CONF. 790838--5

MASTER

High throughput dimensional measurements with electro-optics*

K. L. Swinth
R. A. Walker
N. G. Nedrow

Pacific Northwest Laboratory**
Richland, Washington 99352

Abstract

A dimensional measuring system, the profile monitor, has been developed to measure part dimensions with a standard deviation of 0.0001 inch at a throughput rate of 1200 parts/minute. The monitor is one measurement system on an advanced high speed inspection system designed to monitor the production of cartridge cases. The complete system includes a mechanical handler, measurement instruments (which make five measurements), system monitoring instruments and a dedicated minicomputer. This paper describes the profile monitor and its performance. The profile monitor is an electro-optic system that utilizes fiber optics to project an image of the case onto charge-coupled device image sensors. Measurements are made for five different case dimensions: 1) head thickness, 2) head diameter, 3) extractor groove diameter, 4) gas seal length and 5) total length. The profile monitor consists of five major elements: the case gauging fixture, the optical system including an illumination source and folding optics, the diode array (detector), the processing electronics and the computer. Electronics consist of the diode array and driver, thresholding circuit, measurement timing logic and data buffers. The square image conduit (six micron fibers) is structured to take the edges of the projected case image and transfer the image to a 0.125 inch linear charge coupled device (CCD) sensor. Logic is employed to detect the shadowed edges of the case and count the number of elements darkened by the shadow.

Introduction

A dimensional measuring system, profile monitor, has been developed as part of an advanced, automatic, high speed inspection system. This system, developed by Battelle's Pacific Northwest Laboratories for the U.S. Army, has been installed at the Lake City Army Ammunition Plant to inspect 5.56 mm cartridge cases. The system monitors for case dimensions (profile), surface flaws, vent hole presence, gross dimensional errors, and for the presence of splits in selected regions of the case. The purpose of this paper is to describe the profile monitoring instrumentation and its performance.

The cartridge case measurement/eject system (CCMES) is an automatic system for inspecting and rejecting cases produced by a cartridge case manufacturing line at rates up to 1200 per minute.^{1,2} The system consists of a mechanical handler and measurement instruments under the control of a dedicated computer. The mechanical system is designed to accept cartridge cases from the case manufacturing line and orient and handle them in a manner acceptable to the measurement instruments located on the mechanical handling frame. Measurement instruments are located at inspection stations spread throughout the path of the cases as they travel through the mechanical handler. Measurement electronics are located at the measurement station, while most of the processing electronics are in an airconditioned instrument console positioned near the mechanical handler. The process data is sent from the instrument console to the control computer which processes the data, keeps a running tally, and sends reject signals back to the mechanical handling unit where the unacceptable cases are rejected. Jets of high pressure air are used to remove the rejects from the path of the acceptable cases. The computer allows quick access to the processing information, providing some 17 formats in which to report the data. In addition to monitoring the manufactured cartridge cases, the system has a number of transducers and control systems which monitor overall system operation while the system makes produce measurements. The system-monitoring functions are communicated to the operator through indicator lights on a motor control panel or through messages displayed on a video terminal. Figure 1 shows an overview of the inspection module and indicates the location of the profile monitor.

The profile monitor is an electro-optic system which utilizes fiber optics to conduct an image of the case onto charge-coupled device sensors. Information from the sensors

* Work supported by the U.S. Army's Picatinny Arsenal under a Related Services Agreement with the Department of Energy.

**Operated by Battelle Memorial Institute.

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is processed to provide dimensional measurements with a standard deviation of 0.0001 inch at the system operating rate of 1200 cases per minute. Measurements are made for five different case dimensions: 1) head thickness, 2) head diameter, 3) extractor groove diameter, 4) gas seal length and 5) total length (Figure 2).

Profile monitor

The profile monitor consists of five major elements: the case gauging fixture, the optical system including an illumination source and folding optics, the diode array (detector), the processing electronics and the computer. The electronics consist of the diode array and driver, thresholding circuit, measurement timing logic and data buffers. The following sections describe the various elements of the monitor.

