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AN AUTOMATED SMALL CALIBER AMMUNITION CASE SURFACE FLAW INSPECTION SYSTEM

by

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AN AUTOMATED SMALL CALIBER AMMUNITION CASE SURFACE FLAW INSPECTION SYSTEM[a]

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INTRODUCTION

The Small Caliber Arms Modernization Program (SCAMP) of the Frankford Arsenal is developing the capability for production of small caliber ammunition continuously at high rates. Previously, manufacture was done by batch processes with manual inspection using sample data techniques. The goal of the modernization program is to automatically inspect every case that is produced.

Battelle-Northwest, under contract to Frankford Arsenal, has developed a prototype surface flaw inspection unit for the 5.56 mm cartridge case. This unit is capable of a variable case throughput inspection rate, up to 1200 cases/min. Surface flaws inspected include scratches, dents, scaling, folds and pits. This development effort has included a system for feeding and handling cases at these case throughputs, a computer-based inventory and process control system, optical flaw instrumentation, and process control instrumentation.

SYSTEM DESCRIPTION

The case surface flaw inspection system consists of three major components; mechanical handling, electro-optic instrumentation, and an on-line, real-time computer system. The cartridge case flaw monitor inspection specifications are:

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[a] This article summarizes work done by Battelle-Northwest for the U.S. Army, Frankford Arsenal, Philadelphia, Pennsylvania.

- 1200 Cases/Min Throughput Capability
- Noncontact Flaw Detection
- Continuous 100% Inspection of Each Case
- Flaws Correlated to Specific Cartridge Case Zones
- Video and Hardcopy Data Output
- Keyboard Control of Data Acquisition System Operation
- Computer-Controlled Removal of Unacceptable Cases
- Computer Monitoring of System Integrity
- Computer-Controlled Flaw Data Inventory

MECHANICAL HANDLING

The prototype cartridge flaw inspection unit in Figure 1 and associated accumulator mockup consists of (a) a method of storing approximately 6000 cartridge cases in the accumulator, (b) a means of sequentially retrieving the cases from the accumulator, (c) a transfer station to move the cases from a vertical orientation (mouth down) to a horizontal position (mouth forward), (d) machinery to rotate the cases at a high rate (up to 9000 rpm) while translating them through the inspection station, and (e) a method of discharging cases either into reject or acceptable storage.

The cases to be inspected are stored in the accumulator unit shown in Figure 2. The accumulator assembly rotates and drops cases into the transfer station. This feeds the cases to the inspection station where the electro-optic transducers are located. After the cases pass under the flaw monitor, the unacceptable cases are removed from the line and the computer verifies that the case is no longer on the conveyor belt. Other necessary process signals required for system timing and status are located on the inspection unit. Case throughput rates achieved with this system exceeded 1200 cases/min.

FIGURE 1. Prototype Cartridge Flaw Inspection Unit

FIGURE 2. Accumulator Hardware

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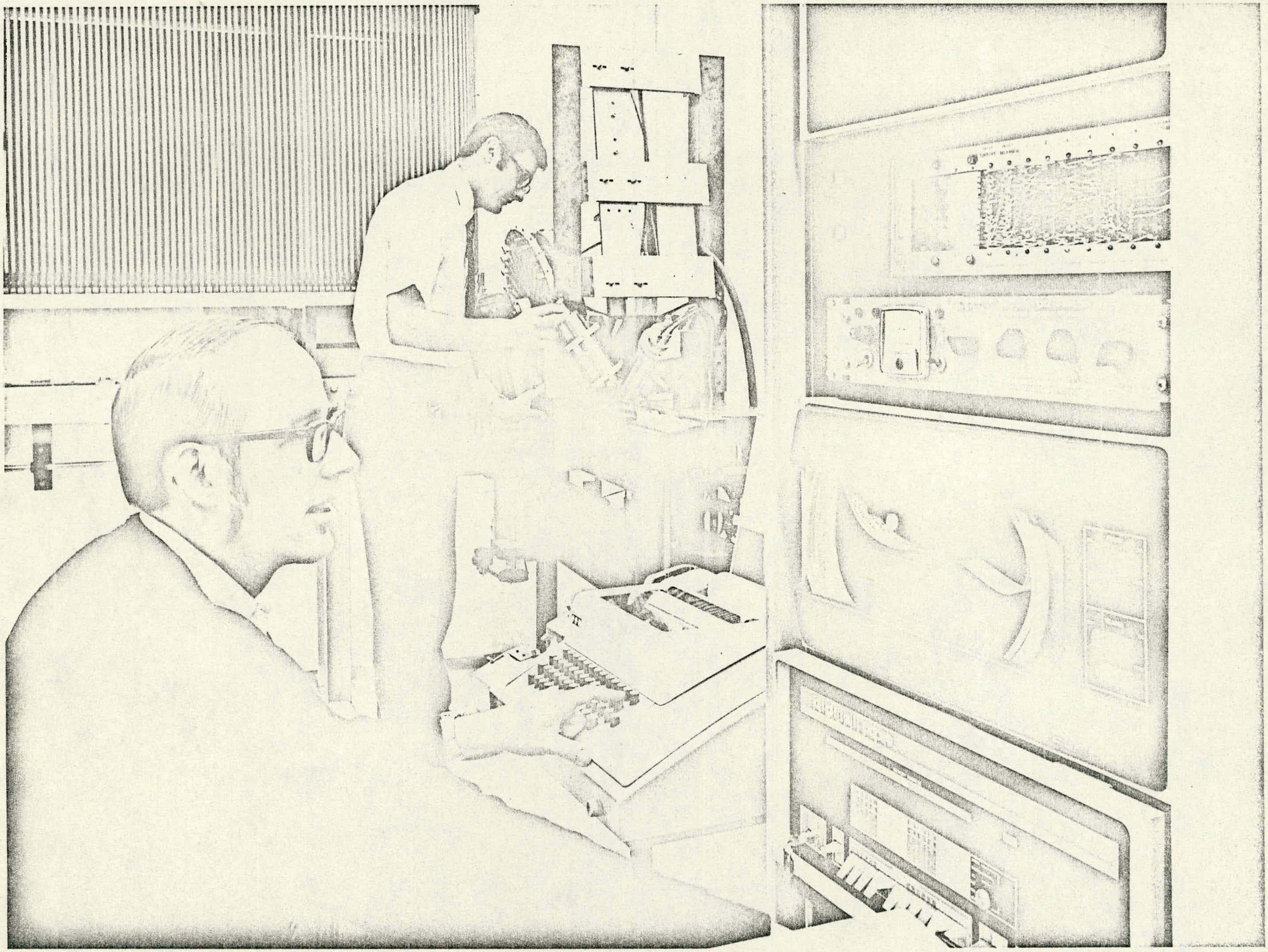

