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INTRODUCTION

1.1 DIGITAL TECHNOLOGY

Digital technology is virtually sweeping the nondestructive testing industry as well as affecting every aspect of American life. We have digital television, digital cameras and video recording systems, digital telecommunications, digital global positioning, digital satellite radios, digital appliances, and personal digital computers with high-speed memory and capacity that were unheard of 20 years ago. Some optical and digital electronic gadgets just recently introduced include small hand-held 10× binoculars with 8× digital cameras, shirt-pocket MP3 players, and real two-way wrist radios with a range of $1\frac{1}{2}$ miles. Dick Tracy had to wait a long time for that one. Can personal identification chips with global tracking be far behind? Standard "Walkie-Talkie" range has reached up to 10 miles.

High-speed computers with high-capacity memory and high-speed data transfer can provide real-time evaluation and control in many nondestructive testing applications. Huge amounts of information can be stored for later review and analysis when desired. AMD beat Intel in the race to be the first on the market to introduce a new 64-bit microprocessor chip. Have we reached the ultimate in computer memory, speed, and data transfer capacity? No, the future still lies ahead.

At the same time, wireless technology is advancing by leaps and bounds. Most people seem to have cells phones rather than those old Alexander

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Graham Bell telephones with wires. The advantages of wireless for industrial automation and the process control industries include worker and work station mobility and the elimination of thousands of miles of expensive conduit and cable. However, there are still many concerns regarding system design and potential signal transmission problems such as signal interference, signal hacking, sudden signal loss and retries, RF interferences, and multipath fading from unwanted reflections. However, it is probably safe to say that we can look forward to continued miniaturization and improvements in all forms of wireless technology.

City parks in Austin, Texas currently offer wireless Internet access; however, there are still some concerns that Bluetooth technology can be compromised. Bluetooth is a universal radio interface in the 2.45 GHz ISM frequency band designed to function on a worldwide basis. A Bluetooth system consists of a radio unit, link controller, link manager, and software. Spectrum spreading facilitates optional operation at power levels up to 100 mW worldwide. This is accomplished by frequency hopping in 79 hops displaced by 1 MHz, from 2.402 GHz to 2.480 Hz. The maximum frequency hopping rate is 1600 hops/sec. Bluetooth devices must be able to recognize each other and load the appropriate software to use the higher-level abilities each device supports and existing protocols.

Notebook PC computers can be used for remote networking using Bluetooth telephone systems, Bluetooth phones, cellular phones and notebooks for conference calls, speakerphone applications, business card exchange and calendar sychronization. Bluetooth technology is an operating system that is independent of any specific operating system. Advantages of Bluetooth technology are:

- Data exchange; signals penetrate solid objects.
- Remote networking and maximum mobility.
- Omnidirectional with synchronous voice channels.

The main disadvantage is that signals can be monitored by a snooping device from any direction or hidden location. Encryption with authenticity check is possible using a challenge-response protocol utilizing a secret key or password. Both devices must share the same secret key. The technology is suitable for many industrial data-sharing applications.

Will wireless RF ID tags help scientists track mad cows from country to country and state to state? Only if cattle ranchers and farmers all over the world are forced to comply with this requirement and that isn't very likely, is it?

1.2 SMALLER IS BETTER

Virtually all sensors, whether they are laser, infrared, acoustic, ultrasonic, or eddy current, have benefited from the high-tech explosion as well. Generally, high-resolution sensors have become smaller, more sensitive, and more robust. For flaw detection, many sensors can be focused more sharply as parts are scanned at faster rates, resulting in high-speed, high-resolution flaw detection. Eddy current and ultrasonic transducer arrays have greatly increased the single pass surface area scanned, while decreasing scanning times.

Piezo-composite ultrasonic transducers have greatly increased the sensitivity and range of ultrasonic transducers while reducing noise. In some applications noncontacting ultrasonic probes with perfect air/gas (compressed fiber) impedance matching can compete with laser profiling applications and other methods for the detection of minute surface defects. Noncontacting sensors also have some advantages in medical applications.

Micro-electromechanical systems (MEMS) have been around for about 20 years and are increasingly important to many manufacturing industries including semiconductor, automotive, electrical, mechanical, chemical, medical, aerospace, and defense. A very rapid growth of MEMS is expected over the next decade.