Gauging fixture

The profile monitor is used to measure dimensions of a 5.56 mm cartridge case. An outline of the case as it appears in the mechanical gauging fixture is shown in Figure 2. Five dimensions are measured as the cases pass in front of the profile monitor at a rate of 1200 cases per minute. The head diameter and extractor groove diameter measurements are made directly from the case while length and thickness dimensions are measured using the upper spindle tip of the mechanical handler as a reference gauging surface. Head thickness is measured from the fixed upper spindle tip to the underside of the head; total length is measured from the upper spindle tip to a spring loaded tip which contacts the case mouth; gas seal length is measured from the upper spindle tip to a spring loaded special fixture (similar to the portion of a gun chamber in the tapered area near the mouth, gas seal area). The gauging and contact surfaces of the fixture are precision ground to improve repeatability and the optical gauging surfaces have a taper to reduce parallax problems.

Optical system

The optical system for the profile monitor is shown in Figure 3. A xenon arc lamp (450 watts) is used to back light the case with a collimated (parallel rays) beam. The imaging lens projects the case and gauging fixture shadow onto the imaging plate where fiber optic image-folding light guides have been placed. Two light guides are associated with each dimension to be measured. The first light guide is positioned to intercept one edge of the shadow to be measured; the second light guide is positioned to intercept the other edge of the shadow to be measured. The light guides are then mechanically formed in a manner to allow both shadow edges of the measurement to be folded together and transferred to a single 0.125 inch long linear CCD (charge-coupled device) sensor. The profile monitor uses a 256 element linear image sensor to detect the shadow edges. The 0.125 inch length provides a resolution element of approximately 0.5 mil. (0.0005 inch).

Computer processor

Five measurements are made on each case as it passes by the profile monitor. As each measurement result is determined, it is stored in a temporary buffer. After the case passes by the profile monitor and all five measurements have been completed, the profile data in the temporary buffer is transferred to a computer dedicated to the inspection system. The computer processes the profile data and determines conformance within acceptable limits. If the profile data for any of the five zones is outside the acceptable limits stored in the computer, a reject signal is generated and the mechanical handler ejects that case from CCMES. The computer also generates statistical information for monitoring the production line that feeds the high speed inspection system. For instance, the status of each of 24 different tool stations on the production line are shown in Figure 3. Nominal head diameter is 374.5 mils. The mean, the max/min, and the standard deviation of the cases being produced by each tool station are calculated and shown on the computer output. The standard deviation shown is a measure of consistency of production.

Image folding and sensing

The technique used to measure the five dimensions of interest are all similar and for purposes of explanation only the methods used for head diameter will be described. The shadow of the case is imaged to an imaging plate as explained earlier (Figure 3). The shadow of the head diameter is then transferred to a CCD linear array (Fairchild 110F) by the fiber optics as shown in Figure 5. The fibers placed at the location of the head diameter edges in the imaging plate intercept the head diameter shadow as it moves by the profile monitor station. At the other end of the fibers the two sections (left and right head diameter edge intercepts) are joined so that a single CCD array can be used to measure the diameter dimension, even though it is greater than the 0.125 inch CCD

array length. The diameter dimension of interest can be calculated from the dark element count: $\text{diameter} = \text{fiber optic separation} + \text{dark elements (element spacing)}$.

Thresholding circuit

To eliminate variations in detecting dark diode counts, a special thresholding technique has been developed. It can be shown that correct detection will be accomplished, independent of illumination fluctuations, if the threshold is set at 50% of light/dark level variation. The 50% threshold also compensates for slight variations in focus or motion blur. Figure 6 illustrates the effect of this technique. In Figure 6, "a" shows a normal light dark profile of a shadow. The effect of reducing the light level is shown in Figure 6b, the light signal is reduced but the light/dark spatial gradient is constant. Setting the threshold at 50% between these two produces invariant detection results.^{4,5} Similarly, the effect of out-of-focus images and/or motion blur is shown in Figure 6c. The light level remains constant but the light/dark spatial gradient changes. Again, a threshold setting half way between light and dark will produce invariant detection results.