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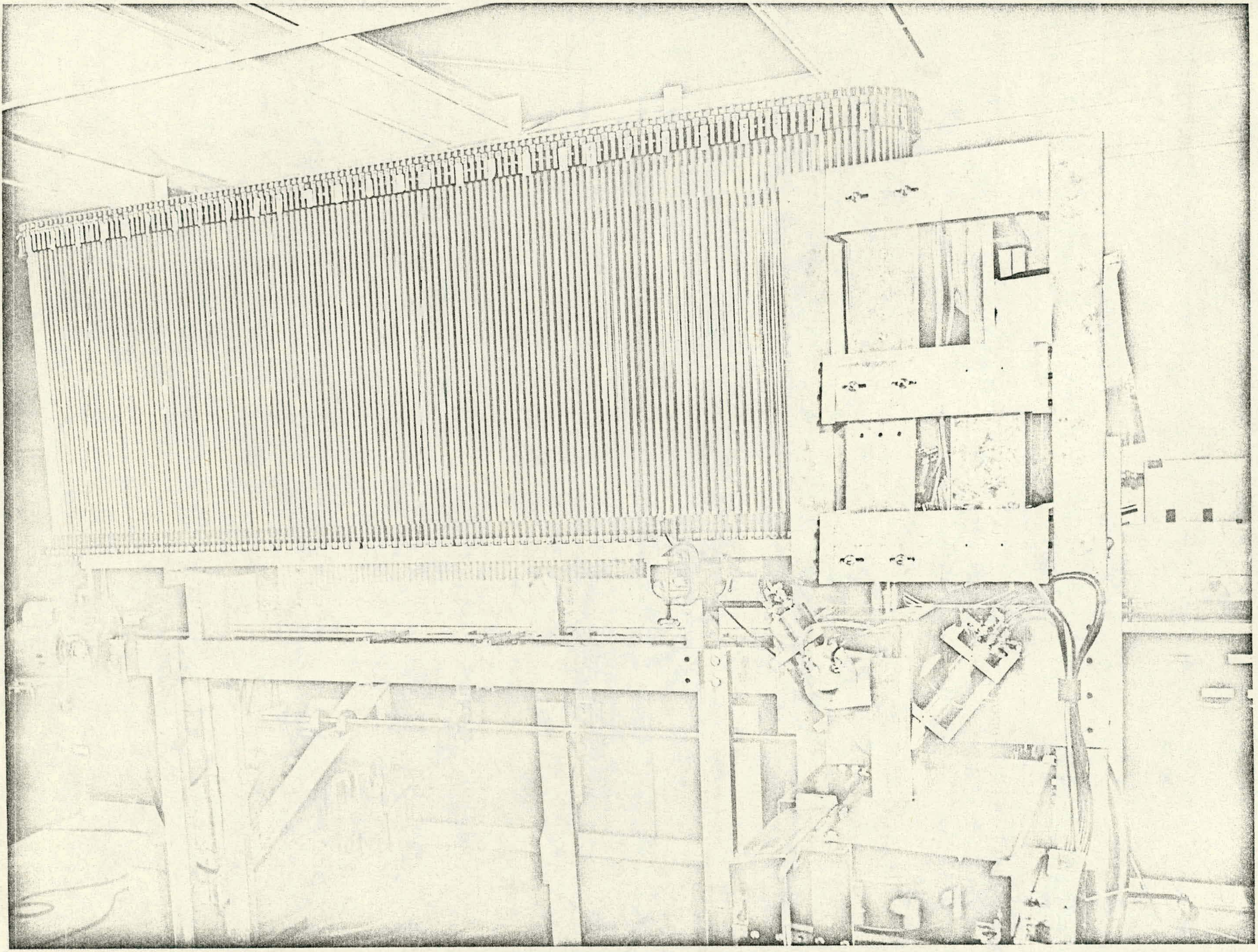

ELECTRO-OPTIC INSTRUMENTATION

Instrumentation was developed both to implement case surface flaw detection based on optical scattering and to support computer flaw data inventory and flawed case control. An initial feasibility study indicated that cartridge case surface flaws could be monitored using surface scattered light and electro-optic instrumentation. This static study was expanded into a dynamic instrumentation technique capable of high case throughputs (1200 cases/min). Successful optical instrumentation development requires trade-offs between optical and mechanical handling parameters. The result of the trade-off was the twin roller, translating ford concept and a multiple optical detector system as indicated in Figure 3.