Small, sensitive airbag accelerometers help protect us in our automobiles and miniature flow valves provide beautiful letter-quality ink jet printing. Other MEMS developments include:

- Micropressure and acceleration sensors for restricted spaces
- Microelectronic components such as capacitors, inductors, and filters
- Micromechanical components such as valves and particle filters

National security applications for MEMS include nonproliferation, counterterrorism, land mine, chemical and biological warfare, and WMD stockpiling detection. Spin-off applications, which benefit mankind, include biomedical diagnostics, food and water safety, and industrial process and environmental monitoring.

The design, fabrication, testing, and inspection of microcomponents and assemblies challenge engineers and designers because the software, tooling, mechanics, size and shape, fluidity, damping, and electrostatic effects encountered in the microcomponent world are considerably different from those associated with the more conventional macrocomponent world.

While MEMS may still be considered in its youth, the birth of nanotechnology has progressed to at least that of a preschooler. Nanotechnology is now widely recognized by the government and various technical groups. New products are being developed and evaluated by many sectors. Nanotechnology has been defined as the manipulation or self-assembly of individual atoms, molecules, or molecular clusters into structures having dimensions in the 10 to 100 nanometer range to create new materials and devices with new or vastly different properties. Scientists believe the ability to move and combine individual atoms and molecules will revolutionize the production of virtually every human-made object and usher in a new high-tech revolution.

DOE nanotechnology accomplishments include:

- Addition of aluminum oxide nanoparticles that converts aluminum metal into a material with wear resistance equal to that of the best bearing steel
- Novel optical properties of semiconducting nanocrystals that are used to label and track molecular processes in living cells
- Nanoscaled layered materials that can yield a fourfold increase in the performance of permanent magnets
- Layered quantum well structures to produce highly efficient, low-power light sources and photovoltaic cells
- Novel chemical properties of nanocrystals that show promise to speed the breakdown of toxic wastes
- Meso-porous inorganic hosts with self-assembled organic microlayers that are used to trap and remove heavy metal from the environment

Unlike one old science-fiction thriller, nanobots may not be able to cure a young man's cancer, phenomenally increase his personal endurance and strength, and protect him against all harmful outside elements by stimulating the growth of gills in his neck, growing eyes in the back of his head, and developing an alligator skin for him, but it can make structural elements smaller, stronger, lighter, and safer. In turn, nanotechnology can make larger structures and all forms of transportation safer for us mere mortals.

Benoy George Thomas, in an article for *PCQuest* (September 2003, p. 174), mentions that scientists Robert A. Freitas and Christopher J. Phoenix claim that someday nanobots may change the very essence of life by replacing the blood currently coursing through our arteries and veins with over 500 trillion oxygen- and nutrient-carrying nanobots. In this scenario, the nanobots would duplicate just about every function of blood, but do it more efficiently.

The bloodstream would be made up of respirocytes each consisting of 18 billion precisely aligned structural atoms. Each respirocyte would have an onboard computer, power plant, and molecular pumps and storage hulls to transport molecules of oxygen and carbon dioxide. These nanobots would be a thousand times more efficient than the red blood cells (RBCs) they replace. If it sounds too good to be true, then it probably is.

While nanotechnology has been heralded as the driving force for America's next industrial revolution, extreme care must be exercised along the way. At present, the hazards and risks associated with nanoparticles are poorly defined. Toxicologists at Southern University in Dallas have discovered that C60 buckyballs (nanoparticles) in modest concentrations can kill water fleas (a source of food for newly hatched fish) and cause damaging biochemical reactions in the brains of largemouth bass fingerlings. Preliminary studies also indicated that similar problems were observed when nanoparticles were inhaled by animals. Therefore, the toxicology effects of nanoparticles must be considered for all phases of work in this field.

1.3 MEDICAL MARVELS

While doctors and scientists can't yet make a fantastic voyage in a MEMS or nanosubmarine through human arteries and blood vessels, they can virtually examine every artery and cavity in the human body. Doctors can go through the groin to open partially plugged carotid arteries leading to the brain, remove small blood clots from the brain using a small corkscrew-shaped device at the end of a microcatheter, or even correct small aneurisms in the brain. And, doctors can even fuse vertebrae disks by going through an incision in the front of the throat. There ought to be easier ways to get to some of these places.