The threshold circuit used in the profile monitor produces the 50% threshold level for the video detector dynamically, by sampling the light peaks and the dark peaks. Resultant voltage levels proportional to the light and dark video levels are stored by "Hold" circuits. The 50% threshold is then set by resistively dividing the difference in the light and dark voltage in half to control the threshold of the video detector.

Multiple measurements

The shadow of the cartridge case moves across the image plate as the part moves by the profile monitor inspection station. To increase the accuracy of measurement, multiple measurements are taken of the diameter dimension as the case moves by the measurement station. (See for example Reference 3.) The theoretical gain in accuracy, while will be shown later to be nearly approachable in practice, is proportional to the inverse of the square root of the number of scans averaged (3). To achieve the theoretical accuracy, the edge must have continuous motion, perpendicular to the array axis that covers a distance greater than one element spacing during the gauging interval. The movement of the shadow edges and the multiple measurement averaging have the effect of increasing spatial resolution of the measurement to a dimension smaller than the CCD element spacing. The CCD used in the profile monitor (Fairchild 110F) has photo site spacing of approximately 0.0005 inches, while the profile monitor was able to demonstrate measurement results with a standard deviation of approximately 0.0001 inches.

Measurement timing

Timing for initiating the logic to take a measurement is accomplished using a combination of two techniques: an optical encoder and a video sequence detector.

The encoder is connected to the mechanical handling system and effectively divides the rotation of the inspection wheel into 7200 intervals or 300 intervals per inspection station. By electronically gating on these pulses, the approximate inspection interval is selected for the profile measurement. The video sequence detector is activated after the encoder indicates that the mechanical handler is in the inspection position. The video sequence detector then looks for the correct sequence of light and dark CCD elements that indicate the shadow edges are in proper position to take measurement data. Figure 7 illustrates the operation of the video sequence detector by showing the illumination profile across the CCD array. In Figure 7 "a" shows the illumination profile with no obstruction in the optical path from the lamp source. Light is noted by high signal, dark is noted by a low signal. Note that the middle of the illumination profile has a dark place near the middle of the CCD array. This effect is caused where the fiber optic from the left image edge are joined to the fiber optics from the right image edge.

For the purpose of detecting proper video sequencing, these special zones are designated on the CCD array. Zone 1 is a portion of the first part of the CCD array; zone 2 is a portion of the CCD array just past the mid point; and zone 3 is a portion of the last part of the CCD array. While the choice of zone size is somewhat arbitrary, the profile monitor uses 8 CCD elements to define a zone size.

Figure 7a shows the video output of the CCD array under "no case present" conditions. The first movement of a case into view of the CCD is shown in Figure 7b, the leading edge (LE) shadow being shown moving through zone 1. Figure 7c shows the leading edge shadow a short time later, moving between zones 1 and 2. As the leading shadow edge moves into zone 2, the trailing edge (TE) appears at the first of the CCD array, as shown in Figure 7d. As the case continues to move past the profile monitor

inspection station, the two case edges continue to move across the CCD array as shown in Figures 7e, f and g.

The video sequence detector logic uses the light/dark sequences in zones 1 and 2 to decide when a video measurement can be taken. After the encoder indicates that the case is in the proper mechanical window to take data, the video sequence detector looks for an all light, all dark and all light video sequence in zone 1 and an all light, all dark sequence in zone 2. When these two conditions are met, the measurement of the number of dark diodes appearing in the video output will indicate the size of the case between the leading and trailing edge of the diameter shadow imaged on the array. The logic is set up to allow 20 measurements of this dimension as the case shadow moves across the CCD array. (The array is scanned at about a 40 KHz rate and the case image moves across the array at about 0.0015 inches per scan, allowing 20 scans to be safely taken before the shadow edge gets to the end of the array.)

After the CCD is scanned 20 times the video sequence detector checks to make sure that the leading edge shadow is still on the CCD array by checking for all-light elements in zone 3. If this condition is satisfied, a valid measurement is assumed and that data is transmitted to the central computer.

