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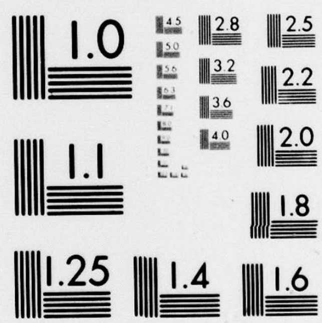

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TECHNICAL REPORT ARLCB-TR-79003

AUTOMATIC ULTRASONIC DETECTION AND MEASUREMENT OF CRACKS IN CANNON

D. C. Winters

April 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER WEAPON SYSTEMS LABORATORY
BENÉT WEAPONS LABORATORY
WATERVLIET, N. Y. 12189

AMCMS No. 32910673190

DA Project No. 6787319

PRON No. 1A827046GGGG

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER
ARLCB-TR-79003

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
Automatic Ultrasonic Detection and Measurement of Cracks in Cannon

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
D. C. Winters

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Benet Weapons Laboratory
Watervliet Arsenal, Watervliet, N.Y. 12189
DRDAR-LCB-TL

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
AMCMS No. 32910673190
LPN - DA Project No. - 6797319
LPN - PRON No. - 1A827046GGGG

11. CONTROLLING OFFICE NAME AND ADDRESS
US Army Armament Research and Development Command
Large Caliber Weapons Systems Laboratory
Dover, New Jersey 07801

12. REPORT DATE
April 1979

13. NUMBER OF PAGES
18

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
Presented at the 27th Defense Conference on Nondestructive Testing, Yuma, Arizona, Oct. 1978

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Automatic
Cracks
End-On
Ultrasonic

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

ABSTRACT

The "end-on" ultrasonic crack measurement technique has been refined and perfected to provide reliable automatic sensing and read out of the maximum crack depth and its location for each crack encountered as the probe moves in

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(Block No. 20 continued)

helical path down the cannon tube. A mechanical scanning machine has been constructed and tested which inspects full length 105 millimeter cannon. An ultrasonic flaw detector senses, measures and continuously reads out the distance from the outside surface to the crack tip or bore surface. Digital logic circuits evaluate successive measurements and determine the maximum crack depth reading. Encoders determine the location of each maximum crack depth reading. This data is transferred to a data acquisition system.

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ILLUSTRATIONS

END-ON TECHNIQUE

At Benet Weapons Laboratory we have developed and refined a technique for accurate end-on measurement of crack depth using a normal beam ultrasonic probe working with an ultrasonic flaw detector. The probe is coupled to the surface of the cylinder with oil, and the flat probe face rests on the curved cylinder wall as in Figure 1. The ultrasonic signal is reflected from the inside diameter and from the tip of the crack. The difference between the leading edges of these two reflections is the crack depth.

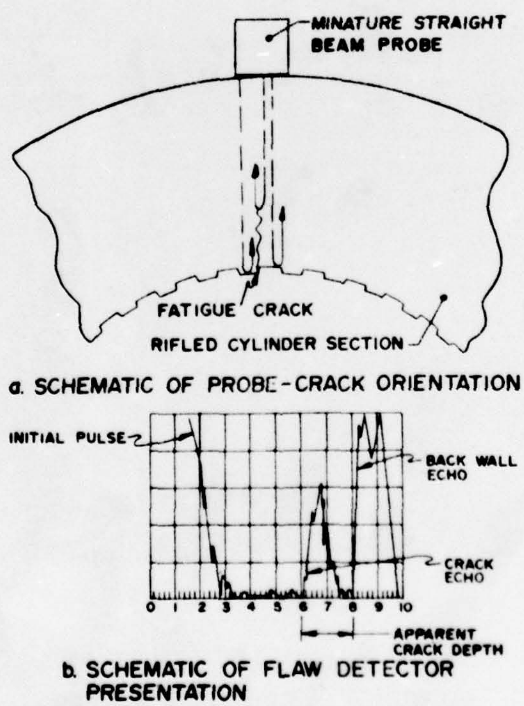
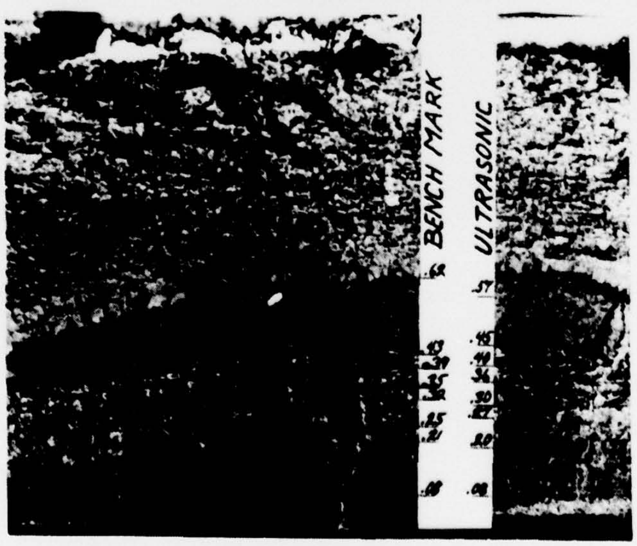