With the new SilverHawk procedure, developed by Dr. John Simpson, leg arteries with 85% plaque blockage can be restored to normal flow and the arterial wall plaque can be saved for additional medical studies. Figure 1.1 shows the SilverHawk tool. The composition of the removed arterial plaque is then studied by heart doctors to help determine if early warning signs of heart attacks and strokes can be developed for otherwise normally healthy

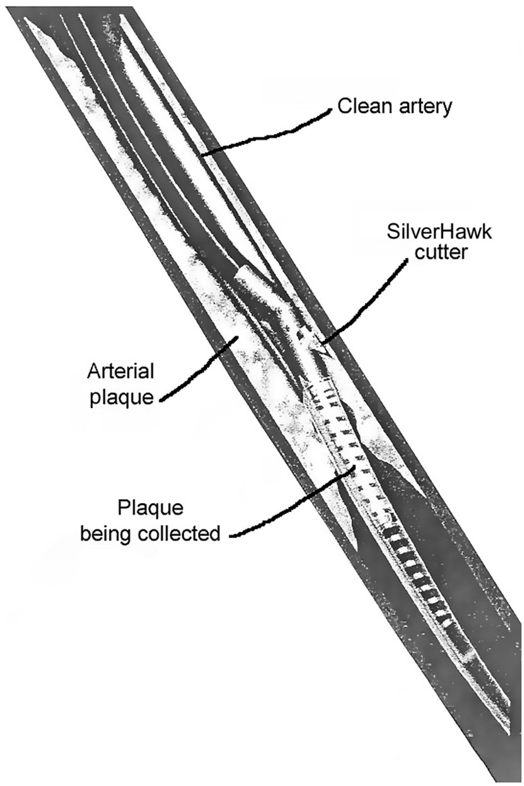

Figure 1.1 SilverHawk tool.

patients. Best of all, these new catheter procedures are highly reliable and relatively inexpensive compared to surgical procedures.

Verging on what might seem science fiction to some, heart doctors now have the ability to give patients with totally plugged heart arteries angio-genesis therapy (AGT), a modified gene therapy cocktail injected in heart arteries to encourage the growth of natural heart artery bypasses. This is an ongoing investigational study that probably will be continued for several years.

Preparation for AGT starts with the patient on the procedure table. A staff member informs the patient about the procedure, gives him oxygen, and places a full-face mask on him and leaves the room. When all staff members and doctor return wearing complete operating attire, rubber gloves, and full-face masks, patients may think they have just slipped into the Twilight Zone. However, if the procedure is successful, substantial improvements in health may be noted.

Enhanced External Counterpulsation (EECP®) therapy is one technique that is truly noninvasive. The goal of this therapy is to stimulate the formation of natural bypasses around narrowed or blocked arteries in the legs and heart.

The EECP system compresses the lower legs, upper legs, and lower buttock to increase blood flow toward the heart. The heart rate is monitored and each pressure wave is timed to increase blood flow to the heart when the heart is relaxing. When the heart pumps, the pressure is released until the heart relaxes again.

The goal of this therapy is to stimulate the growth of collateral blood vessels both aiding normal blood circulation and relieving chronic angina, which has proved unresponsive to other medical therapy. When successful, EECP can eliminate or reduce nitrate use and provide improved ability for patients to exercise more.

While these medical marvels are not nonintrusive for the most part, microsurgery and gene therapy are not very destructive in nature either; they owe much of their success to scientists and engineers working closely with the medical community to help prolong and extend the quality of human life. Once again, it proves there are no limits to imagination and innovation.

1.4 IMPROVING SHUTTLE SAFETY

Primary reaction control system (PRCS) thrusters are a critical part of the power and guidance systems of space shuttle orbiters. A space shuttle orbiter has 38 PRCS thrusters to help power and position the vehicle for maneuvers in space, including reentry and establishing earth orbit. However, minor flaws in the ceramic lining of a thruster, such as a chip or crack, can cripple the operations of an orbiter in space and jeopardize a mission. In the past, these thrusters had to be detached and visually inspected in great detail at one of two NASA facilities—the White Sands facility or the Kennedy Space Center—before and after each mission.

In 2002, James Doyle, president of Laser Techniques, Inc., successfully demonstrated that a miniature, high-performance laser could locate and map hidden thruster features smaller than the head of a pin, to an accuracy of 0.0003 inch. Figure 1.2 shows James Doyle near the rear of a space shuttle with three vertical PRCS thrusters pictured. His initial development work led to the issuance of a NASA contract to build a full-scale, portable in-situ thruster mapping system.

A cutaway view of a thruster shows the laser inspection system and related mechanical actuator in place and ready for inspection in Figure 1.3. The mechanical actuator for the sensor carrier arm and module are retracted when the assembly is placed in the thruster. The thruster interface unit helps center and align the assembly. When a vacuum is pulled on the vacuum locking device, special o-rings lock the assembly in place, readying it for inspection. The sensor carrier arm can be extended, retracted, and rotated. The sensor, which is held by the carrier arm, also rotates about the axis of the thruster and has a tilt mechanism for contour following.

