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Abstract
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ADVANCED EMAT INSPECTION SYSTEMS: PROJECTILES AND WELDS

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ABSTRACT

EMAT's appear particularly suitable for automated inspection systems because of their ability to operate at high temperatures, at high speed, and without couplant. This paper reviews the progress in two important areas: the high speed inspection of artillery projectiles and high temperature inspection of MIG welds. In each case, material is presented illustrating the system concept and the ease of detection of appropriate flaws. Included is a discussion of the operational characteristics of such systems using SH and SV waves for inspection. The paper also describes the advantages of employing SH waves for volumetric inspection of very thick sections of complex geometries.

PROJECTILES

The electromagnetic-acoustic transducer (EMAT) is a device of particular interest to those areas of nondestructive evaluation (NDE) when its application may lead to significantly higher rates of inspection and, therefore, to reduced inspection costs. The application described in the first five posters specifically addresses the use of EMAT's for near complete inspection of artillery projectiles (155 mm) in one inspection station.

Poster 2 shows the planeview of a proposed automated EMAT inspection station for nondestructive evaluation of artillery projectiles for crack-like flaws and other imperfections which could cause failure. The inspection is to be accomplished in one inspection station by using (1) eddy currents or acoustic surface waves to inspect the outer surface in the base, (2) angle shear waves launched from the circumference through the base to inspect the interior of the wall in the base region, (3) angle shear waves launched in the longitudinal direction to locate ID and OD circumferentially oriented defects, and (4) angle shear waves launched circumferentially to inspect the ogive and bourellet regions for longitudinally oriented defects and to inspect the interior of the projectile well.

The mechanical projectile handling device shown in Poster 2 would function as follows: (1) the projectile would be gripped from the ID at the nose with pressure applied to the shoulder of the base, (2) the projectile would then be lifted to a location ¼ inch from each electromagnet pole piece, (3) ultrasonic inspection would be accomplished by electronically scanning a raster of EMAT's while the projectile is rotated in the applied dc magnetic field bias, and (4) following the completion of the ultrasonic scan, the projectile would be placed back on the conveyor for further disposition. Defective projectiles would be shunted aside at this point.

Poster 3 shows the proposed system architecture for controlling the handling machinery and the electromagnet power supplies, and for processing of the data from the ultrasonic inspection channels to determine whether a flaw is present. The signal processing scheme involves a departure from conventional ultrasonic inspection techniques in that a correlation receiver is used to filter and demodulate the received ultrasonic signals. The main advantage of this scheme is that the signals from all the channels can be processed with uniform fidelity. Other new developments include the use of highly efficient power amplifiers for energizing the input EMAT's, and sensitive receiver preamplifiers which optimize the signal-to-noise performance. The design of new electronics was necessary because EMAT's are subject to different breakdown characteristics and present much lower input impedance levels than ordinary piezoelectric transducers. A typical ultrasonic inspection channel functions in a "pulse echo" mode, although provisions for using separate transducers for transmission and reception of the ultrasonic signals are included in the design. The received waveforms are demodulated by the correlation receiver and converted to digital format. They can then be processed by the central processor which also controls the functioning of the projectile handling machinery and determines the disposition of the projectile based on internally stored accept/reject criteria. Provisions are included for updating the stored set of accept/reject criteria as the experimental data base is expanded and verified by independent nondestructive and destructive testing.

The dynamic range of the system shown in Poster 3 is in excess of 70 dB at 1.8 MHz. The correlation receiver includes a range gate which blanks the output except when a resolution cell of interest comes into range. The correlation receiver also helps to discriminate against impulsive electrical noise.

Poster 4 illustrates the functioning of a typical ultrasonic channel operating in a "pulse echo" mode. The demonstration was performed by using most of the electronic subsystems described in the preceding poster with the exception of the digital data processor and multiplexers. An oscilloscope and a four digit LED panel were used to display the received ultrasonic signals after linear preamplification, multiplication by a reference rf signal and integration in the correlation receiver.

