STATUS OF ADVANCED UT SYSTEMS FOR THE NUCLEAR INDUSTRY

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INTRODUCTION

An advanced ultrasonic testing (UT) system is a configuration of hardware that includes some type of computer. The computer may be hardwired to perform specific functions or have appropriate software. It may typically be used for data acquisition, signal processing, image generation, pattern recognition and data analysis. Additionally, advanced systems have data storage and are, therefore, different from the standard transducer-pulser/receiver systems that rely on human filtering and written documentation of the filtered data.

More and more utilities and service vendors are using or are considering an advanced UT system for preservice (PSI) and inservice (ISI) inspections. A major utility has purchased five Amdata IntraSpect Ultrasonic Imaging systems. Another has bought and is using a NES/Dynacon's UDRPS system. Science Application Inc's Ultra Image III, along with Infometric's TestPro software, is being used for turbine rotor bore inspection. IntraSpect imaging technology is being combined with pattern recognition capabilities by a leading service vendor. New and potential users of advanced UT systems are increasing in numbers every day. What these systems offer is so attractive that regulatory agencies consider their deployment an "intelligent choice" for inspection.

BACKGROUND

The most significant difference between nuclear power plant UT inspection and, say, aircraft inspection, is the radiation background that is present and increases with years of service. Inspection personnel must always consider the ALARA guidelines (As Low As Reasonably Achievable) for radiation. The human factors include biological hazard and psychological stress. Under these pressures, the data processing capabilities of the human brain are also limited. This is why UT inspection data, when collected manually, is usually in summary form.

On the economic side, inspection costs are tied directly to the radiation dose rate at the inspection site. Allowable radiation dose per quarter is regulated and oftentimes results in shortages of qualified personnel to perform UT ISI in nuclear plants. This has economic impact via the deployment of limited personnel to do a job that has not changed in size or scope. The longer the down time, the higher the cost of purchasing replacement power to counter the loss of generating capacity.

Advanced systems were developed with the goals of reduced radiation exposure and increased reliability. These systems use scanners for high-density coverage of components, and since some of them are mechanized and remotely controllable, radiation exposures to personnel can greatly be reduced. Digital recording and processing of data facilitate repetition of stored scan patterns, data logging for data review, and application of signal processing techniques for noise reduction.

Advanced Systems

The number of systems becoming commercially available is growing each year. The NDE managers of utilities, the end users of these systems, are often faced with the decision as to "What system is right for my inspection problem?" "Is an advanced UT system a cost effective way to go?" To help this group, the Electric Power Research Institute (EPRI) has initiated a project whose end product will be a Utility NDE Managers' Guide to Advanced UT Systems. A short summary of the available data to date will be presented here. Tables are used to give an immediate overview of capabilities.

There are two broad classifications of advanced UT systems. These are feature-based systems and image-based systems. A feature-based system is very similar in concept to a radar system for aircraft. Parameters, or "features" are extracted from the ultrasonic signals accumulated during an inspection. These features are believed to contain information about the reflector that produced the original ultrasonic echo. As in radar, processing of echo features can be used to identify the reflector. Imaging systems use arrays of ultrasonic signals obtained from surface scanning to create "pictures" of reflectors located within a material. The purpose of the images is to assist an inspector in obtaining information on the spatial characteristics of his inspection problem.

EPRI is currently examining systems that combine feature-based and image-based capabilities into, as they are conceived, feature-enhanced imaging systems. Considerations are being given to the use of Personal Computers (PC's) for the hardware and software needs of these systems. Tables I and II cover systems that are in use today. Table I lists the hardware that comprises these systems. The software and software function capability of these systems are listed in Table II. The systems mentioned are not restricted to Tables I and II hardware and software. Table III describes commercially available components that may be used as alternatives and/or enhancements. Several UT systems that are still under development are listed in Table IV.

Qualification

A major concern of the utility NDE manager is the compliance of the system he chooses with NRC guidelines. The USNRC has issued guidelines that define minimum acceptable performance requirements. Qualification tests have been developed to evaluate advanced UT systems against the established criteria defined by the NRC. Systems that have met all of the USNRC requirements for IGSCC detection and sizing are listed in Table V.