The high-performance laser sensor is shown in Figure 1.4 and compared in size to a 2002 penny. It is important to note that the sensor is used to inspect and map the inner thruster surface area starting about 0.5 inch from the injector face to about 1.5 inches downstream of the thruster throat. Most ceramic coating defects are upstream of the thruster throat and very difficult to eval-

Figure 1.2 James Doyle, president of Laser Techniques Co., at back of space shuttle near three vertical thrusters.

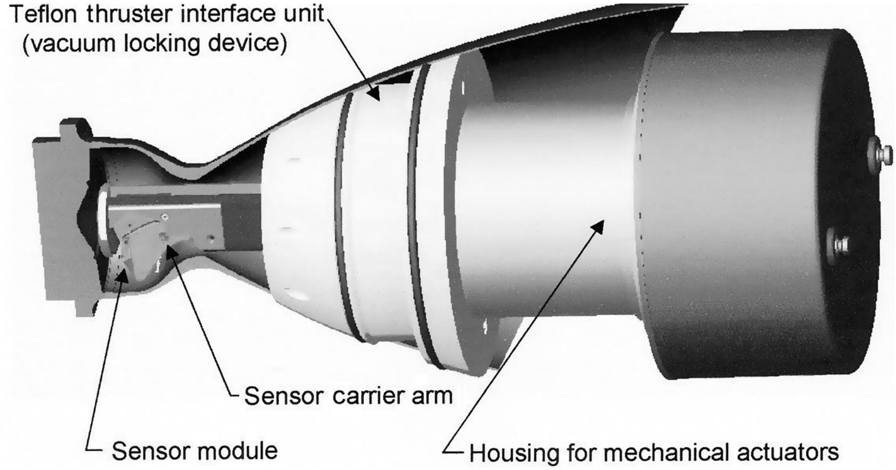

Figure 1.3 Cutaway view of thruster. Courtesy of Laser Techniques Co.

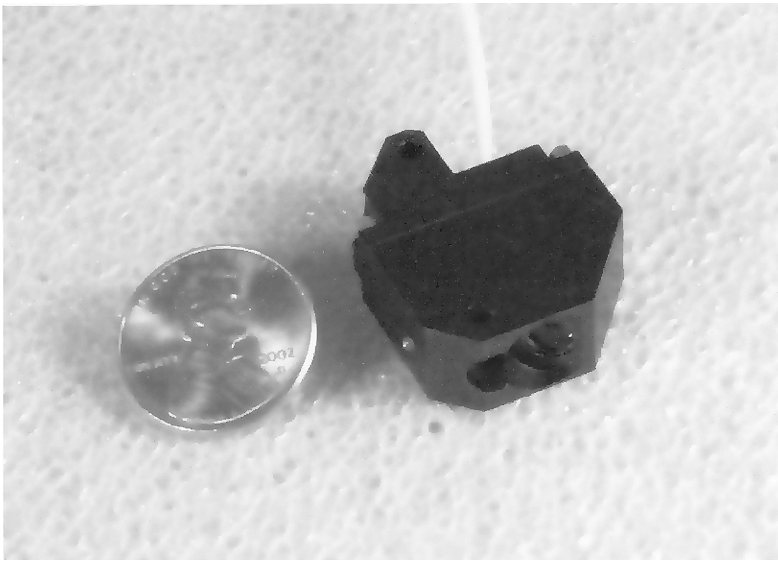

Figure 1.4 Comparison of penny to high-performance laser sensor. Courtesy of Laser Techniques Co.

uate visually. With the scanning laser system, this area of the thruster can be quickly inspected and mapped, providing technicians with accurate 3D data for evaluating the ceramic surface condition of the thrusters.

The portable laser scanner system has been sent to the White Sands test facility in New Mexico where it will be used in thruster life-testing projects and routine thruster overhaul and refurbishment programs.

