AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

Automated Surface Flaw Inspection

Kansas City Division

J. B. Van Sooy

KCP-613-5272

Published April 1994

Final Report

Approved for public release; distribution is unlimited.

Prepared Under Contract Number DE-ACO4-76-DP00613 for the
United States Department of Energy

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Printed in the United States of America.

This report has been reproduced from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P. O. Box 62, Oak Ridge, Tennessee 37831; prices available from (615) 576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Rd., Springfield, Virginia 22161.

A prime contractor with the United States
Department of Energy under Contract Number
DE-ACO4-76-DP00613.

AlliedSignal Inc.
Kansas City Division
P.O. Box 419159
Kansas City, Missouri
64141-6159

MASTER

KCP-613-5272
Distribution Category UC-706

Approved for public release; distribution is unlimited.

AUTOMATED SURFACE FLAW INSPECTION

J. B. Van Sooy

Published April 1994

Final Report

J. B. Van Sooy, Project Leader

Technical Communications
Kansas City Division

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

gtd

Contents

<i>Section</i>	<i>Page</i>
Abstract	5
Summary	5
Discussion	7
Scope and Purpose	7
Activity	7
Accomplishments	8
Appendices	
A. Subcontractor’s Feasibility Study of Automatic Surface Flaw Detection	9

Abstract

A study was conducted by Battelle Pacific Northwest Laboratories (PNL) to evaluate the feasibility of automating surface flaw inspection for squib valve housings manufactured at AlliedSignal Inc., Kansas City Division (KCD). A borescope/video camera system was developed that was at least equal to the current KCD method in sensitivity to surface flaws. However, the images from this system were not found to be of high enough quality to allow automatic video processing for product acceptance. PNL proposed a three-phase process to further develop automation of this inspection, with the final result being either a partially or fully automated system, depending on the success of the image refinement and software development.

Summary

PNL was contracted to study the feasibility of developing an automated inspection system to detect scratches and surface flaws in squib valve housings. Ideally, the system would sort defect-free surfaces from surfaces that require additional evaluation, resulting in a significant inspection time savings. A secondary benefit from such a system would be an increase in the uniformity of surface flaw inspection techniques.

A borescope/video camera system was developed to scrutinize valve housing critical surfaces. This system lends itself to automation more readily than the current KCD microscope method, and the image from this system was found to be at least equal to the microscope in sensitivity to surface flaws.

To fully automate inspection of these surfaces for flaws, automatic video processing was proposed to determine the presence and severity of flaws on the critical surfaces. At the time of the study, the image from the video system was not of high enough quality to be compatible with the available flaw detection software.

PNL proposed a three-phase ongoing continuation of this program that would include the development of an elaborate fixturing and automated handling system, enhancement of the video image, identification of the best available image processing software, and test and documentation of the finished system. No further activity was authorized, however, because of cost and valve housing schedule factors.

Discussion

Scope and Purpose

Evaluation of valve housing critical surfaces for flaws was identified as a candidate for process improvement because of the tedious nature of manually screening these surfaces. It was felt that an automated system could provide significant improvements in inspection cycle time and also provide increased uniformity in the performance and output of this inspection process.

The process for evaluating flaws in valve housing critical surfaces requires the inspector or machine operator to judge the depth of the flaw by attempting to feel the flaw with a sharpened toothpick. Although this toothpick method is required by the product drawings, it is a somewhat arbitrary requirement meant to provide a very high degree of confidence in the product being accepted while at the same time being manufacturable. The new system was conceived as one that would only identify possible defects, with manual disposition being required on questionable parts. Because valve housings generally have a low incidence of critical surfaces with flaws that require manual disposition, an automatic system to identify questionable surfaces would be a useful tool.

Activity

A contract was initiated with Battelle Pacific Northwest Laboratories (PNL) to conduct a feasibility study for the automatic inspection of valve housings to detect scratches in valve seats. The study resulted in two conclusions:

1. The flaws could be detected by using a scanning approach, in which a borescope probe is moved in and out of the part while the part is rotated. The image from the borescope would be displayed on a video screen through a video camera mounted on the borescope.
2. Glare from the borescope light source made it difficult for the video processing flaw detection equipment to detect flaws in the surface. Methods, such as polarizing the light, diffusing the light, etc., were investigated to eliminate the glare problem, but these were unsuccessful.

