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APPLICATION OF THE EDDY CURRENT
METHOD TO HIGH SPEED THICKNESS MEASUREMENT*

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ABSTRACT

The high speed production of small-caliber ammunition cartridges presents many new problems for quality assurance instrumentation. An example is the requirement of measuring the wall thickness profile of 5.56 mm brass cartridge cases at production line speeds of up to 1600 cartridges per minute. An eddy current system is presently being developed at Battelle-Northwest to perform this inspection. The inspection system will determine the cartridge case wall thickness profile at four positions along the case with nominal thickness ranging from 0.0165 in. to 0.0075 in. Using a breadboard prototype system, we have detected variations in cartridge case wall thicknesses of 0.0005 in. during simulated production line test conditions. A specially designed set of elongated eddy current inspection coils is used to perform the thickness profile scan as the cartridge cases are translated and rotated past the test fixture. Quadrature component signal presentation techniques permit discrimination against unwanted signals caused by coil-to-coil spacing variations. Potential errors due to coil temperature changes are minimized by automatically controlling the ambient temperature of the coil fixture and by incorporating specialized circuitry to compensate for residual drifts in base signal amplitude. Output signals are mated to a computer where accept/reject decisions are made. This paper outlines the basic principles utilized in the test system and describes the test system operation. Typical results obtained with a breadboard prototype are presented.

1. INTRODUCTION

Recent improvements in the production of small caliber brass cartridge cases brought about by the Army's "Small Caliber Ammunition Modernization Program" (SCAMP) have resulted in a need for on-line and high speed nondestructive inspection systems. Cartridge case wall thickness is one parameter which must be monitored to assure the production of

high quality ammunition. An eddy current inspection system has been developed at Battelle-Northwest to perform 100% inspection of cartridge case wall thickness at production line speeds up to 1600 cases per minute.

An eddy current method was chosen as the inspection technique because it can

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be performed rapidly without contacting the cases and it is adaptable to production line requirements. The application of eddy current methods to this test situation presented several unique problems such as high speed operation and high measurement accuracy requirements. This report describes the test system design and presents typical results obtained with a breadboard prototype system.

2. MEASUREMENT REQUIREMENTS

The eddy current inspection system was designed to accommodate 5.56 mm military cartridge cases. Thickness measurements are made on the production line as an integral part of the fabrication process. Figure 1 is a sketch of the 5.56 mm cartridge case. The cartridge is approximately 1.76 inches in total length and 0.375 inches in diameter at the base. Wall thickness measurements are made at four positions along the wall of the case.

FIGURE 1. 5.56 mm Cartridge Case

The positions to be measured are 0.535, 0.910, 1.300 and 1.660 inches from the primer pocket end with nominal thicknesses of 0.0165, 0.0105, 0.0075, and 0.0105 inches, respectively. Wall thickness determinations are made at these positions for the entire circumference of the cartridge, resulting in a wall thickness profile at these positions.

The case inspection rate of the entire systems is 1600 cases per minute, which is the production rate of the fabrication process. This high rate of inspection is accomplished by using two identical inspection systems each operating at speeds of 800 cases per minute. The accuracy requirements for the wall thickness measurements are 0.0005 inches for each of the positions measured.

3. EDDY CURRENT TEST PRINCIPLES

The eddy current method was chosen as the inspection technique because it can be performed rapidly without contacting the cases and it is adaptable to high speed production line requirements. Although several unique problems are present in the measurement of cartridge case wall thickness using eddy current techniques, the basic principles of eddy current thickness measurement are applicable.^(1,2)

Figure 2 is a complex plane presentation of the effect upon eddy current inspection coil impedance as material thickness and coil to material spacing are varied. By properly monitoring the complex impedance, one can separate coil-to-material spacing variations from material thickness changes.

Separation of these two variables was considered mandatory for cartridge case thickness measurement due to the

5.56 mm CARTRIDGE CASE

Fig 1 @ 62%

potential spacing variations which may occur in high speed mechanical handling systems.

**FIGURE 2. Complex Plane Presentation
Of Inspection Coil Impedance**

A test frequency of 25 kHz was chosen for the inspection system. Selection of this frequency was based upon the conductivity of cartridge case brass ($6.2 \mu\Omega\text{-cm}$)⁽³⁾ and the penetration depth of eddy currents in the material (one depth of penetration at 25 kHz = 0.031 inches). One test frequency was used for all four inspection coils in order to simplify the system design and reduce fabrication costs, while maintaining sufficient sensitivity to thickness variations.

4. INSPECTION SYSTEM DESIGN

4.1 MECHANICAL HANDLING APPARATUS

The mechanical handling system used to present the cartridge cases to the inspection coil fixture consists of a 24 inch diameter inspection wheel containing 24 cartridge case positions. As the wheel rotates, two mating transfer wheels simultaneously position cases on and remove cases from the inspection wheel at the rate of 800 per minute. Figure 3 shows a portion of the inspection wheel (dashed lines) and the eddy current test fixture.

**FIGURE 3. Eddy Current Test Fixture
And Inspection Wheel**

The cartridges are held at the primer pocket end and at the mouth by rotating spindles. As the cartridges pass by the eddy current test fixture they are rotated about their major axis at a speed of 3600 rpm. During the rotation, the cartridges essentially unwind their perimeter along the inspection coils, allowing a thickness measurement to be made over their entire circumference at the four measurement positions. Two of these inspection wheels and test coil fixtures operating at 800 cases per minute result a total inspection system throughput of 1600 cases per minute.