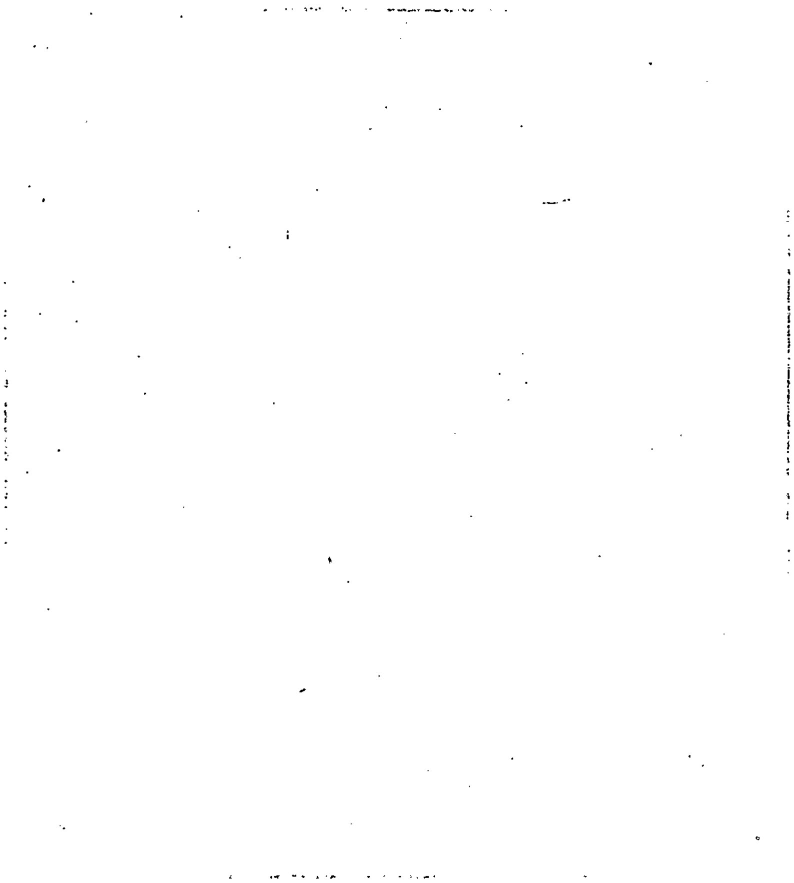

FIGURE 3. Flaw Monitor Station Optics

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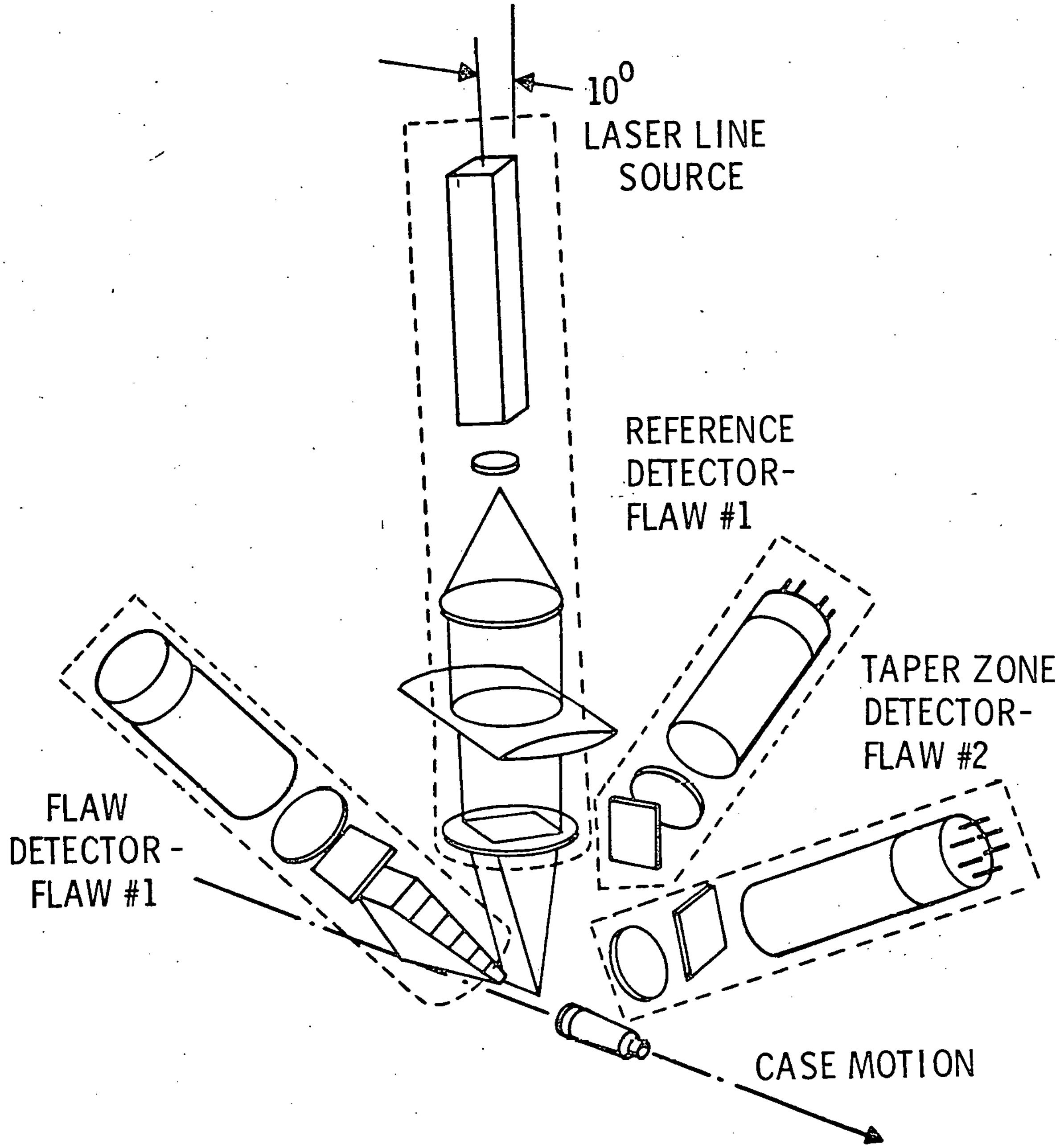
~~FLAW MONITOR STATION OPTICS~~



For optimum surface flaw detection (flaw scattered light to background scattered light ratio) the ideal illumination would be a point source focused on the case surface. However, the spiral case motion would result in flaw sampling only a spiral line on the case. With the line source, flaw signal-to-background ratio is sacrificed for total case inspection. In addition, each surface point may be illuminated more than one time resulting in multiple flaw detection.