Similar video sequence logic is used to initiate the other measurements, always using the mechanical encoder to first set up the proper mechanical window and then initiating the video sequence detection logic.

Automatic calibration

The profile monitor includes the capability of self check against standard case dimensions. The mechanical handling system positions a calibration standard between normal production cases every 12 case positions. The calibration standard alternates between a minimum tolerance sample and a maximum tolerance sample so that for every 24 production cases the profile monitor looks at two calibration standards, one with minimum tolerance dimensions and the other with maximum tolerance dimensions. This enables the profile monitor to compensate for small variations in measurement parameters due to time drift, temperature drift or other slowly changing characteristics. This feature has been found to be a useful tool in achieving the high accuracies experienced with the profile monitor.

Profile measurement results

During operation, precision ground steel standards are used to calibrate the profile monitor on CCMES. Dimensions on these standards have been measured in a metrology laboratory to within ± 50 microinches. Standards from the same set can be used to assess the repeatability of measurements made on the profile monitor. Measurements made on cartridge cases will include both the measurement precision and the variations in the cases as manufactured. The following sections discuss system calibration and measurements made with the monitor.

System calibration

Counts from the diode arrays are buffered in the measurement instrumentation and bussed to the computer once during each measurement interval. The computer takes the integer number and performs the following calculation to convert each measurement to mils (.001 inch):

$$Y = \frac{A}{S} X + B_F + B_S$$

Y = Case Measurement (0.1 mils)
A = Magnification constant (slope)
S = Number of Scans
X = Counts from diode array
B_F = Image folding constant
B_S = Spindle Correction factor

To calibrate the instrument, the constants A, B_F and B_S must be determined and the constant S must be entered. Instrument calibration is accomplished by placing CCMES in the closed loop or case recirculation configuration and repetitively passing selected standards through the system on a single measurement position (spindle) to eliminate the variability among spindles. The collected data is then used along with the known steel standard dimensions to compute a least squares estimate of the linear regression coefficients, A and B_F. The constant B_S is determined in a separate series of passes during which known standards are measured several times on all 24 spindles. The

average of the measurements is performed for each measurement and each spindle to correct for small variations from spindle to spindle. Due to manufacturing tolerances, this correction must be performed to maintain the high precision for the case measurements. The calibrations are performed under software control.

As mentioned earlier the system includes automatic drift compensation. Compensation is performed by making small corrections to the image folding constant, Bf. The autocalibrate software makes corrections based on the last 50 readings of two fixed standards (called targets) attached to the profile exam wheel. The amount of correction applied is the average error for both targets over the last 50 exam wheel revolutions. This factor compensates for any long-term drift in profile optics or electronics since the last profile instrument calibration. Two targets, a maximum and a minimum dimensional case, are used in the profile drift compensation. The standards, while are located between two spindle positions, are calibrated against the precision steel standards.

Measurements on standards

Table 1 shows a set of measurements made with the profile monitor on known steel standards. The entries in the table are based on the difference between the measured value for the dimension and the value determined for that dimension in the metrology laboratory. The system was operated in the closed loop configuration with the same standard measured on a given spindle 50 times. The overall average errors are shown at the bottom of the table. The standard deviations provide an estimate of the measurement precision while the means provide an estimate of the measurement accuracy compared to a known standard. The diameter measurements (extractor groove, head diameter are made directly on the cases and have average standard deviations of about 0.1 mil and a mean biased by about 0.1 mil. The other measurements are made on gauging surfaces and include errors due to changes in the contact of the gauge with the cartridge case. Although the average errors are not much different, one will note that the individual measurements show more variability.

Measurements on product

Figure 4 showed a typical data format with head diameter measurements for a series of brass cases fed through the CCMES. The standard deviations are larger (~1.3 mil) as one would expect, because both measurement precision and the variation in the brass are being measured. The measurements on the standards give an estimate of the measurement precision.

Figure 8 compares head diameter measurements made with hand gauges against measurements made by the profile monitor. Both sets of measurements are based on 24 randomly selected brass cases from several thousand used in machine testing. The range on the hand-gauged measurements represents the ovalicity of the manufactured case. Profile monitor measurements can fall anywhere in this range because the orientation in the spindle is random. Similar correlations exist for the other measurements.