TABLE I

COMMERCIALLY AVAILABLE AUTOMATED UT SYSTEMS/SERVICES -- HARDWARE

	INTRASPECT 98	P-SCAN	SDL-1000	SMART UT	UDRPS	ULTRA IMAGE III	ZIP-SCAN
VENDOR - SERVICE GROUP	AMDATA INC./CE	INDEPENDENT TESTING LABS. & UNIVERSAL TESTING LABS. INC.	SIGMA RESEARCH INC.	GENERAL ELECTRIC COMPANY	NES / DYNACON SYSTEMS INC.	ULTRA IMAGE INTERNATIONAL	U.S.TESTING COMPANY INC.
AUTOMATED SCANNER	AMAPS	AWS-4	SDL-1003	ALARA-1 OR AMAPS	ALARA-1, AMAPS OR VERSASCAN	ALARA-1 OR AMAPS	MIMIC
SEMI-AUTOMATED SCANNER		MWS-2	SDL-1004	GENERAL DYNAMICS	VERSASCAN	ULTRA IMAGE STD. MINATURE	
GUIDE TRACK & MOUNTING	FLEX-STEEL WITH MAG. WHEELS	STEEL TRACK WITH TIMING BELT	FLEX-STEEL WITH LOCK-ON CARRIAGE	RIGID TRACK OR FLEX-STEEL & MAG. WHEELS	RIGID TRACK FLEX-STEEL & MAG. WHEELS OR PLASTIC BELT	RIGID TRACK OR FLEX-STEEL & MAG. WHEELS	FLEX-CHAIN & NON-METALLIC WHEELS
SCANNER CONTROLLER	COMPUTER INTERFACED & JOYSTICK	COMPUTER INTERFACED	COMPUTER INTERFACED	CONTROLLER W/ AUTO OR MANUAL OR COMPUTER INTERFACED	COMPUTER INTERFACED & JOYSTICK	CONTROLLER W/ AUTO OR MANUAL OR COMPUTER INTERFACED	COMPUTER INTERFACED
TRANSDUCER	CONTACT OR BOOTED	CONTACT	CONTACT & IMMERSION	CONTACT OR BOOTED	CONTACT, BOOTED OR MULT.(6) ARRAY	CONTACT OR BOOTED	CONTACT
UT COMPONENTS	METROTEK	P-SCAN	SDL-1000	ULTRA IMAGE III	ANY COMMERCIAL UNIT	ULTRA IMAGE III	ZIPSCAN
DATA STORAGE	HARD DISK & FLOPPY & CASSETTE	MAGNETIC TAPE CASSETTE	HARD DISK & FLOPPY	HARD DISK & FLOPPY & VHS OF A-SCAN OR RF	HARD DISK, 9-TRACK OR OPTICAL DISK	HARD DISK & FLOPPY	HARD DISK & FLOPPY
DATA DISPLAY	RGB COLOR CRT	B/W CRT (2 EA.)	RGB COLOR & B/W CRT	RGB COLOR & B/W CRT	RAMTEK COLOR CRT	RGB COLOR & B/W CRT	B\W CRT
HARDCOPY UNIT	TECHTRONIX & COLOR POLAROID	EPSON FX 80	B\W & COLOR POLAROID	VHS & COLOR POLAROID	RAMTEK VERSATEC & TECHTRONIX COLOR	TECHTRONIX 4632/4634 & MATRIX COLOR POLAROID	3M VRG 4000
COMPUTER - DATA PROCESSING	HP 9836C	P-SCAN PROCESSOR	SDL-1001	ULTRA IMAGE III	HP-1000 & AP 400 ARRAY PROCESSOR	ULTRA IMAGE III Z-80 80286/8087	LSI-11/73