As the case translates, it presents an irregular surface to the illuminating line source. Since the surface flaw scattered light intensity depends on the relative flaw size and illumination power density (Watts/unit area), the line source must have an adequate focal depth to provide uniform flaw detection at all points on the case. The 10° incidence angle was chosen to optimize light collection by the shaped aperture from all case surface points (case normals vary from +23° to -25° resulting in a wide scattered light solid angle). This incident beam is aligned on the case such that the specular and incident light beams are collinear with exception of the 10° tilt. This collinear beam axis bisects the angle formed by the two Flaw #1 detectors.

The initial flaw instrumentation did not include the Flaw #2 detector. As the instrumentation effort proceeded it was noted that flaws on the case neck region, specifically wrinkle flaws, were extremely difficult to detect with the Flaw #1 system. Experimentally it was noted that neck region wrinkle flaws (very small surface perturbation) could only be frequency differentiated, therefore, the Flaw #2 system was added to the flaw monitor station.

Experimentation with a single detector (Figure 3 optical configuration) indicated that the detector signal contained an envelope resulting from the line source and case motion interaction. This envelope made simple signal level triggering for flaw indication almost impossible (Figure 4). Flaws on the neck and extractor region would be hidden by the main signal envelope. Since the flaw and reference detectors observe similar scattering patterns, signal subtraction may be used to remove the background envelope and enhance the surface flaw signal. The reference and flaw detectors are positioned symmetrically about the specular and incident beam axis. As a flawed case rotates in the inspection zone, a surface flaw scatters light sequentially to the flaw and reference detectors and the flaw signals of the two detectors are time shifted. Because of this time differential, flaw signal enhancement results when the two detector outputs are subtracted. Conventional voltage comparison techniques may then be applied to the differential signal for flaw detection.