The bottom figure in Poster 4 shows the output of the A/D converter which is included in the correlation receiver as a function of separation between the EMAT and a simulated flaw located in the bourellet region at the 155 mm projectile. The output signal is maximized when the two are separated by approximately 1.25 inches which correspond to the setting of the center of the receiver range gate.

Poster 5 shows the detection of a simulated flaw (EDM notch) located in the OD in the bourellet region and also the detection of a material flaw located on the ID in the ogive region. Both signals are rf tone bursts centered at approximately 1.8 MHz.

The bottom table in this poster summarizes the peak amplitude of the received ultrasonic signals as a function of different simulated flaw sizes and locations on the projectile. The system's sensitivity is best illustrated by its ability to detect EDM notches as shallow as 0.009 inches.

In summary, it is believed that the presently available EMAT technology has sufficient sensitivity to locate flaw sizes which are currently of concern to projectile manufacturers.

WELDS

Bulk horizontally polarized shear waves (SH waves) can be excited in metal parts by means of periodic magnet electromatnetic transducers. The principle of transduction of such waves is illustrated in one of the figures in Poster 6. A periodic magnet is used to establish an alternating magnetic field at the surface of the metal part to be inspected. A coil carrying electrical rf currents, and placed between the magnet and the surface of the metal part, is used to induce eddy currents which penetrate into the metal within one skin depth at the frequency of operation. As a result of Lorentz forces on the lattice due to the interaction between the eddy current pattern and the periodic magnetic field, the ultrasonic beams are excited at the surface directly beneath the transducer. The notable feature of the above excitation process is that the excited shear waves are polarized in parallel in the plane of the surface of the metal part. Such waves exhibit many properties not exhibited by vertically polarized shear waves (SV waves) which are ordinarily generated by piezoelectric transducers. Because the direction of SH waves can be varied by changing, the rf frequency and the transducers are not sensitive to other wave types (surface, longitudinal and SV), they are of considerable interest. Because the SH waves are excited electromagnetically, the transducers are largely insensitive to surface conditions and can operate over rough unprepared metal surfaces and at elevated temperatures. New applications involving the use of SH waves in NDE are in prospect.

In certain ferromagnetic steels such as the Fe-2½% Cr-1% Mo, the Lorentz excitation process is substantially enhanced by magnetostrictive processes. This leads to improved sensitivities and, therefore, to better defect detectabilities. In many applications, such as the inspection of welds at preheat temperatures, the above transducer and wave type properties are highly desirable because they cannot be matched with piezoelectric wedge transducers.

Poster 7 shows the results of some preliminary experiments with SH EMAT's on Fe-2½% Cr-1% Mo steel plates, 4 inches in thickness which contained sections of MIG welds and simulated defects (3/32 inch side drilled holes). Of particular interest is the figure in the upper left hand corner of this poster. This figure shows that the SH wave signal transmitted through an Fe-2½% Cr-1% Mo steel plate does not vary substantially over temperature ranging from ambient to 500°F. This is a significant result showing the independence of the transduction process to large thermal variations. Another interesting result is shown in the figure below. It shows the detection of a 3/32 inch side drilled hole in a MIG weld using 1.8 MHz SH waves excited at approximately 30° with respect to surface normal. A tone burst 10 cycles long was used in this test. The display is not an oscilloscope photo but an output of a Versatec copier. The signal was generated by using digital signal averaging techniques and represents the result of averaging together 250 frames of data. The echo at 10 microseconds represents a reflected signal generated by delamination in the Fe-2½% Cr-1% Mo base metal, while the signal centered at approximately 25 microseconds represents the energy reflected from the side drilled hole used to simulate a lack of fusion defect. The sample used to generate the above data is shown in the photo on Poster 6.

It is hoped that the use of SH type shear waves will lead to better defect detectabilities because the transducers discriminate against spurious signals generated by mode conversion and because the ultrasonic beam can be electronically scanned, thereby allowing the concentration of the input acoustic power on the region of particular interest to the NDE inspector without physically moving the transducer element.