Figure 1

The ultrasonic signal reflects from the small jagged facets at or near the crack tip. Figure 2 shows a fracture surface from a cylinder that has been fatigue cycled at pressure until the crack has grown to 0.08 inch. Many cycles at half pressure have produced the first bench mark. As fatigue cycling has continued further crack growth has occurred. Bench marks have been induced at 0.02 inch, 0.27 inch, 0.30 inch, etc. When the cylinder has failed by fracturing through the wall, it has been wedged open to expose the fatigue crack fracture surface. Visual measurements are then compared to the interim ultrasonic measurements.



FATIGUE DEMARCATION, FRACTURE SURFACE SPECIMEN 58805

Figure 2

Figure 3 plots the ultrasonic measurement accuracy as determined on specimen 58805 and three other cylinders. The accuracy of measurement is ± 0.03 inches. Using this technique it is possible to pick up an initial crack at 0.02 inch but more reliably at 0.05 to 0.08 inches.

In order to get a usuable signal reflection from the crack tip the flaw detector gain must be 50 db greater than that gain which will bring the back wall signal to mid-screen on the flaw detector.

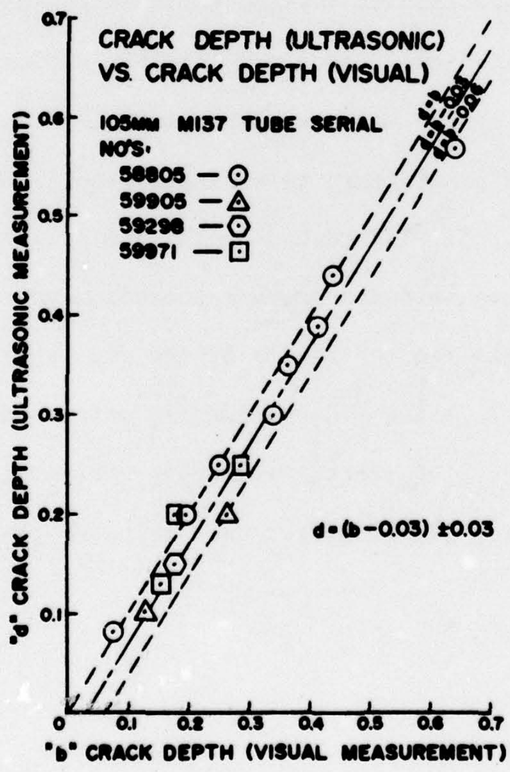
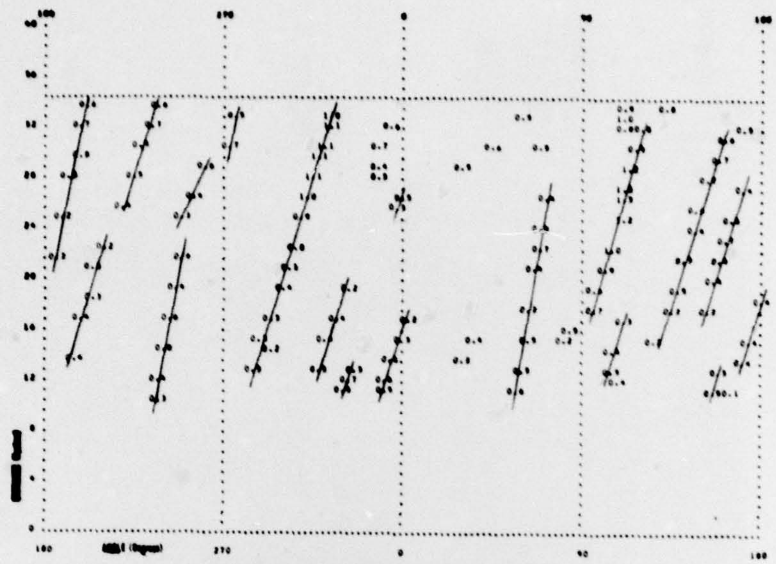