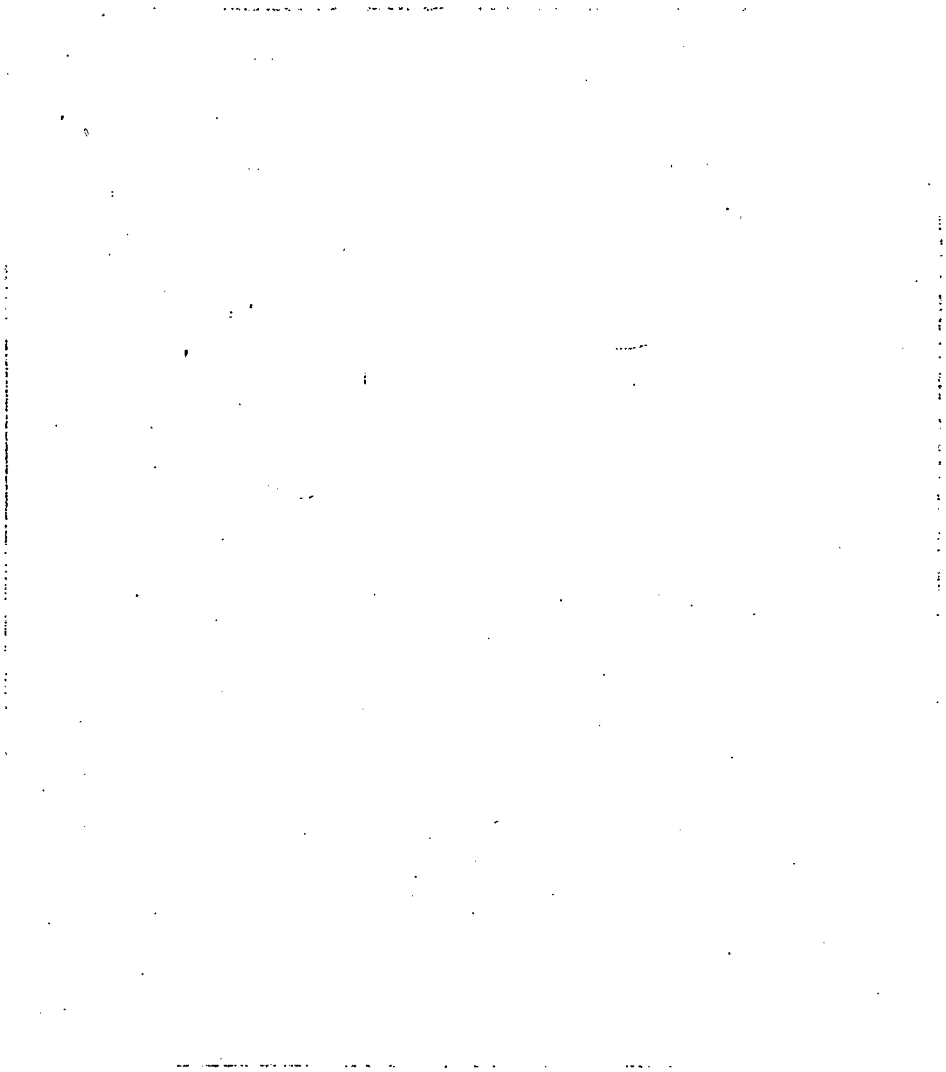


FIGURE 4. 5.56 mm Case Zones, Reference and Flaw Detector Waveform Envelope

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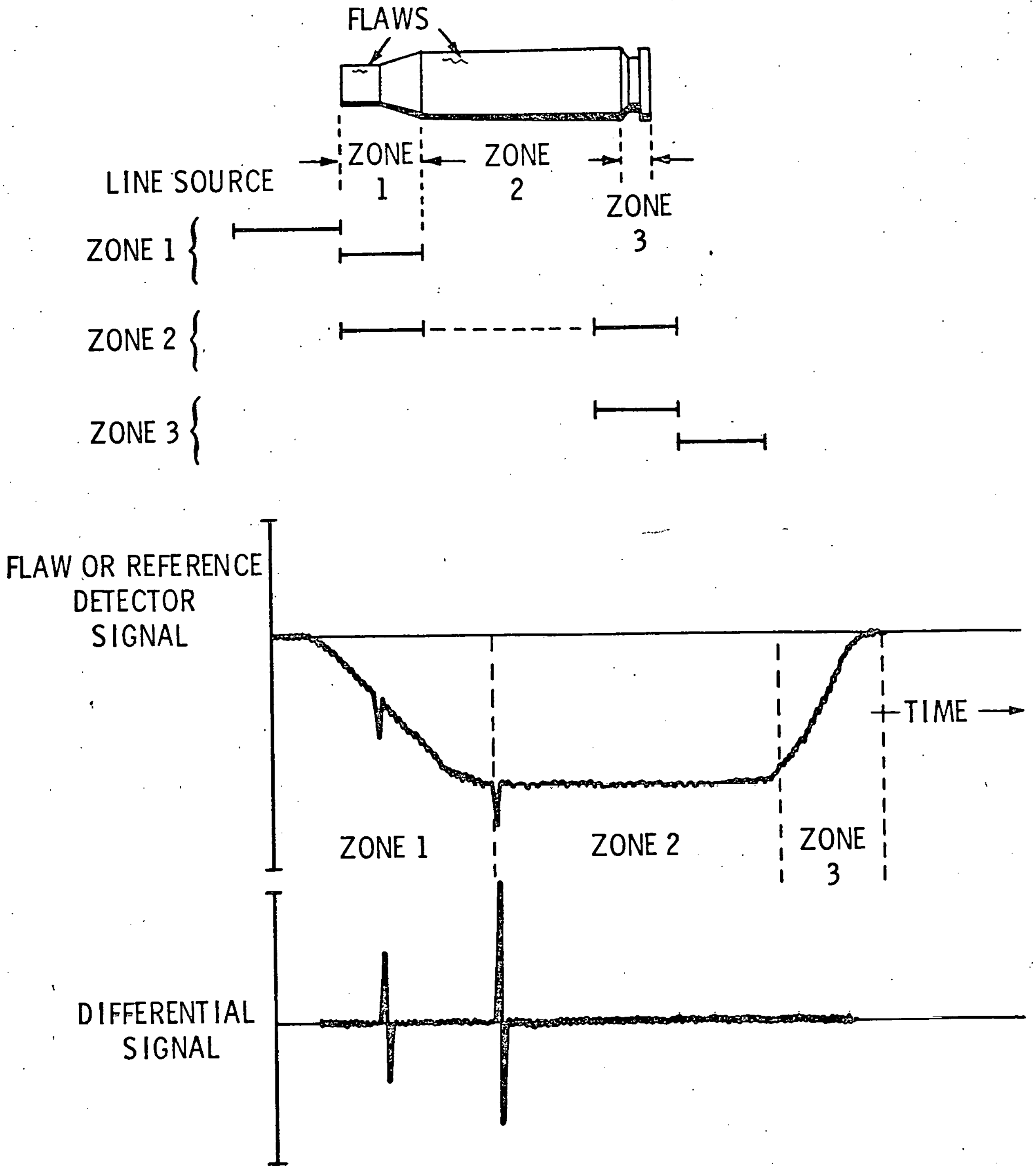
~~FLAW DETECTOR SIGNAL PROCESSING~~



The Flaw #2 detector also views only scattered light by utilizing the aperture filter as indicated in Figure 3. The center of the aperture is coincident with the neck region specular reflected light. The collecting lens raises the photomultiplier efficiency and reduces space problems in the inspection zone. When the air hold-down assembly is placed in the inspection zone, part of the neck scattered light is blocked by the air hold-down tube. This does not affect the flaw detection capability of this detector, since scattered light from only one side of the spatial block is sufficient to convey flaw information to the photomultiplier tube.

To enhance flaw detection and provide a data correlation means between flaw inventory and the case forming processes, the case was divided into three zones as indicated in Figure 4. Zone 1 is defined as the region between the case mouth and main body. The main case body is Zone 2, and Zone 3 includes the case extractor region. Positions of the line source and case intersection are shown for each defined case zone. It was determined experimentally that although three case zones can be defined, only two detection sensitivities are required to indicate all major case flaws. It was also determined that because of the necessity of detecting bent mouths, which are low profile surface deviations, Zone 1 sensitivity should be greater than Zone 2 or 3. Zone 2 or Zone 3 flaws of this magnitude are not considered critical (MIL-STD-636) and should pass through undetected. In addition, Zone 2 picks up surface nicks and scratches caused by the tumbling sequence in batch manufacturing. Thus, detection sensitivity must be reduced to compensate for this increased optical scattering background.