ACKNOWLEDGEMENT

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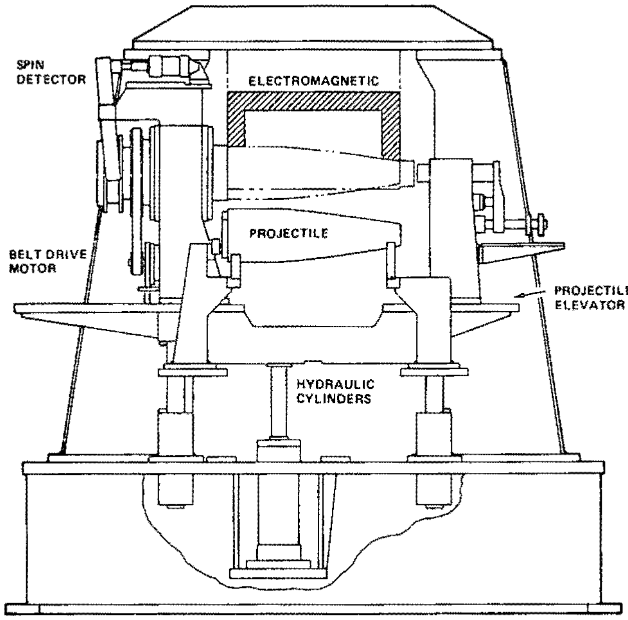
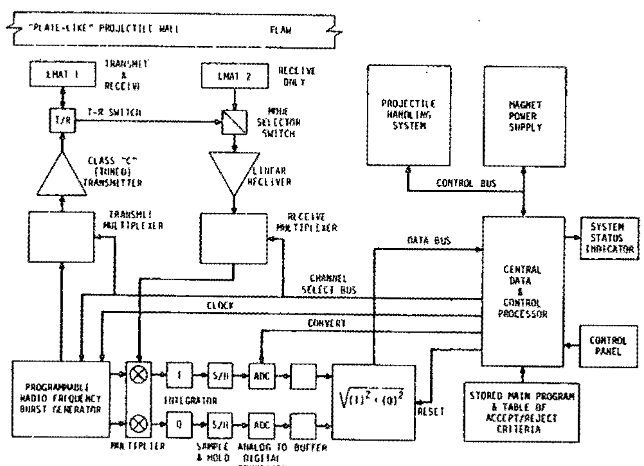


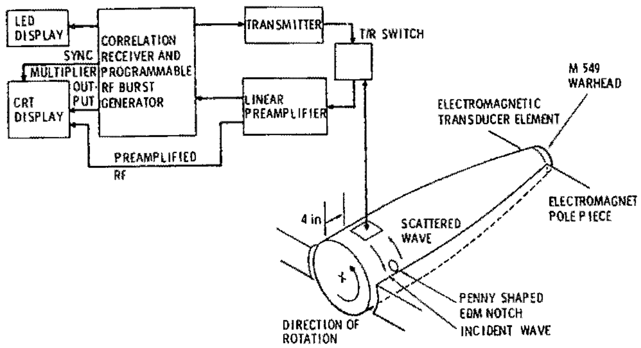
- LAUNCHING AND RECEIVING OF ULTRASONIC SIGNALS WITHOUT INTIMATE MECHANICAL CONTACT BETWEEN TRANSDUCER AND METAL PART.
- PROJECTILES AUTOMATICALLY INSERTED AND POSITIONED.
- EXPANDABLE ULTRASONIC DATA BASE BY ADDITION OF MORE ULTRASONIC CHANNELS.
- DECISIONS MADE AUTOMATICALLY BASED ON COMPARISON TO STORED ACCEPT/REJECT STANDARDS.
- INSPECTION RATE COMPATIBLE WITH ANTICIPATED PRODUCTION RATES.
- SINGLE ELECTROMAGNET PROVIDES MAGNETIC BIAS TO ENTIRE ARTILLERY PROJECTILE.