CCMES has two features which allow verification of operation during on-line measurements at 1200 cases/minute. First, a sample insert device allows insertion and recovery of known samples or standards. The measurements (individually tabulated by the computer) on the samples can then be compared with their known values. Second, a sample of the product can be collected separately and their individually tabulated measurements can be compared with hand gauging results.

Conclusions

The profile monitor instrument for CCMES is capable of making five precision dimensional measurements on cartridge cases at the rate of 1200 cases per minute (linear velocity 4.36 ft/sec). The monitor provides 100% inspection of cartridge cases during manufacture and the information can be used for real time quality control. The monitor permits identification of specific tooling problems for repair during shut down of the system. Furthermore, immediate identification of the problems permits specific turret stations on the manufacturing line to be shut down thus preventing manufacture of rejectable product. The monitor shortens the time required to identify tooling problems compared to traditional sampling techniques and eliminates 100% of the faulty product from the production output.

Techniques developed for the CCMES monitor can be applied to other high speed dimensional measurements. Such measurements are applicable where sophisticated quality control, parts sorting or adaptive process control are needed. The dimensional measurement techniques can be applied to such items as engine parts, bolts, extruded materials, pellets, etc.

References

1. Coleman, W. J. and K. L. Swinth, "Development of an Automated Cartridge Case Measurement/Ejection System." Proceedings of the Society of Photo-Optical Instrumentation Engineers (Advances in Laser Engineering), 122:1977.
2. Coleman, W. J. and K. L. Swinth, "Automatic Cartridge Case Inspection and Process Control Monitor." Proceedings of the Society of Photo-Optical Instrumentation Engineers, (Effective Utilization of Optics in Quality Assurance), 129:1977.
3. Swedecor, G. W. and W. G. Cochran, Statistical Methods, 6th ed., 1967, Iowa State U. Press, Ames, IA.
4. Nyussonen, D., "Linewidth Measurements with an Optical Microscope: The Effect of Operating Conditions on the Image Profile." Applied Optics, 16, pp. 2223-2230, 1977.
5. Novotny, D. B. and D. R. Ciarlo, "Automated Photomask Inspection, Part II." Solid State Technology, June 1978.

TABLE 1: Normalized Profile Instrument Error for V Steel Standards Precision

SPINDLE-	N	HEAD DIAMETER		EXTRACTOR GROOVE		GAS SEAL		HEAD THICKNESS		TOTAL LENGTH	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation=	Mean	Standard Deviation	Mean	Standard Deviation
1	50	0.11	0.07	0.24	0.11	0.09	0.03	-0.09	0.06	-0.34	0.09
2	50	0.00	0.06	0.07	0.10	-0.23	0.13	0.05	0.16	-0.09	0.14
3	50	0.02	0.07	-0.04	0.12	-0.17	0.05	-0.65	0.14	0.15	0.13
4	50	0.06	0.10	0.00	0.10	0.06	0.07	-0.20	0.19	-0.07	0.14
5	50	0.06	0.11	0.22	0.13	-0.73	0.46	-0.25	0.07	0.27	0.12
6	50	-0.01	0.08	-0.06	0.12	0.00	0.02	-0.42	0.14	0.46	0.16
7	50	0.03	0.07	-0.08	0.12	-0.07	0.08	0.56	0.11	-0.42	0.22
8	50	-0.01	0.08	-0.10	0.10	0.11	0.11	-0.02	0.20	0.26	0.16
9	50	0.03	0.08	0.06	0.14	0.02	0.15	-0.01	0.06	-0.22	0.14
10	50	0.09	0.09	0.24	0.11	-0.02	0.19	-0.20	0.02	-0.17	0.15
11	50	0.13	0.11	0.11	0.10	0.06	0.07	-0.09	0.14	-0.00	0.05
12	50	0.15	0.12	0.09	0.10	-0.09	0.13	-0.48	0.09	-0.04	0.10
13	50	0.16	0.10	0.43	0.16	-0.23	0.07	0.02	0.32	-0.98	0.11
14	50	0.07	0.09	0.10	0.12	0.06	0.16	-0.14	0.15	-0.17	0.06
15	50	0.12	0.08	-0.00	0.15	0.27	0.11	-0.55	0.32	-0.47	0.15
16	50	0.14	0.09	0.03	0.14	0.22	0.15	0.43	0.11	0.12	0.08
17	50	0.18	0.08	0.33	0.13	0.14	0.02	0.40	0.06	0.20	0.02
18	50	0.17	0.07	0.03	0.13	0.09	0.13	0.21	0.06	0.05	0.08
19	50	0.05	0.09	-0.01	0.12	-0.20	0.14	-0.40	0.14	-0.02	0.19
20	50	0.18	0.08	0.10	0.11	-0.06	0.15	0.31	0.27	-0.04	0.08
21	50	0.19	0.09	0.18	0.16	0.31	0.08	0.33	0.12	-0.06	0.15
22	50	0.16	0.11	-0.01	0.17	0.07	0.09	0.48	0.24	0.08	0.05
23	50	0.13	0.09	-0.02	0.14	-0.23	0.10	-0.12	0.17	-0.17	0.09
24	50	0.24	0.06	0.09	0.11	-0.07	0.17	0.42	0.14	0.14	0.13
AVG:	1200	0.10	0.09	0.08	0.13	0.03	0.12	0.02	0.14	0.07	0.12
COMBINED AVG:		0.01	0.12

