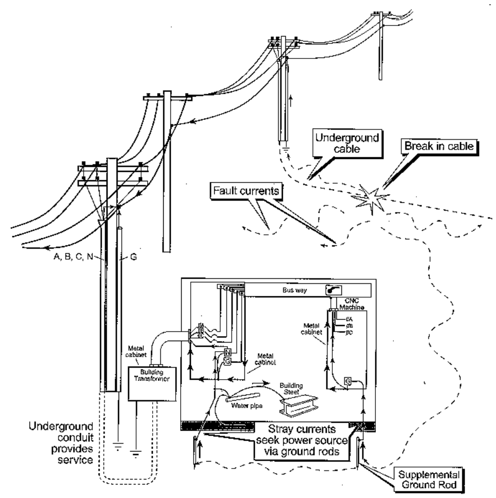

Fig. 6. Power system ground fault causes a high current via the supplemental ground rod through a CNC machine

Drawing a comparison with other electronic equipment, like computers, electronic motor drives, programmable logic controllers, none subscribe to such a local grounding practice. The analogy would be to drive a separate ground rod in the office, and connect it to the logic ground inside your personal computer. Such a practice is not recommended by IEEE Standards such as STD-1100 on powering and grounding sensitive electronic equipment. Instead, a single-point ground, from individual electronic cabinets, is individually bonded to a local ground grid. Since specific practices for CNC machines are not provided by any existing codes or standards an initiative is currently underway to bring end-users, CNC machine manufactures, consultants and utilities together to work out and publish a best powering and grounding practice for these very important tools of industry.

VI. CASE STUDIES

Digin to Utility Underground Primary Conductor on 13.2 kV Grounded System

A machine shop experienced failures of electronic components within his CNC machines during the cable fault. A contractor had dug into the underground cable while excavating with a back hoe. The CNC machines had driven ground rods connected directly to the ground plate inside the machines. No other electrical or electronic equipment inside the shop experienced any damage.

Repeated CNC machine failures during Thunderstorms

A manufacturer of turbine airfoils experienced repeated damage to CNC servo drives and amplifiers during several thunderstorms. The CNC machines had driven ground rods connected directly to the ground plate inside the machines. No other electrical or electronic equipment inside the facility experienced any damage. Once the driven ground rods were removed, the failures stopped occurring.

Downed Utility Primary Conductor on 4.34kV ungrounded system

Two neighboring machine shops experienced damage to the electronic components in their CNC machine during the cable fault. The utility conductor was ripped off the pole during a storm and the cable fault arced on the ground without clearing overcurrent protection. A utility crew was dispatched to open the faulted section. The CNC machines, which failed, had driven ground rods connected directly to the ground plate inside the machines. No other electrical or electronic equipment inside the facility experienced any damage.

VII. BEWARE OF ISOLATED-GROUND ROD CODE VIOLATION!

When manufacturers have required an additional earth ground rod located at the CNC machine, end-users are responsible to assure that the installation meets code requirements. Although permitted by the NEC, the additional rod is intended as a supplemental grounding electrode and must be bonded to the rest of the building grounding system. Too often this ground rod, which might be incorrectly thought of as "isolated and dedicated" to the CNC machine and from the otherwise "noisy" building ground, is not bonded to the building electrical system ground. See Fig. 7. for a typical but unsafe effort to isolate the CNC machine ground. This creates an electric shock hazard and is a violation of the NEC.

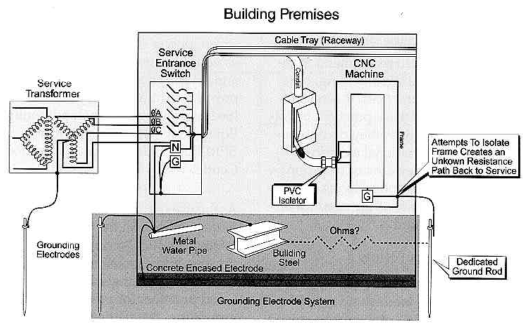

Fig. 7. Incorrect and unsafe "Isolated Dedicated" Ground Rod installation for CNC machine

This effort to further distance the CNC machine from the "noisy" building ground using an isolated ground rod creates new hazards to both people and machine during lightning storms or power system ground faults when dangerous potential differences can exist between the incorrectly isolated ground rod and the rest of the building's grounding system.