TABLE II

COMMERCIALLY AVAILABLE AUTOMATED UT SYSTEMS/SERVICES -- SOFTWARE

		INTRASPECT 98	P-SCAN	SDL-1000	SMART UT	UDRPS	ULTRA IMAGE III	ZIP-SCAN
	VENDOR - SERVICE GROUP	AMDATA INC./CE	INDEPENDENT TESTING LAB & UNIVERSAL TESTING LAB	SIGMA RESEARCH INC.	GENERAL ELECTRIC COMPANY	NES/DYNACON SYSTEMS INC.	ULTRA IMAGE INTERNATL	U.S.TESTING COMPANY INC.
	SCAN MOTION							
	AXIAL	###	###	###	###	###	###	###
	CIRCUMFRENTIAL	###	###	###	###	###	###	###
	SKEW	###	###	###	###	###	###	###
	DATA RECORDING							
	AMPLITUDE	###	###	###	###	###	###	###
	POSITION	###	###	###	###	###	###	###
	ARRIVAL TIME	###	###	###	###	###		###
	RF WAVEFORM	###			#	###		###
	RECTIFIED WAVEFORM		###		###	###	###	###
	INSTRUMENT SETTINGS	###	###	###	###	###		
	DATA DISPLAY							
	A-SCAN	###	###	###	###	###	###	###
	B-SCAN	###	###	###		###	###	###
S	C-SCAN	###	###	###	###	###	###	###
O	3-D ISOMETRIC	#		###		###		
F	PROJECTED VIEWS		###			###		
T	TIME-OF-FLIGHT	###		###	###	###		###
W	FLAW MAP					###		
A	ZOOM	###		###	###	###	###	
R	DAC CURVES	###				###		
E	AVERAGING							
	TEMPORAL AVERAGING	#				###		
	SPATIAL AVERAGING	###				###	#	
	SYNTHETIC APETURE							
	HOLOGRAPHY			###				
	SAFT	#				#		###
	ARTIFICIAL INTELLIGENCE							
	ALN							
	FEATURE EXTRACTION	#				#		
	PATTERN RECOGNITION					#		
	SIZING TECHNIQUES							
	TANDEM TECHNIQUE	###	###			###		
	MODE CONVERSION TECHNIQUE	###	###			###		
	CREEPING WAVE	###	###			###		###
	CRACK TIP DIFFRACTION	###				###		###

FULL CAPABILITY
PARTIAL CAPABILITY

TABLE III

COMMERCIALLY AVAILABLE COMPONENTS SUPPORTING AUTOMATED UT SYSTEMS

SYSTEM	MANUFACTURER	FUNCTION / DESCRIPTION
ALARA-1	VIRGINIA CORP	An automated mechanical scanner and scanner controller that can be interfaced to a computer. Mechanical system provides skew motion as well as standard scan motion. Rigid track and guide assembly.
ALN	ADAPTRONICS/ GEN.RES.CORP.	Adaptive Learning Network (ALN) allows training of the system to distinguish key features of the UT signal unique to specific defects or conditions and assists the inspector in confirming defect or geometry conditions.
AMAPS	AMDATA SYSTEMS INC.	An automated mechanical scanner and scanner controller that can be interfaced to a computer. Configured for hard shoe or booted transducer assembly. Flex-steel, wrap around track with magnetic wheels.
ROBBI	KRAFT WERK UNION	An automated UT inspection system designed primarily for flaw sizing and not significantly used for initial inspection and detection. System is presently being reconfigured for full inspection use.
SDL-1000	SIGMA RESEARCH INC.	An automated UT inspection system capable of A, B, C and 3D scan imaging but principally designed for ultrasonic holography inspection and high resolution imaging of previously detected indications.
SUTARS	SOUTHWEST RESEARCH INSTITUTE	An ultrasonic tracking system used with manual UT to integrate scan position with UT data. Tracking sensors strap to pipe to provide position data for hand held transducer.
TEST PRO	INFOMETRICS INC.	IBM PC based hardware and software allows integration of all automated UT components and assories to provide fully automated UT system. PC is a value-added component to current automated UT systems. RF waveforms are recorded; artificial intelligence and pattern recognition algorithms are built into the software. Provides additional analysis capability using standard PC software such as Lotus 1-2-3.