Based on the results of the feasibility study, PNL proposed a three-phase program to develop an automated inspection system for valve housings. The proposed program was broken down as follows:

Phase I -- Design and fabricate the valve housing staging fixture and design the control system architecture to facilitate either fully or semiautomatic flaw detection, dependent upon the success of the image enhancement effort. Also conducted during this phase would be the image enhancement effort. This effort would consist of investigating methods of improving the raw image quality by further experimentation with the borescope light source and by contacting commercial image processing software manufacturers to attempt to find a better method to process the borescope images. An informal project review was also

proposed at the end of Phase I. The Phase I estimated cost was \$278,974.

Phase II -- Develop and demonstrate a system that would automatically determine the position of flaws. The Phase II estimated cost was \$90,884.

Phase III -- Document system configuration with operating instructions, system and detail drawings, and manufacturer's literature. System shipment and on-site demonstration would also occur during Phase III. The Phase III estimated cost was \$81,592.

PNL's final report on the feasibility study is included for reference as Appendix A.

Accomplishments

The borescope/video camera system was found to be a viable alternative to the microscope method of identifying surface flaws. It was discovered that currently available automated systems could not reliably identify flaws, even at a somewhat crude threshold required for sorting for manual disposition.

Because of the limited possibilities found for a system of this nature and because the reduced production schedules for valve housings reduce the positive effects realized through funding of this project, activity was discontinued after the feasibility study was completed.

Appendix A

Subcontractor's Feasibility Study of Automatic Surface Flaw Detection

Pacific Northwest Laboratories
Battelle Boulevard
P.O. Box 999
Richland, Washington 99352
Telephone (509) 375-2101

September 21, 1990

Mr. John Van Sooy
Allied-Signal Aerospace Company
Kansas City Division
P.O. Box 419159
Kansas City MO 64141-6159

Dear Mr. Van Sooy:

Subject: Final Letter Report
Feasibility of Automated Inspection of Valve Housings
ASAC Project Number DE-AC04-DP00613, PNL Project Number 17586

INTRODUCTION

The Pacific Northwest Laboratory (PNL) has conducted a study for Allied-Signal Aerospace Company (ASAC) to determine the feasibility of automatically inspecting valve housings to locate scratch defects. Scratches in the inside surface of the valves housings result in their malfunction. Presently, these housings are inspected manually under a microscope, which is a tedious task. The purpose of this project was to determine if the housings could be inspected automatically so parts without defects would be screened so they would not have to be inspected manually. Final inspection of defects by ASAC will continue to be performed manually, but from the output of the automatic inspection system, the inspector would know the location of the flaws. This method would reduce inspector fatigue and labor. The approach examined in this project was to use a borescope to image the internal surfaces of the valve housings to a video camera mounted on the borescope. Any scratches in the housing surfaces will be detected using video image processing. The main areas examined in this feasibility study were to determine if the scratches could be seen in the valve housings using the borescope approach, to examine methods to achieve high contrast between the flaws and the nominal surface, and to perform video processing of the image to determine the problems that would be encountered in automating this inspection process.

A sleeve containing a mirror could be slipped over this probe. This increased the diameter of the probe to 3.5 mm. One sleeve contained a 45 degree mirror, so that a surface area parallel to the length of the probe could be viewed. For these tests, this was known as the 90 degree probe. This probe allowed the inspector to scan the inside surface of the valve housing. However, because the input light is illuminating the surface at the same angle as it is being viewed, a high amount of reflected glare would be expected from this probe, especially on straight walls in the housing. The disadvantage of this probe is that counterbore areas would be hard to inspect, because the area would be parallel to the illuminating light and would be viewed edge-on by the video camera.

A second sleeve was also used that contained a mirror so that an area 65 degrees from the axis of the basic borescope probe could be viewed. This was known as the forward oblique probe. The advantage of the forward oblique probe is that it was forward looking, so that flat areas (counterbores) in the valve housing perpendicular to the length of the probe could be inspected. The other advantage of the forward oblique probe was that on a straight wall, the light would not reflect directly back to the video camera, causing less glare in the image. The disadvantage of the forward oblique probe was that some distortion would be expected in the image.