COMPUTER SYSTEM

The Data Acquisition and Control system is centered around a Digital Equipment Corporation PDP-8/e minicomputer. The computer system is configured as follows:

- PDP-8/e which has an 8192 Word Memory (12 Bit Words)
- Real Time Clock
- Power Fail-Auto Restart

- ASR-33 Teletypewriter
- High Speed Paper Tape Reader/Punch
- Datapoint 3300 Video Display Terminal and Keyboard

A block diagram of the case flaw detection system electronics is shown in Figure 5. The process input signals are:

- Fork Synchronize
- Fork Present
- Case Zones 1, 2, and 3
- Case Present
- Count of 24 Synchronize
- Case Reject Confirmation
- Flaw
- Status Signals (e.g., Laser Malfunction).

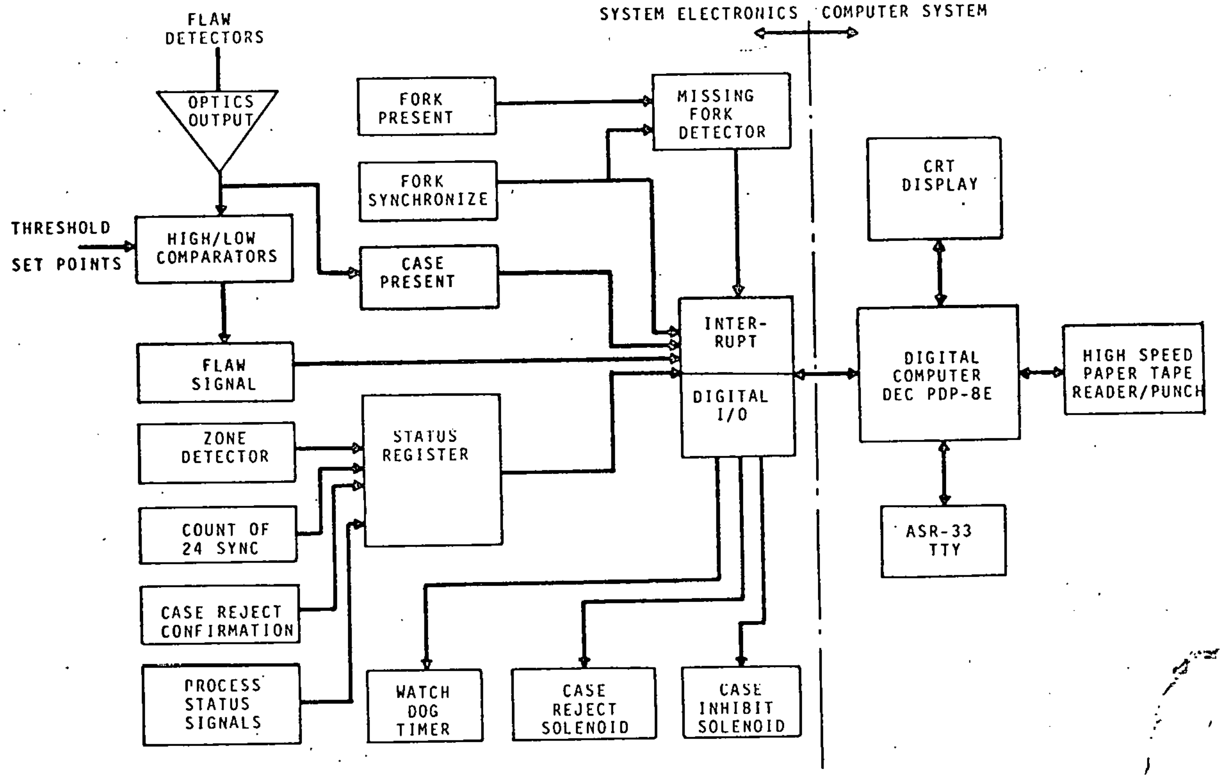


FIGURE 5. Block Diagram, Case Flaw Detection System Electronics

Interface logic was designed to condition and synchronize process signals into computer compatible inputs. The interrupt and skip facilities of the PDP-8/e are used for control of all input/output operations.

Computer output signals include the following:

- Flawed Case Reject
- Case Inhibit Reject
- Watch Dog Timer

The FLAWED CASE REJECT signal is based upon computer logic which has detected and processed a flaw signal six fork positions prior to the reject station. The flaw reject input/output transfer (IOT) instruction generates a pulse which is stretched to 37 msec using a one-shot. This pulse controls a solid-state relay which gates off the 115 VAC power to an air valve solenoid. This air valve is fail-safe, i.e., if power is lost, the solenoid is de-energized and opens the valve which causes air to reject all cases.

The computer controls the removal of a case from the transfer star wheel prior to its movement onto the conveyor where a fork is missing due to mechanical malfunction. If the case were dropped onto the conveyor, it would result in two cases being pushed by one fork which would result in erroneous flaw measurement and case rejection due to incorrect case position on the conveyor. The CASE INHIBIT signal is based upon MISSING FORK computer logic. It is output two fork positions prior to the position where the fork would normally push the case down the conveyor. The CASE INHIBIT instruction generates a pulse which is stretched to drive a solid-state relay which gates off the 115 VAC air valve solenoid. This valve is also fail-safe.

The WATCH DOG TIMER is a computer-controlled circuit which enables the operator to know if the central processing unit has inadvertently "hung up." This could be the result of hardware malfunction, modified software (e.g., jump self), or an externally caused halt. Because the system is to operate in a noisy environment, a light was chosen as the enunciator. When the light comes ON, the operator knows that the computer is no longer accepting

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data or controlling the process. Under this condition, the fail-safe system design will result in the removal of all cases from the measurement station. The watch dog timer works by the computer issuing an IOT instruction each clock interrupt (20 msec). This pulses an integrating one-shot that has timing components which alarm if not pulsed within 100 msec. Thus, in normal operation, the one-shot will never reset.