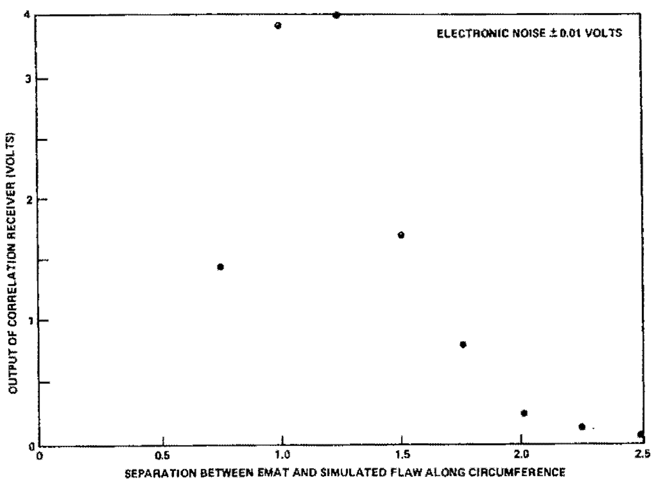
Poster 2.



- CENTRAL DIGITAL PROCESSING UNIT CONTROLS ALL PHASES OF INSPECTION.
- EACH ULTRASONIC CHANNEL FUNCTION IN "PULSE- ECHO" OR "PITCH-CATCH" MODE.
- RECEIVED ULTRASONIC SIGNALS DETECTED BY MEANS OF A CORRELATION TECHNIQUE TO INSURE BETTER SENSITIVITY AND IMMUNITY TO IMPULSIVE AND CROSSTALK INTERFERENCE.
- ULTRASONIC CHANNELS SCANNED SEQUENTIALLY.
- ACCEPT-REJECT DECISIONS MADE BY CENTRAL CONTROL PROCESSOR ON A SCAN BY SCAN BASIS.
- SYSTEM CAN BE REPROGRAMMED FOR INSPECTION OF OTHER PROJECTILE TYPES.

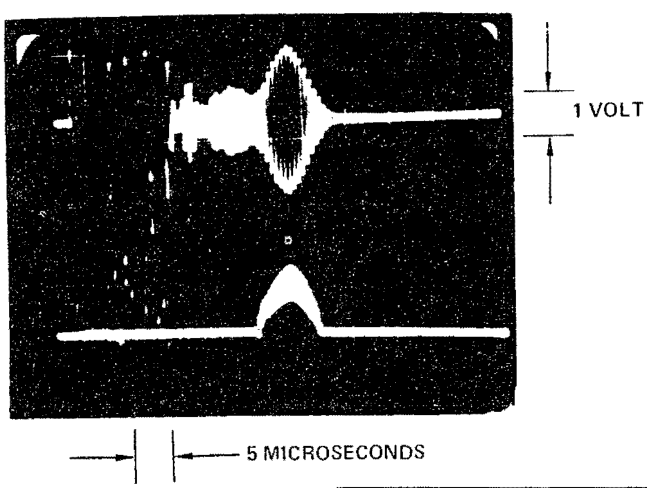
Poster 3.