TABLE IV

NOT YET COMMERCIAL AUTOMATED UT SYSTEMS AND TECHNOLOGIES

SYSTEM	DEVELOPERS	FUNCTION / DESCRIPTION
ALOK	IzFP & KRAFT WERK UNION	Amplitude detection with time-of-flight signatures are used to detect flaw conditions. System uses standard UT transducers but is being upgraded to incorporate phased array transducer and will be capable of ALOK, ultrasonic holograpthy and line SAFT imaging.
CUDAPS	EPRI & ADAPTRONICS GEN.RES.CORP	Computerized Ultrasonic Data Acquisition & Processing System(CUDAPS) incorporates ALN systems to provide a complete automatic UT system. Major components are ALN-4060 Flaw Descriminator, LSI-11 Microprocessor and AMAPS scanner controlled by an ALN-4033 Scan Controller. System has been configured at the EPRI NDE Center.
PVIS	EPRI & SIGMA RESEARCH, INC.	Pressure Vessel Imaging System (PVIS) is an ultrasonic holography inspection system for heavy section steel inspection. The system can preform A,B,C,3D and holographic imaging and integrate multiple images into final 3D images. System under evaluation at NDE Center.
SAFT	NRC, BATTELLE-NORTHWEST & CE	Synthethic Aperture Focused Technique (SAFT) is a UT technology which provides focused UT images in the complete inspection volume. A transducer or point UT source is scanned over the volume surface and resulting UT data is analyzed to provide very high resolution focused UT image data at all points in the inspection volume.
SECTOR SCAN	EPRI & VINTEK, INC.	Real-time sector scan UT imaging uses a phased array or mechanically scanned transducer to provide real-time L and S wave images in a sector B-scan mode. Technology is similar to commonly used medical real-time sector scan units.

TABLE V

ADVANCED SYSTEMS SATISFYING IGSCC DEMONSTRATION REQUIREMENTS

System	Detection	Sizing
ALARA 1	X	X
ANL 4060	X	
CUDAPS	X	
Intraspect	X	X
P-Scan	X	X
Sutars	X	
Robie		X
Ultra Image III	X	X
UDRPS	X	X
Zipscan	X	

Cost-Effectiveness

Another concern of the utility NDE manager is the cost-effectiveness of inspections with advanced systems. Benefits most frequently cited by experienced utility users, service groups, and vendors are:

Better, and more complete coverage	Post review/analysis
Traceable results	Better reliability
Permanent recording	Low-radiation exposure
Real-time results	Immediate sizing
Fewer over/under calls	Documented data
Data comparison	Potentially lower cost

Many of the above benefits have significant long-term cost payoffs that are only realizable over a long time and are not immediately measurable. Each advanced system has different features and components which its marketing literature vigorously promotes. It is not always easy to identify the components or feature most important to a particular utility need. If a significant repair cost can be avoided because of the use of a UT system with advanced data display capabilities, it makes little difference if the system also possesses advanced pattern recognition capabilities. Both capabilities are equally important, but certainly not needed by all utility end users and/or applications.

To obtain cost information on automated/advanced UT inspection, a survey of the utilities, vendors, and service groups who have used such systems was conducted. Table VI summarizes the findings of this survey.

A total of 29 utilities and inspection service groups were surveyed. Twelve groups or 41% responded; however, several had no relevant data which gave an effective response of 21%. Those responding represent a total of more than 120,000 inches of welds that have been inspected by advanced UT--about 1,900 equivalent 20-inch diameter pipe welds. The data incldues GEDAS, IntraSpect, P-Scan, and UDRPS inspection results.

Recognizing that inspections with advanced UT systems provide benefits not readily available with manual UT, the initial equipment cost must be scaled accordingly to obtain the effective inspection cost. Specifically, to obtain the effective cost ratio of advanced UT to manual UT inspection (AUT/MUT), the initial AUT/MUT cost ratio must be divided by the benefit ratio. The average initial AUT/MUT cost ratio was 2.12--advanced UT inspection initially cost 2.12 times more than equivalent manual UT inspection; the average advanced UT to manual UT benefit ratio was 3.93. Therefore, the average effective AUT/MUT cost ratio is 0.64 and hence the effective cost of advanced UT inspection comes out to be less than two-thirds of the cost of equivalent manual UT inspection.

Technology Transfer

Ultrasonic NDE technology has advanced a great deal within the last two years. Advances have been so rapid that it is often difficult for a utility NDE manager to keep informed of all of the available inspection systems and their capabilities. The terms and concepts used by the developers and manufacturers of the equipment may leave the end user in a state of apprehension when a problem appropriate to an advanced system arises. EPRI is supporting efforts whose goals are to aid the utility NDE manager by providing him with a guide for selection and use of advanced systems and workshops to disseminate the latest information.
MNA/3060RPTSAS.