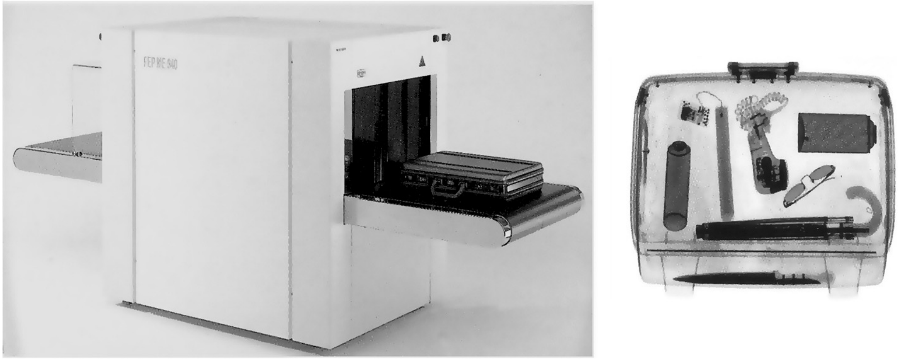

Figure 1.5 Gilardoni airport security system for luggage inspection showing typical suitcase luggage content (normally in color). Courtesy of Gilardoni Scientific Industry, Italy.

At the ASNT 13th Annual Research Symposium, keynote speaker Bob DeVries reviewed his NDE team's investigative work following the Columbia shuttle disaster that centered on a piece of external tank foam that struck the leading edge of the space shuttle during its launch. After each NASA impact test on the thermal protection system, including the leading edge of the shuttle, nondestructive evaluations were made on the reinforced carbon-carbon components that were impacted. As a result of Mr. DeVries' team efforts, future improvements can be made in material design and structure.

1.5 AIRPORT SECURITY

Gilardoni of Italy fabricates high-tech X-ray inspection systems for increased airport security. These systems are capable of identifying the contents of passenger luggage and parcels as shown in Figure 1.5. Note that a knife and dynamite stick appear in the photo along with other suspicious items. With this equipment, the radiation dose received by luggage contents is so low that ordinary camera film may be packed with the luggage and exposed to the X-rays with no adverse affects. The X-ray inspection system features sophisticated electronics and advanced solid-state detectors. The double-energy X-ray scanning feature of this system provides for selective detection of explosive devices, and therefore this system is capable of improving the security of prisons, banks, hotels, exhibitions, and other locations.

1.6 PROCESS CONTROL

The three key variables for proper process control are flow, pressure, and temperature. Chemical and nuclear reactors must precisely control these variables to prevent fires, explosions, or even reactor core meltdown. These catastrophic events can result in injury or death to operating personnel. These disasters can also result in toxic fume releases to the atmosphere and contamination of the water supplies, thereby endangering the general population. World health depends on protecting the environment.

In the chemical and petrochemical industries, thermocouples, resistant bulb thermometers, contacting and noncontacting pyrometers, and infrared scanners are used to measure temperature, determine heat flux patterns, and evaluate temperature excursions.

From a mechanical standpoint, pumps, fans, motors, and compressors are subject to damage and possible failure when bearing wear and excessive vibration of rotating parts occur. Accelerometers and lasers may be used to analyze and determine the extent of vibrations. In some cases, simple sonic devices can also detect bearing noise and provide a relative indication of bearing wear.

The ultimate goal of the process control industry is to shut down the process or isolate defective equipment and repair it before catastrophic failure occurs. Other NDT methods commonly employed by process control industries include:

- Neutron or gamma radiation gauges for noncontacting process flow, level, or density
- IR analyzers for measuring moisture in anhydrous gases and some nonaqueous liquids
- Ultrasonic transmission to detect pipe and vessel thinning caused by corrosion
- Alloy analyzers for material and part identification
- Hand-held sonic detectors for overhead gas pipe leaks
- Visual inspection in combination with other methods to determine corrosion

1.7 INSTRUMENT SYCHRONIZATION WITH PXI

As electronic instruments become more complex, the need to synchronize multiple instruments for testing and characterization of various devices becomes more important. PXI is a modular-based instrumentation platform designed for measurement and automation applications. PXI is an acronym for *P*CI e*X*tensions for *I*nstrumentation. PXI systems incorporate the PCI bus in rugged modular Eurocard mechanical packaging systems with electrical and software features that provide complete systems for test and measurement, data acquisition, and manufacturing applications.