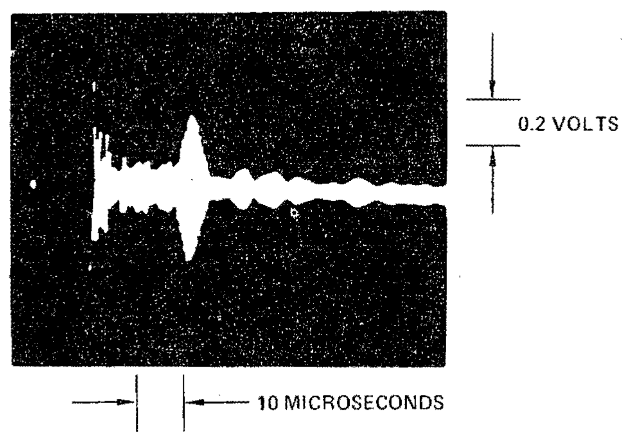




- **ADJUSTABLE RANGE GATE TO EXCLUDE UNWANTED SIGNALS.**
- **DETECTION OF SIMULATED FLAWS OF 0.009 INCH AVERAGE DEPTH.**
- **DISCRIMINATION AGAINST IMPULSIVE ELECTROMAGNETIC INTERFERENCE.**
- **TRANSDUCER POSITION FIXED WHILE PROJECTILE IS ROTATED TO PROVIDE OF ONE CIRCUM-FERENTIAL SEGMENT.**
- **AVAILABLE DYNAMIC RANGE IN EXCESS OF 70 dB AT 1.8 MHz CENTER FREQUENCY.**

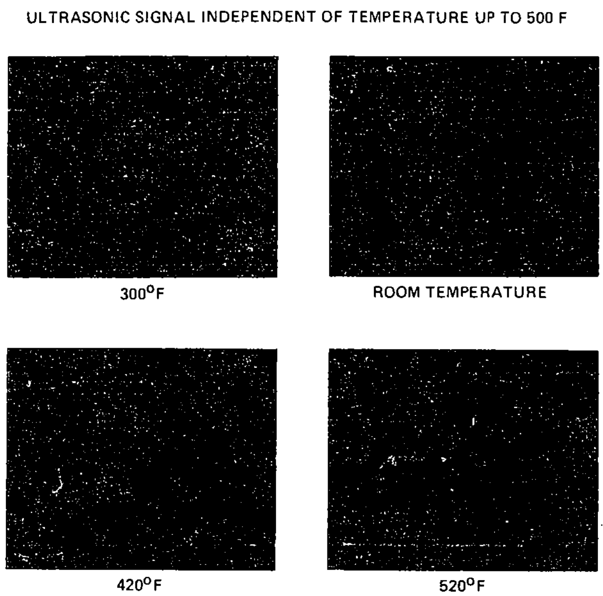
Poster 4.

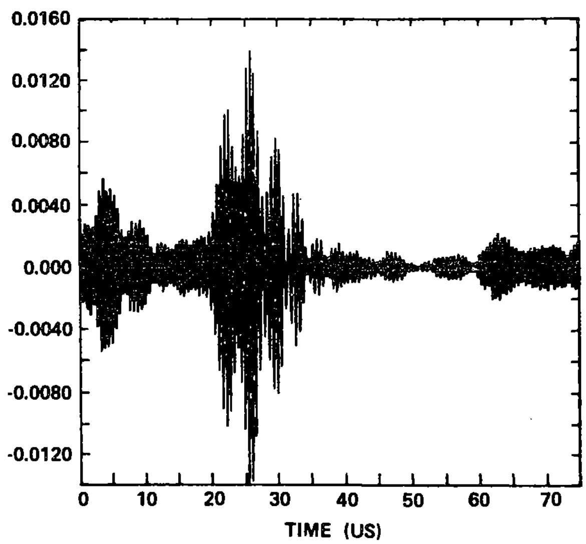




Simulated Defect No.	Distance From Base (inches)	OD / ID	Surface Length (inches)	Max. Depth (inches)	Cant Angle w/respect to axis	Output Level (V)	Field Configuration	Sample No.
1	6.5	O.D.	.146	.014	0	1.2	Parallel	88
2	8	O.D.	.158	.014	0	1.6	Parallel	88
3	9.5	O.D.	.186	.019	0	2	Parallel	88
4	9.5	O.D.	.256	.052	0	4	Parallel	88
5	11	O.D.	.116	.009	0	.8	Parallel	88
6	12.75	O.D.	.190	.022	0	2.8	Parallel	88
7	14.5	O.D.	.174	.015	0	1.2	Parallel	88
8	2	O.D.	.172	.020	10	.6	Parallel	85
9	2	O.D.	.177	.020	20	.2	Parallel	85
10	2	O.D.	.186	.018	30	.08	Parallel	85
11	2	O.D.	.374	.011	0	2.2	Parallel	09
12	3.5	O.D.	.222	.035	0	3.6	Parallel	09
13	5	O.D.	.105	.019	0	1.5	Parallel	09
14	3	O.D.	.179	.021	0	3	Parallel	51
15	5	O.D.	.157	.107	0	2	Parallel	51
16	2	I.D.	.030	?	90	.8	Normal	88
17	2	I.D.	.030	?	90	.6	Normal	88