SOFTWARE

The software for the case surface flaw inspection unit is a real time data acquisition and control system. The data are acquired as process events occur, and the rejection of the flawed cases is done as the result of decisions made from the analysis of the acquired data from the cases being tested.

The start-up execution of the program begins with extensive initialization that sets pointers, flags, and data files to their respective initial values. When the initialization is completed, the interrupts are enabled and activated and program control passes to the executive monitor. Figure 6 shows a graphical representation of program control and data transfer. The assembly language control program occupies 4096 words of core memory.

The executive monitor operates by examining software flags to determine if:

- There are any flaw data sets to process
- There is a request to initiate a display on the video terminal or teletype
- There is a display in progress that needs the next line of data formatted and the printing reinitiated
- The flaw count data files have been requested to be initialized to zero.

The monitor continually examines these flags in a sequential manner; and if a flag is found to be set, the monitor passes program control to the subroutine which services that flag request.

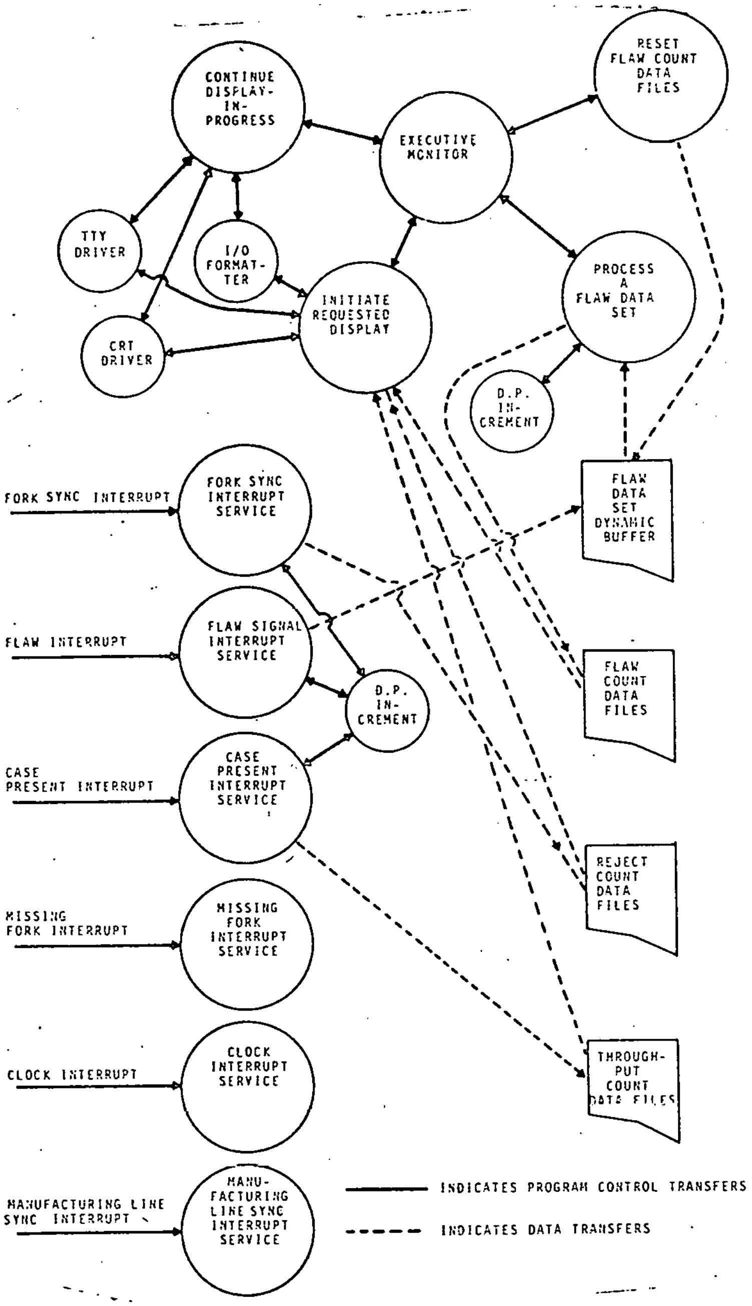

FIGURE 6. Program Control and Data Transfer Map

The data are acquired by responding to interrupt signals from the flaw test station as previously described. The acquisition of the data is interdependent, i.e., each test parameter is dependent upon other system conditions being met. Thus, abnormal test conditions are detected; and decisions are made as to the disposition of the test data and whether or not to reject the case in the test station. For example, if a flaw signal is received in a position where a fork is missing, the data are ignored.

A flaw data set is saved for flaw data processing when a flaw is recognized in a zone of a case. A flaw data set contains the case zone in which the flaw was detected. The flaw counter is incremented for the flaw zone and manufacturing line designated by the flaw data set. Also, the "total flaws" counter is incremented for the designated manufacturing line.

The "total system reject" counter and the respective "manufacturing line reject" counter are incremented when the fork synchronize interrupt service routine recognizes that the case just inspected does contain flaws and is to be rejected. The counter for the "cases rejected due to missing forks" is incremented when the belt position with the missing fork passes through the flaw detection station.

DATA OUTPUT

The display of the contents of the flaw data files on the video display is initiated automatically every 30 sec by request from the real time clock. Operator communication with the system is through the teletype keyboard. One of six output commands may be given plus time initialization, clearing flaw data buffers to zero, and deletion of an incomplete or erroneous command. One of the three video formats available is shown in Figure 7. Time is represented in military format as the day of year, hour, and minute. The first column lists the 1 through 24 manufacturing line numbers which the reject data are normalized to; the second, third and fourth columns represent the number of flaws in Zones 1, 2 and 3 respectively; and the last column represents the total case flaws in each line. Regular operator requests are inhibited during teletype printout. However, in urgent conditions, the teletype printout can be aborted after which operator requests can be made. This method insures that a hardcopy of all operator/system communication is maintained. Summary process data hardcopy output is shown in Figure 8. Belt speed is represented in cases per minute. Other units are self explanatory.