Figure 3

AUTOMATIC SYSTEM

It takes several thousand cycles to initiate cracks in gun tubes during fatigue tests. These cracks initiate and grow in the region near the origin of rifling. This whole area is searched about every 500 cycles. There may be only one or two cracks at initiation increasing to a large number such as shown in the crack map of Figure 4 after many sets of cycles. Since it isn't known at the beginning which crack will fail, and since the profile of the crack is important to the study and prediction of fatigue failure, all data, for each 500 cycle scan, is acquired and stored. To do this automatically, an ultrasonic scanning system has been implemented. This system can also inspect cannon after manufacture to evaluate cracks found by magnetic particle inspection. It will record depths and location accurately and this data can then be compared to automatic magnetic particle inspection data taken from the inside of the gun tube. Accurate location information both inside and outside prevents random inclusion signals in the vicinity of cracks from being interpreted as cracks with depth. This will permit better evaluation of gun tubes and less rejects.



AUTOMATED ULTRASONIC FATIGUE CRACK MAP
8 INCH HOWITZER M2A2

Figure 4

MECHANICAL SCANNING SYSTEM

A mechanical scanning machine has been designed and constructed for Benet Weapons Laboratory by the Tektran Division of Arcair Company (Figure 5). It will hold any of three full size gun tubes, the 105 mm M68, the 105 mm M137, or the 105 mm XM205. The heaviest weighs 1660 pounds and is 17.5 feet long.

A stepping motor rotates the gun on adjustable rollers at speeds from 2 to 60 rpm. A second motor moves the ultrasonic inspection probe along the gun at speeds from 0.5 to 15 inches per minute. A full inspection can be completed in fifteen minutes.

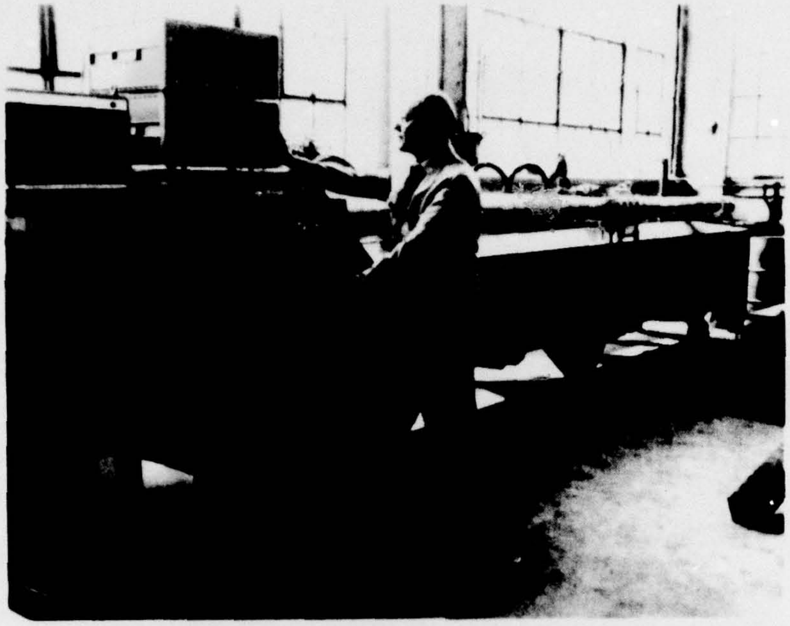


Figure 5

The control panel (Figure 6) has power and speed controls. It has a "home" button for accurately setting the search start position for both rotation and longitudinal position. When the head is returned to this position the position registers in the logic circuit chassis are zeroed. It has a control for the couplant circulator pump. There is a large emergency off knob.