VIII. CNC INDUSTRY SURVEY ON MACHINE GROUNDING AND GROUND RODS

A survey of CNC machine tool manufacturers was undertaken to determine the recommendations for proper grounding of their equipment. The results indicate that there are conflicting grounding recommendations and requirements. There is a widespread belief by many CNC machine tool manufacturers that the building's equipment grounding system is "noisy" because of other equipment in the facility, such as welders, wire EDM machines, and motor drives. To combat the problem of electrical noise on the equipment grounding system, 10 of the 15 CNC machine tool manufacturers surveyed require or recommend that a ground rod be driven into the earth at each CNC machine and connected to either the CNC machine's frame or the logic ground bus. Three of the ten CNC machine tool manufacturers, who recommended a ground rod, stated that the equipment warranty would be voided if a ground rod were not installed[5].

The most commonly stated purpose of the ground rod is to carry away or eliminate electrical noise from the CNC machine's signal reference. There is a general belief that the ground rod will provide a lower impedance path for noise than the equipment grounding system. The recommended impedance of this ground rod varies by manufacturer and ranges from less than 5 ohms to less than 100 ohms. Of those manufacturers that recommend installing a ground rod to solve unexplained problems, about half report that unexplained operating problems go away more often than not. In addition, at least one manufacturer feels that the ground rod provides some lightning protection, but other CNC manufacturers specifically do not recommend a ground rod in high-lightning areas[5].

IX. RECOMMENDED PRACTICE FOR POWERING AND GROUNDING A CNC MACHINE

To help defuse the confusing and conflicting grounding practices, the following powering and grounding technique is offered. This technique is believed to help eliminate related operating problems while maintaining the safety requirements of electrical codes. Even if the following recommended practice is not followed, it is important to point out that a ground rod must never be driven at and connected directly to the CNC machine's ground plate[4].

Fig. 8. depicts the installation of a shielded isolation transformer located as close to the CNC machine as physically and electrically possible. The shielded isolation transformer has several advantages. First, a shielded isolation transformer with taps allows the selection of the proper nominal voltage required by the CNC machine. Second, the shielding helps filter electrical noise and reduce voltage transients flowing on the power conductors. Also, by placing the transformer close to the CNC machine, the effective area of exposure to radiated noise is reduced. Third, the addition of the transformer establishes a new zero voltage signal reference. This helps prevent electrical noise flowing on the building's equipment grounding system from affecting the signal reference of the CNC machine. The new signal reference is created by the connection of the neutral of the transformer's secondary to the equipment grounding system via the bonding jumper and to the grounding electrode system via the GEC. The bonding jumper also provides a path for fault current, which allows the proper operation of overcurrent devices[4].

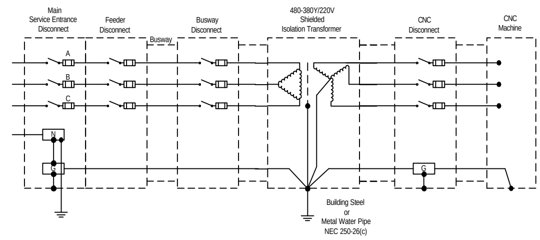

Fig. 8. Recommended Practice for Powering and Grounding a CNC Machine

Note in Fig. 8. that there is no longer a ground rod connected directly to the CNC machine's ground plate; however, the GEC of the transformer, which is typically connected to the nearest building steel or water pipe, may be, in fact, connected to a ground rod. Surprisingly, this should not be a problem. Large currents, such as those caused by lightning and utility faults, flowing to and from the earth at the shielded isolation transformer's earth connection should not adversely affect the operation of the CNC machine since the current now does not pass directly through the CNC machine's enclosure[4].