PROFILE MEASUREMENT

CARTRIDGE CASE PROFILE MONITOR

96

Table 1. CCMES 5X Computer Formats

Format	Frames
Overall Status	(1)
Total Reject	(1)
Segment Reject	(1)
Profile Defects	(1)
Eddy Current Defects	(1)
Flaw Defects	(1)
Profile Status (5 Parameters)	(5)
Operating Parameters	(1)
Snapshot Profile (Select 1 Parameter)	(1)
Sample Insert Data	(2)
QA Sample Data	(2)

17

PROFILE STATUS						05/03/77 11:45 SEG 00-00:27	
HEAD DIAMETER						NOM = 374.5 TOL = 3.5	
LINE	N	MEAN	MIN	MAX	STD DEV		
1	1524	- .5	- 6.8	4.1	1.3		
2	1523	- .8	- 4.7	3.5	1.3		
3	1380	- .7	- 4.1	3.1	1.4		
4	1510	- .6	- 3.6	3.5	1.3		
5	1419	- .6	- 4.8	3.6	1.3		
6	1295	- .7	- 11.4	3.1	1.4		
7	1436	- .8	- 5.8	3.2	1.4		
8	1292	- .6	- 5.1	3.1	1.3		
9	1376	- .6	- 4.7	3.1	1.3		
10	1194	- .7	- 4.7	3.7	1.3		
11	1405	- .5	- 5.4	3.3	1.3		
12	1234	- .6	- 4.5	3.8	1.3		
13	1519	- .6	- 5.1	3.6	1.2		
14	1519	- .5	- 6.2	3.7	1.3		
15	1290	- .5	- 4.4	2.8	1.3		
16	1514	- .5	- 5.3	3.4	1.2		
17	1423	- .7	- 9.3	3.4	1.3		
18	1309	- .7	- 3.9	3.3	1.3		
19	1502	- .6	- 4.1	3.6	1.3		
20	1306	- .7	- 8.4	3.1	1.4		
21	1379	- .6	- 4.4	3.3	1.3		
22	1471	- .7	- 3.9	3.2	1.2		
23	1395	- .6	- 4.6	3.7	1.3		
24	1237	- .6	- 4.4	3.7	1.3		

Fig. 2. Sample status format showing actual measurement on brass.

2

CCD
SIGNAL

← dark elements →

5
FB

(a)

(b)

(c)

b
b
F

VIDEO SEQUENCE DETECTOR

1
h
FS

Fig. 11. Hand gauges.

Fig. 12. Comparison of hand-gauged and CCMES measurements on brass cases.