FIGURE 7. Video Display of Flaw Data Files

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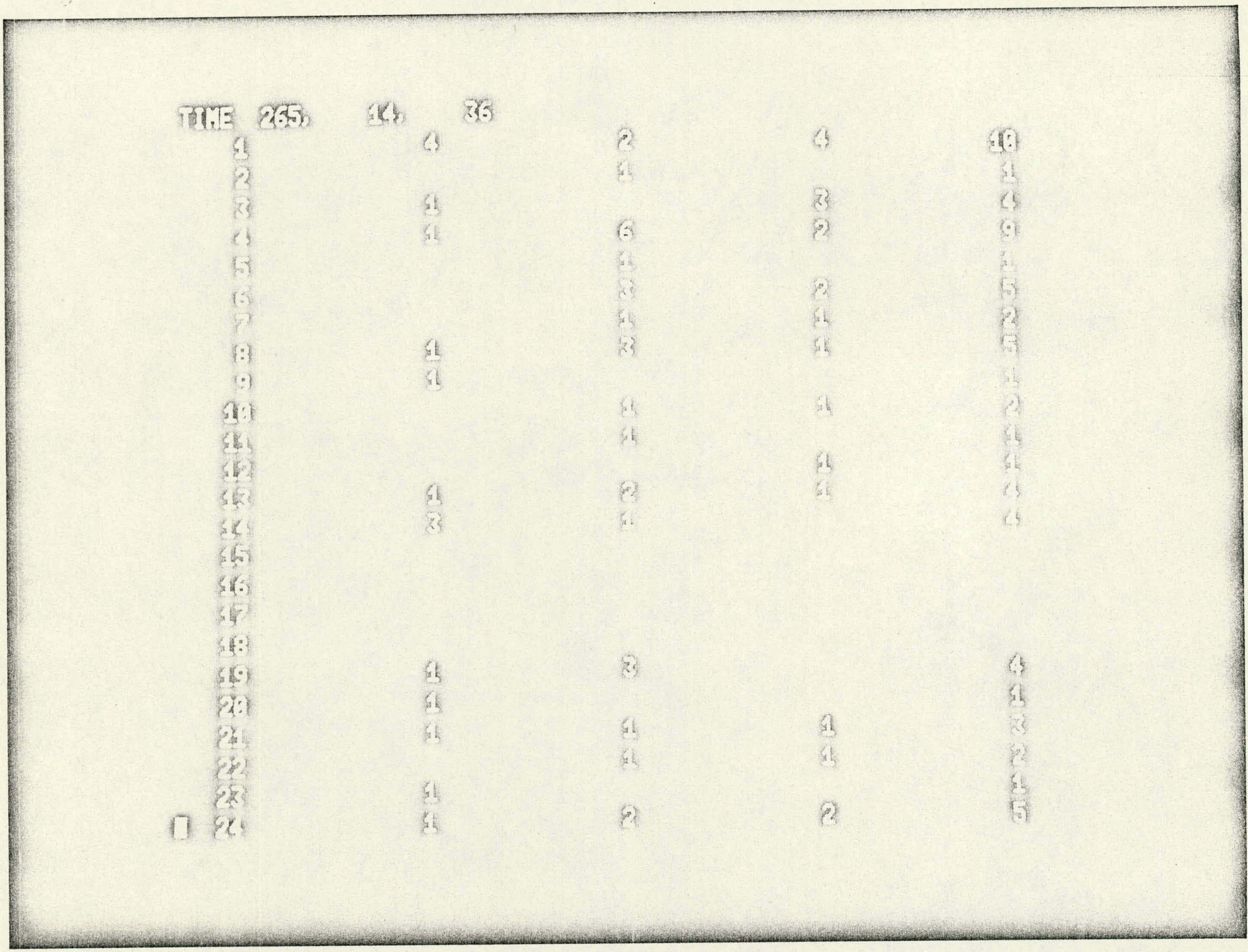

```
TIME  265,    14,     36
    1         4           2           4          10
    2                     1                       1
    3         1                       3           4
    4         1           6           2           9
    5                     1                       1
    6                     3           2           5
    7                     1           1           2
    8         1           3           1           5
    9         1                                   1
   10                     1           1           2
   11                     1                       1
   12                                 1           1
   13         1           2           1           4
   14         3           1                       4
   15
   16
   17
   18
   19         1           3                       4
   20         1                                   1
   21         1           1           1           3
   22                     1           1           2
   23         1                                   1
█  24         1           2           2           5
```

```
                    FORMAT F2T OUTPUT

TIME 265,   16,   16
TOTAL THROUGHPUT:         1671      TOTAL REJECT:    49
BELT SPEED:   602
MISSING PINS  ON BELT:       1
CASES EJECTED DUE TO MISSING PINS:      9
FLAWED CASES NOT REJECTED:        1
ACCEPTABLE CASES REJECTED:        1
```

FIGURE 8. Hardcopy Output of Summary Process Data

CONCLUSIONS

This development program has demonstrated that an automatic surface flaw monitor can perform "in process" quality control measurements of 5.56 mm cartridge cases at high speeds. The detection of surface flaws using scattered laser light has been demonstrated to provide the necessary sensitivity, speed and noncontacting characteristics for this manufacturing process as well as detecting surface flaws on complex surfaces. A dedicated computer is necessary to acquire data on-line in real time and provide rapid data output in a form suitable for process operator decision making. The multi-disciplinary team effort approach to a complex development program has proven beneficial in achieving the "total system" for this surface flaw monitor.