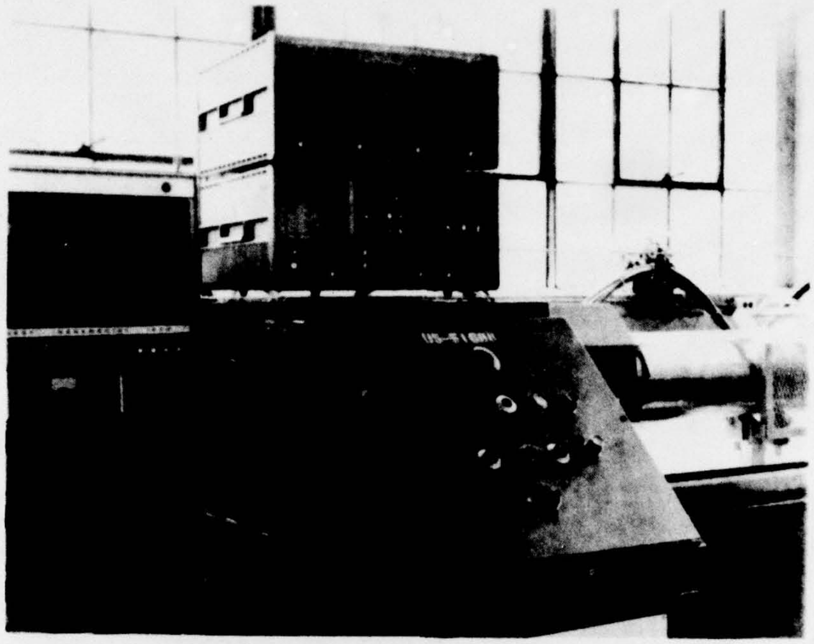


Figure 6

The search head assembly shown in Figure 7 is held against the gun by air pressure. The equipment requires a standard shop supply air line and fitting. The ultrasonic probe is held in a fixture that has roller wheels in contact with the gun. A thin film of oil is pumped into this search head and emerges under the probe. The oil is caught in a full length catch tank. It is then filtered and recirculated. Cams along the back of the tank cause the air supply to the carriage to be activated to move the search head away from the gun until it has passed irregular shapes or threads or sharp tapers on the gun barrel. The next cam moves the head back against the gun.

The whole assembly is mounted on wheels to allow for some portability. Once in position, the leveling jacks are used to level the system.