Also note in Fig. 8. that the circuit conductors to and from the shielded isolation transformer should be enclosed in a metallic conduit/raceway where practical. This will help shield the circuit conductors from radiated noise. Furthermore, an equipment grounding conductor should supplement the conduit/raceway where practical. This will help maintain a continuous, low impedance equipment grounding path[4].

The use of the shielded isolation transformer along with the other techniques previously mentioned is believed to help prevent many of the CNC machine's operating problems associated with power quality. Malfunction, degradation, and damage to the electronic components within the CNC machine would be expected to decrease. Other techniques which could be used in addition to the previous techniques presented in this article include: (1) dedicated circuits, to electrically separate disturbing loads from the CNC machine, (2) cascaded transient voltage surge suppression, to suppress voltage transients and filter noise originating externally and internally from the building, (3) physical separation of the CNC machine from sources of radiated noise such as welders, wire EDM machines, and motor drives, and (4) installation and maintenance practices as described in the sidebar[4].

X. OTHER HELPFUL HINTS

Not all operational problems are the result of inadequate grounding, nor can all problems be solved by proper grounding. Good system design, which includes facility lightning protection (where appropriate), surge protection, the use of dedicated circuits for the CNC machine, and the segregation of large cyclical or other "disturbing" loads on power feeders separate from the CNC machine, is important to avoid operational problems. For more severe power supply variations, such as voltage distortion, sags, swells, and interruptions, some form of power conditioning may be required [6].

XI. INSTALLATION AND MAINTENANCE PRACTICES FOR CNC MACHINES

It is important to point out that malfunction, degradation, and damage to electronic components are not always related to the supply of power to the machine. The design of the CNC machine, its installation, operating environment, and maintenance can also cause the same symptoms. To minimize electrical noise generated internal to the CNC machine, snubber circuits and suppression diodes should be used on relays and contactors. The internal signal cables should be separated from the internal power cables as much as possible. Care taken during the initial installation to minimize the adverse effects of the operating environment can help reduce normal maintenance. Items of concern during initial installation include: (1) shock mounts, to reduce vibration, (2) rubber sealed enclosures, to reduce dirt build-up, (3) deoxidizing agents, to reduce oxidation, and (4) air conditioning, to maintain an acceptable operating temperature for the electronic components. Items of concern for normal maintenance include: (1) tightening connections, (2) deoxidizing connections, and (3) removing dirt build-up[6].

XII. CONCLUSION

As the usage of CNC machines become more prevalent in the industry, minimizing production downtime, product loss, and expensive repair bills become increasingly important. Following proper powering and grounding, installation, and maintenance procedures can help prevent malfunction, degradation, and damage to the electronics. The purpose of this article was to set forth a grounding technique to help prevent operating problems related to power quality and to call attention to the confusing and conflicting grounding techniques recommended by CNC machine tool builders and service technicians.

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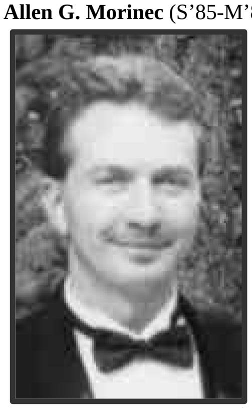

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Mr. Morinec is presently the Chair of the Cleveland IEEE Section and has been Chapter Chairman of the IEEE Power Engineering Society, Cleveland Section since 1992. He assisted in the development of four IEEE standards on Power Quality as an IEEE working group member. Mr. Morinec is a member of the International Association of Electrical Inspectors and a Registered Professional Engineer in Ohio. The Cleveland Engineering Society and Cleveland IEEE Section awarded Mr. Morinec "Young Engineer of the Year" during the 1995 National Engineers Week.