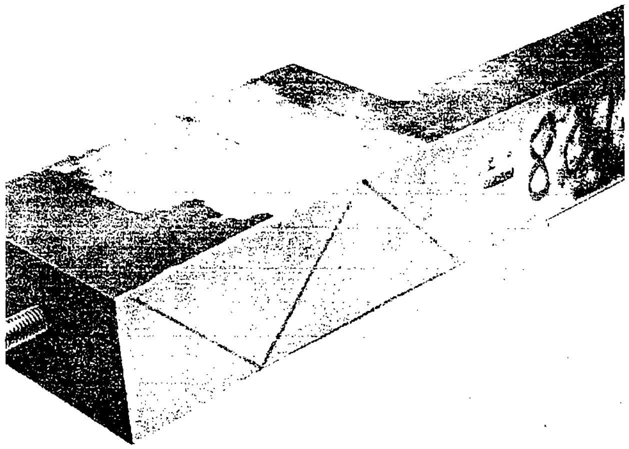
Poster 5.

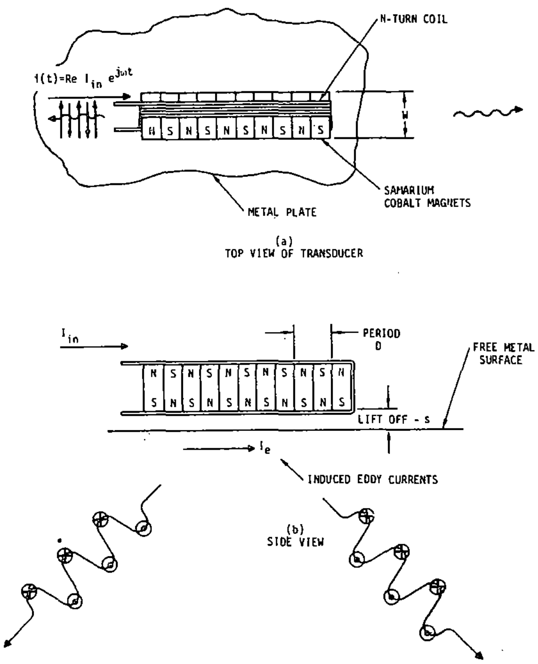




- GENERATION OF FEWER SPURIOUS SIGNALS.
- ELECTRONIC BEAM SCANNING FOR OPTIMUM ILLUMINATION OF FLAWS.
- ELECTRONIC PROCESSING OF RECEIVED SIGNALS FOR IMPROVED DYNAMIC RANGE (TIME AVERAGING).
- ABILITY TO INSPECT AT ELEVATED TEMPERATURES.

Poster 6.





- **SH WAVES CAN BE SCANNED BY CHANGING RF FREQUENCY.**
- **SH WAVE TRANSDUCERS DO NOT GENERATE OR RECEIVE BULK LONGITUDINAL AND SV WAVES, HEAD WAVES OR SURFACE WAVES.**
- **TRANSDUCERS INSENSITIVE TO SURFACE CONDITIONS: ROUGHNESS AND TEMPERATURE.**
- **IN CERTAIN FERRO MAGNETS SIGNALS ENHANCED BY MAGNETOSTRICTIVE EFFECTS.**

Poster 7.