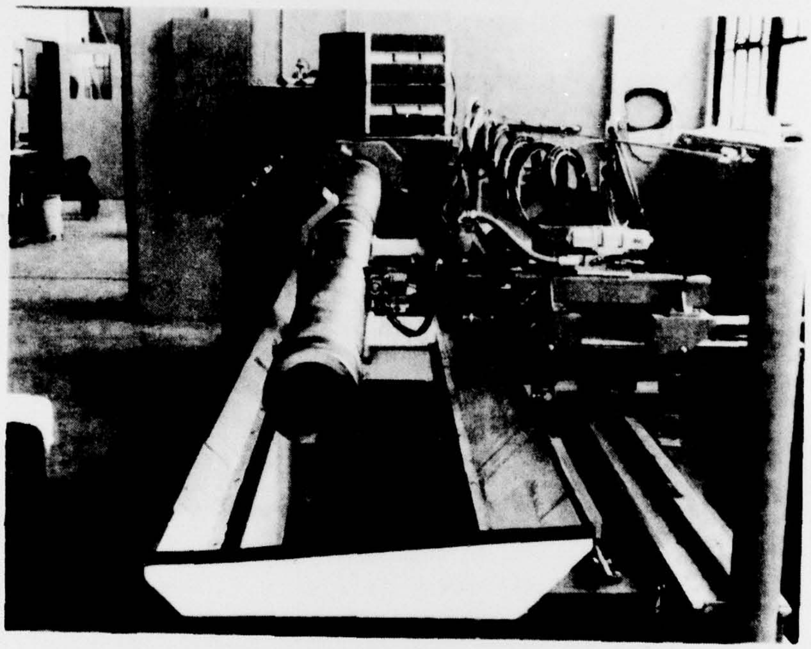


Figure 7

There are two incremental encoders to record the position of the search head relative to a key fixture on the gun, such as a locking slot on the M68. The encoder for rotation is accurate to 1°. It is connected to the gearing driving the chuck and locating dog. The horizontal position encoder is accurate to 0.1 inch. It is driven from the stepping motor which moves the carriage the length of the gun by means of a rack and pinion gear arrangement.

The stepping motors have proven troublesome due to their large voltage pulses which get into the grounding system. Due to a ground loop which couldn't be eliminated they were picked up in the high gain preamplifier stage and appeared in the output as false indication of flaws. The problem was eliminated by synchronizing the flaw detector timing to the stepping motors.

ULTRASONIC SYSTEM

A preamplifier is mounted on the probe carriage and gets its power from the main Immerscope flaw detector. Its function is to transform the high impedance of the transducer to the low impedance of the twenty five feet of coaxial cable connecting the preamp to the Immerscope. It is a grounded single ended input amplifier. Stepping motor pulses arriving on the iron frame of the system introduce a ground loop voltage at the transducer case ground. It would require a three wire ungrounded transducer whose return line is connected to the preamp input and which in turn is grounded back at the flaw detector to eliminate this loop. This will require a mechanically modified transducer and cabling, and a redesign of the probe head, since the ground connection is used to physically mount the transducer to the head.

The use of a preamplifier with the flaw detector results in very high gain and a high signal-to-noise ratio. It allows the very small crack signal from the rejected cannon flaw to be displayed almost full scale on the flaw detector screen. Manual measurements that are made with a Krautkramer USIP11 flaw detector produce very small signals that are barely visible on the screen.

A Tektran Immerscope II is used in this system. It includes the standard SW-25 sweep circuit and the PR-17 Pulser-Receiver unit. An FG/FDC-10 flaw gate and flaw depth circuit module provides distance to crack tip measurements accurate to a hundredth of an inch. Its circuits are configured to provide the depth of the first indication in the gate whose amplitude is greater than 20% of screen height.

Flaw depth data from the Immerscope is continuously fed into the logic circuits at the flaw detector repetition rate. These circuits are located in the C-chassis shown mounted above the flaw detector in Figure 8. This data is continuously subtracted from the wall thickness. The difference is the actual crack depth. As the probe travels over the cannon surface the crack depth numbers change. They get larger as the probe gets more directly over the crack tip and then get smaller as the probe travels on past the directly over position. The logic circuits operate on the changing crack depth readings. The depth numbers are stored in two registers. Register B is the previous reading. Register A is the present reading. If A continues to be larger than B nothing happens. When A becomes smaller than B for the first time that depth reading is transferred to an output register. At this time the position of the probe with respect to the cannon is also transferred to the output registers. This data is then held until it is checked.