PXI modular instrumentation (Figure 1.6) adds a dedicated system reference clock, PXI trigger bus, star trigger bus, and slot-to-slot local bus to provide

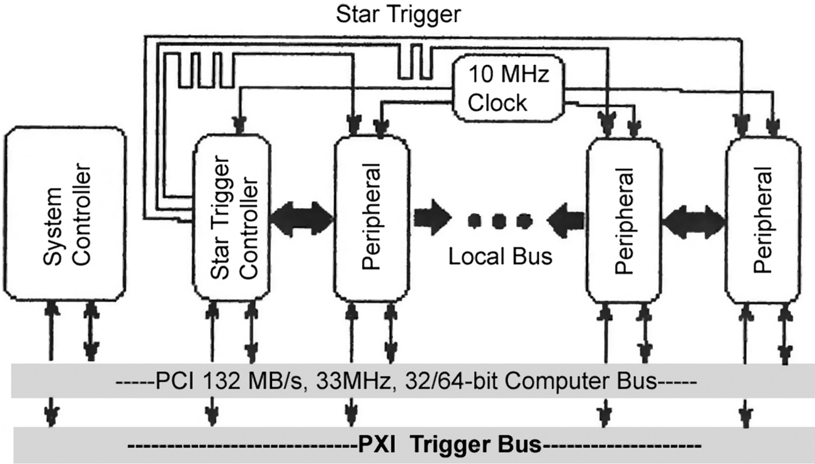

Figure 1.6 Instrument synchronization with PXI.

advanced timing, synchronization, and side-band communication while maintaining PCI bus advantages. System functions are as follows:

- The PXI backplane provides a common 10 MHz reference clock for sychronization of multiple modules.
- PXI defines eight trigger bus lines for sychronization and communication between modules.
- The star trigger bus provides an independent trigger for each slot oriented in a star configuration from slot 2 in any PXI chassis.
- The PXI local bus is daisy-chained to each peripheral slot with its adjacent peripheral slots. Each local bus is 13 lines wide and can handle analog signals as high as 42 V between cards or provide a high-speed side-band communications path that does not affect PCI bandwidth.

1.8 PCI VS. PXI

PXI offers the same performance features as PCI. PXI and CompactPCI systems can have up to seven peripheral slots per bus segment, whereas most desktop PCI systems have only three. Otherwise, all PCI features apply to PXI and CompactPCI.

1.9 60,000-MILE-HIGH SPACE ELEVATOR

While the ancient ones thought they could build a stairway to heaven, they never achieved their dream. Today modern man believes he can build a 60,000-

mile-high elevator in the next 10 to 20 years. If so, the space elevator envisioned by science fiction may soon become a reality, capable of greatly reducing the cost of putting modern satellites into space.

The expected success of a space elevator is based on the 1991 development of nanotubes made of cylindrical carbon molecules that are many times stronger than the strongest steel. Why blast satellites into outer space when you can give them a 60,000-mile-high elevator ride? To date, the most promising idea has been conceived by scientist Bradley Edwards, who has proposed a single, thinner-than-paper, 3-foot-wide ribbon, stretching from earth to the 60,000-mile goal.

As described in local newspapers, a spacecraft would first be launched to lower a narrow ribbon to earth where it would be tied down to a base station. Then the spacecraft would move outward, releasing more ribbon and establishing its position in space. Automated mechanical climbers would then be sent up the ribbon to widen and reinforce it. It is estimated that construction of the 3-foot-wide ribbon could be completed in about 30 months.

Following ribbon construction, as many as eight mechanical tractors could be used to each lift 13 tons of cargo into space. The tractors could be clamped on both sides of the ribbon by tank-like treads and powered by earth-bound lasers. When the construction of the elevator and its upper platform has been completed, satellites could be launched from the platform.

Many adverse factors could affect the building and life expectancy of the space elevator. Some of these factors include falling or orbiting space debris, radiation fields, storms, and terrorist attacks. Science fiction writer Arthur C. Clarke hopes to live long enough to see the construction of his real-world space elevator. However, if we concentrate on putting people on Mars, orbiting satellites and space shuttle missions may become fond memories of the past.

1.10 PROLIFERATION OF INFORMATION

The proliferation of NDT information on the Internet is analogous to the proliferation of standards and practices for the technical societies, as discussed in Chapter 2, Acoustic Emissions.

There appears to be an abundance of information on most company websites engaged in the manufacture and distribution of NDT products. Many of these sites adequately cover company history, their complete product line, applications, downloadable product information sheets, and in some cases, complete instruction manuals. However, simple theory of operation and system block diagrams showing how the equipment works or functions are often missing. Some educational websites that offer NDT training help by providing this basic information.

At times the NTD technology seems to be advancing so rapidly that, before the information can be recorded, newer, better equipment, and software packages are being developed and are "just around the corner." Unfortunately, sometimes it takes a very long time to get around the corner. When this happens, it's time to shoot the writer and publish the work. Perhaps company publications representatives could help their companies, customers, general public, and potential authors alike by releasing new information as quickly as possible, when company confidentiality is no longer needed.