The cartridge cases are spaced at approximately 2.5 inch intervals on the inspection wheels which rotate at 33 rpm. A nominal cartridge-to-test fixture spacing of 0.008 inches is allowed which requires precise mechanical location of the cartridge cases. Cartridge case wobble on the rotating spindles is less than ± 0.005 inches. The resulting operating range of case to test fixture spacing variations is 0.013 to 0.003 inches. The lower spindle tip which is inserted into the mouth of the cartridge

Fig 2 @ 53%

Fig 3. @ 47%

case is fabricated from a nonmetallic ceramic material. This is to eliminate any effects upon the lower inspection coil signal by the presence of a metal near the area of inspection. The test fixture guard shown in Figure 3 is designed to protect the test fixture from possible damage due to misaligned or damaged cartridges.

4.2 TEST FIXTURE DESIGN

The inspection test fixture (Figure 4) consists of four elongated inspection coils housed in an aluminum shield. A driver-pick-up coil configuration is used to perform the inspection.

FIGURE 4. Eddy Current Wall Thickness Test Fixture

A 10-turn driver coil and 40-turn receiver coil are wound on each coil form. The inspection coils are 1.5 inches long and approximately 0.143 inches in width. An end effect is present as the cartridge cases pass by the test coils for 0.36 inches from each end of the inspection coils. This results in a 0.78 inch active inspection length of the coil. The cartridge case rotation speed of 3600 rpm is sufficient to allow slightly more than one revolution of the cartridge in the active inspection length of the inspection coil. The approximate time required for the

thickness measurement is 0.017 sec. The time between cartridges at 800 cases per minute is 0.075 second.

The inspection coils are mounted in an aluminum housing which serves both to shield the test coils from stray electromagnetic fields and to provide mechanical protection of the test coils. The front face of the aluminum housing is tapered to match the profile of the cartridge cases. Imbedded in the aluminum housing near the ends of the inspection coils are small electric heaters which are used to maintain a constant temperature at the inspection coils regardless of the ambient temperature level. The high thermal conductivity of the aluminum material facilitates the maintenance of a uniform temperature across the face of the test fixture. A series of solid-state signal preamplifiers are located in the test fixture behind the inspection coils. These preamplifiers boost the coil output signals and drive 25 feet of interconnecting cable that links the test fixture with the signal processing instrumentation.

The entire test coil fixture is mounted upon an adjusting platform which provides the necessary alignment mechanisms. This platform also contains a device for precise movements required during system calibration procedures.

4.3 SIGNAL PROCESSING ELECTRONICS

The basic electronics package for each inspection coil used in the system is shown in Figure 5. Quadrature balance voltages are generated from the master oscillator signal to null the signal present when a cartridge case of nominal thickness is positioned in front of the test coil. The output signal from the receiver coil is amplified and serves

Fig 4 @ 53 70

as the input to the 0° and 90° phase detectors. The resultant output consists of two signals representing the quadrature (complex plane) components of coil output voltage. Phase rotation of the output signals is accomplished with sin-cos potentiometers. The

FIGURE 6. Thickness Measurement Instrumentation Output Signal

inspection system are shown in Figure 7. The approach and leave

FIGURE 5. Eddy Current System Electronics

"vertical" channel signal is adjusted during calibration procedures to respond primarily to cartridge wall thickness variations. This signal is further amplified and biased to interface with the peak detection circuitry. A standard proportional controller is used to control the heat output of the heaters located in the test fixture.

5. TYPICAL RESULTS

The "vertical" channel output signal is presented to the peak detection circuitry in the form shown in Figure 6. This signal is derived from the vertical portion of the thickness loci shown in the insert. The signal is inverted (with respect to the insert) to make increasing thickness cause an increase in signal amplitude and vice versa.

Typical output signals obtained with a breadboard prototype of the

FIGURE 7. Typical Output Signal of Thickness Measurement Instrumentation

signals are ignored by the peak detection circuitry and only the maximum and minimum values occurring between the approach and leave signals are detected. The actual thickness profile measurement for each cartridge is made in approximately 0.017 msec. Variations in wall thickness of less than 0.0005 inches have been detected using this system.

6. SYSTEM OPERATION

The signals obtained with the eddy current system are input to the system computer where accept/reject decisions are made based upon preset limits of cartridge case wall thickness (see Figure 8). Unacceptable cartridges will be rejected automatically from the production line. System

Fig 6 ② +15%

Fig 7 @ 50%

calibration is accomplished using known wall thickness standards. Calibration consists primarily of adjusting system gain, phase rotation, and bias levels. Normal operation of the system will be essentially a hands-off operation, monitored only by the computer.

cartridge cases. Slight modification of the system to permit inspection of larger cartridge cases is anticipated. Other high speed, production line applications of the methods used in this system are envisioned.

8. ACKNOWLEDGEMENTS

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FIGURE 8. Computer Interface Logic

7. CONCLUSIONS

An eddy current system has been developed and designed to perform high speed, noncontacting wall thickness measurements on small caliber ammunition cartridge cases. Wall thickness variations of less than 0.0005 inches have been detected using this system. Specialized inspection coil designs allow wall thickness profiles to be made around the circumference of the cartridges. Quadrature component presentation of the signal allows discrimination against coil-to-cartridge spacing variations. Interfacing of the eddy current system with a computer allows accept/reject decision to be made automatically and enhances the high speed capability of the system.

The application of this measurement system is not limited to 5.56 mm

Fig 8 @ 50%