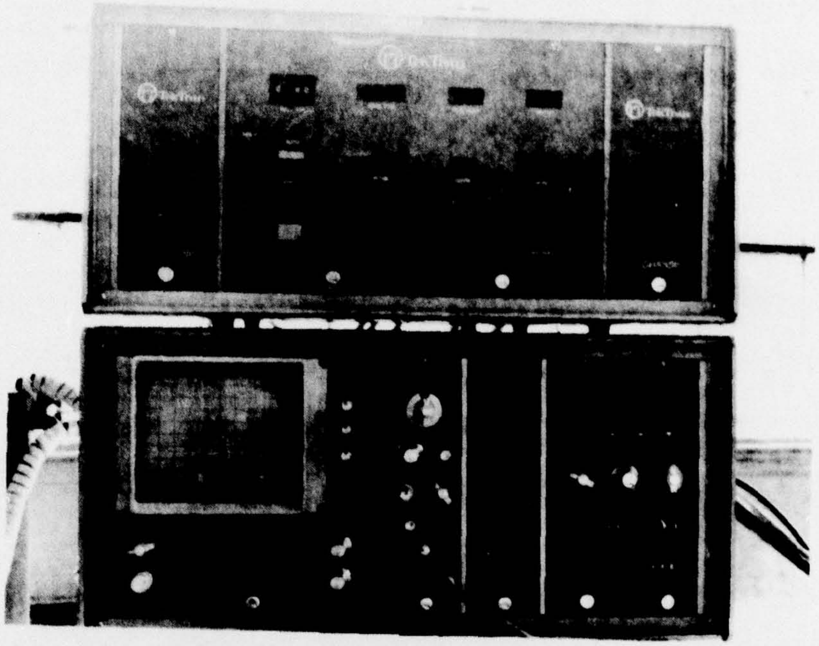


Figure 8

The logic looks for a selected number of A less than B readings up to a maximum of 256. Previous experience has shown that surface noise, intermittent couplant supply, and other factors can cause flase maximum readings. If another A greater than B reading occurs before the selected number of checks are finished the logic circuits are reset, a new maximum is found and new depth and position data replace the old. Then another set of checks take place. If no A greater than B reading occurs this time, the new depth and position data replaces the old in the output registers. The new data is not yet sent to the data acquisition system. It must wait for a selected number of degrees of rotation of the cannon. The number can be from

0 to 99 degrees. This is done by counting output pulses from the incremental encoder that encodes rotation position. The number of degrees of hold off can be optimized with respect to the flaw detector repetition rate and the cannon rotation speed. When these checks are concluded a "read out" pulse is generated and the correct updated data is transferred to the data acquisition system. The logic system registers are then reset and ready for the next crack reading.

The position of the probe with respect to the cannon is continuously updated on up-down counters located in the C-chassis. The encoders cause these counters to be incremented or decremented depending on the direction of motion. Position data is transferred from these counters to the output registers when the comparator indicates a maximum.

SYSTEM PERFORMANCE

The complete system is now in operation. It has been checked out on a 105 mm M68 cannon that has a defect in it. The defect is an inch long and 0.050 inches deep. During the scanning system acceptance test a plot has been made of the gun along the 0.8 inch thick section of the last 6 feet of the muzzle end which contains the flaw. The scanner hit this flaw three times. It also showed a second flaw a few inches away from the first. Both of these had been seen with black light magnetic particle inspection. The specifications require the system to detect and measure a 0.1" deep crack. The performance exceeds the specs.

The system measures 0.03 inch on the flaw rather than 0.05. This is due to the measurement gate setting being kept about 0.02 inch from the inside diameter signal to avoid false readings on the inside diameter. This offset appears inevitable if data is to be restricted only to flaws.

A present limitation on the use of the scanning system for inspecting full length cannon is the requirement that when the wall thickness changes the new thickness must be measured ultrasonically and manually inserted by means of thumb wheel switches. The gates must also be manually readjusted for this new setting. This limitation can be overcome by having this data stored in a computer memory, along with the appropriate gate settings, and then inserted at the proper time by signals from the length encoder.

DATA ACQUISITION AND ANALYSIS SYSTEM

A Digital Equipment Corporation DECLAB11L34-VE data acquisition system is now on order. This will replace our present incremental tape based system which has been used to check out the Tektran equipment. Data will be stored on a removable disk subsystem.It is proposed that for fatigue measurements on field cannon a disk will stay with the gun and at each inspection a new batch of data will be added to the disk.

The data acquisition system is based on a PDP11/34 minicomputer with 32K words of MOS memory and a capability for using Fortran IV language. Programs have been written for the laboratory IBM 360 computer which select the maximum crack from the data on a cannon.

They will be adapted to the PDP11/34. Programs will be written that predict remaining fatigue life from the crack growth curves using fracture toughness criteria. A DECWRITER 11 will be a part of this system and will produce crack "maps" similar to Figure 4 for each set of crack data taken.

CONCLUSIONS

The "end on" ultrasonic crack measurement technique is utilized to both read the crack depth and determine its location.

The prototype mechanical scanning system has been tested and performs correctly.

The ultrasonic preamplifier and flaw detector are able to measure a crack 0.050" deep, which exceeds the specification.

The digital logic circuitry for determining the true maximum crack depth and location works correctly.

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