TABLE VI

AUT/MUT COST QUESTIONNAIRE SUMMARY 7/10/86

Utility, Vendor or Service Group	1	2	3	4	5	6	7	WEIGHTED AVERAGE & TOTALS
1. Type of automated UT system.(GEDAS,Intraspect,P-Scan,UDRPS & GESMART UT)								
a) Approximate inches of weld inspected	9,000	1,500	35,000	10,000	500	67,000	7,190	130,190
b) Estimated cost compared to equivalent manual UT inspection (MUT)	3.00	0.90	2.50	1.00	1.90	2.00	2.50	2.14
2. In your recent experience for an average UT inspection, what is the:								
a) % AUT Inspection	90	7	83	50	0	90	?	83
b) % MUT Inspection	10	93	17	50	100	10	?	17
c) Total number of welds inspected	25	40	120	100	200	130	?	116
d) Total number of weld inches inspected	1,750	1,500	6,000	5,000	7,500	8,380	?	6,855
e) Estimated cost to the utility per weld inch	28.00	?	20.83	50.00	?	61.00	?	46.02
f) Average % repeat inspection including sizing	10	5	5	10	1	20	?	14
g) Average % sizing	10	4	5	7.5	1	2	?	4
h) Average radiation level at weld site (mR/hr)	250	150	20*	50	30	500	?	415
i) Average inspector (Level I/II) exposure per outage	1,600	1,000	150*	600	1,200	1,200	?	1,169
j) Average cost per mR for total outage	8.00	?	83.00*	?	?	9.23	?	9.08
3. Estimated AUT/MUT cost ratio	3.00	1.00	2.50	1.10	1.90	2.00	2.50	2.15
4. Average MUT inspection speed: (weld inches/10 hr. shift)	140	70	200	240	300	80	?	132
5. Average AUT inspection speed: (weld inches/10 hr. shift)	140	95	400	240	?	140	?	222
6. Average number of welds inspected per outage	40	100	75	60	300	130	?	102
7. Average number of weld inches inspected per man per outage	550	500	500	?	?	160	?	302
8. Benifits								
9. AUT/MUT benifits ratio	4.00	2.00	2.00	?	1.10	5.00	2.00	3.82
Effective AUT/MUT cost ratio (item 1b divided by item 9).	0.75	0.48	1.25	?	1.73	0.40	1.25	0.56

* These are for DOE work and may not be representative.

Utility response -- 3 out of 16 with 1 N.A.

Vendor response -- 9 out of 13 with 4 N.A.

Total response -- 41%

Effective response -- 24%

DISCUSSION

Dr. Berens: I have one question. I think in terms of NDE reliability in terms of either finding them or sizing them. I wonder if you could address that question as to how well we do that in the electric (inaudible) region.

Dr. Behravesh: Well, the reliability studies are being conducted by the regulators and under their contracts, and we have been sort of staying a bit away from that because of the fact that we know that we are not as effective in NDE as we want to be. Most of our concentration in the nuclear industry is in the area of improving the techniques and demonstrating the capabilities of those techniques. Knowing that reliabilities are not as high as we want them to be, we are not, basically, concentrating much on that. So I don't have any reliability numbers for you.

Dr. Berens: Is Gerry Posakony here? I think it's only fair to Mohammed to mention that we did invite representatives of the NRC to present a paper on NDE reliability, and they are in the process of performing experiments and they didn't feel they were performing one that had any results. So, that was a question that was kind of unfair.

Dr. Don Thompson, Ames Lab: Did you take into account the cost-benefit ratio (of the manual reading), whether it was about 50, 55 percent, and take into account the cost of the automation? How do you actually come out in dollars?

Dr. Behravesh: Those were actually in dollars, if you assume that the cost of manual examination is $1, the effective cost of an automated examintion, based on those numbers, was 60 cents.

Dr. R. B. Thompson: That must be based on some assumed lifetime of the equipment, how long you amortize the initial costs.

Dr. Behravesh: That is weighted by the amount of actual examination that is performed, up to a given limit.

Dr. R. B. Thompson: How long does that have to last to pay for itself?

Dr. Behravesh: The equipment pretty much can pay for itself in one outage. Outages are the periods where the plant is shut down for maintenance and examination, and examinations are quite expensive. Typical examination runs into several hundred thousand dollars. So if you were thinking of one system costing a hundred thousand dollars, the price is somewhat insignificant. Not that it does not come into consideration, but it's insignificant.

Dr. Berens: Maybe we can continue this afternoon. Supposed to have someone from Battelle Northwest on our panel this afternoon.