Field-of-View

One of the first tests performed in this project was to determine the field-of-view of each of these probes. A ruler was positioned a known distance from the probe, and the number of marks that could be read on the ruler were recorded. The results indicate that the total field-of-view for the straight probe was 38 degrees; for the 90 degree probe it was 44 degrees; and for the forward oblique probe it was 48 degrees. The difference in the fields-of-view of the three probes is due to the different entrance apertures. No distortion of the image was noticed in the straight-through or 90 degree probe; but for the forward oblique probe, the distance between the lines on the ruler was 1.5 times greater at the bottom of the image than on the top of the ruler. As shown later in the test results, the actual illuminated field of the image is smaller than these values.

Detection of Defects

Table 1 lists the flaws in the three ASAC supplied parts. Drawings, not included in this report, were supplied by the sponsor to help locate the defects. Not all of the scratches listed in Table 1 were rejectable defects, and besides these defects, scratches and marks not listed in Table 1 were detected with the borescope system in this study. As shown in Figure 4, only the large scratches could be detected with the straight-through probe. However, as also shown in Figure 4, no scratches could be detected with the straight-through probe on some of the parts because the angle of the area that was to be inspected (25 degrees) reflected the light away from the probe and

so it appeared dark on the video image. Thus, it would appear that the straight-through probe could not be used for this inspection process. This was unfortunate because if this probe could be used, there would not be a need to scan the part (0,z) in order to detect the flaws. The probe could be placed at the top of the area to be inspected, and one video image would be analyzed for flaws.

The scanning approach would involve using the forward oblique or 90 degree probes to move in and out of the part as the part, or the borescope, was rotated. Early testing quickly indicated that it would not be practical to rotate the borescope sleeve rather than the part. As shown in Figure 5, when only the sleeve is rotated, the illuminated area in the image also rotates, and this would make video processing of the image very difficult to perform. This occurred because when only the sleeve on the borescope is rotated in the part, the image moves on the detector in the camera, causing the area to be analyzed in the image to move. Also, the direction of the valve axis rotates on the monitor screen. Thus, either the part needs to rotate; or the camera, with the borescope probe attached to it, must rotate as one unit.

The scratches generally appeared as a dark lines in the image, as shown in Figure 5. Using the 90 degree probe generally resulted in a bright circular light pattern appearing in the image, as shown in Figure 6. This occurred because the light is projected from the probe through a series of fibers that form a circle around the outer edge of the probe. The inner core of the fiber bundle is used to return the image to the video camera. Because of the short distance between the probe and the wall of the valve housing, the light does not have enough space to adequately diffuse, and because the incident angle of the illuminated beam was near zero degrees, the circle of light is seen on the inside wall of the housing. Generally, this pattern was not seen with the forward oblique probe because the light from the wall is reflected away from the probe. The only place where the circle of light is seen with the forward oblique probe was when the angle of the inside surface being inspected was approximately 25 degrees, as also shown in Figure 6. This occurred because the image is being projected at a 65 degree angle and the incident beam is orthogonal to the surface.

The light pattern that was seen by the probe varied depending upon the angle of the inside surface and the distance the probe was from the surface. Figure 7 shows some of the scratches and light patterns that were observed in the different parts. More scratches were observed using the borescope approach than are listed in Table 1, or observed using the microscope at ASAC. A line in the image sometimes appears where the angle of the inside surface changes. This is also shown in Figure 7. Generally, the scratches were parallel to the valve hole axis and the borescope was set-up to that these were viewed as vertical lines on the monitor. When the borescope was set-up in this manner, the lines indicating a change in the surface angle were horizontal. As shown in Figure 7, the image contrast for the change in surface angle and a defect were very similar.

Based on this test, it was then attempted to block out some of the input fibers so that a slit of light is projected onto the inside surfaces of the valve housings. A great amount of input light was lost in the process, with not much improvement in the contrast between the flaw and the nominal wall.

Another method that was tested to minimize the glare in the image was to fabricate an aperture stop at the exit aperture of the sleeve on the borescope probe. The stop was made of a diffusing plastic material, so that the input light would be diffused as it went through it. A hole was fabricated in the aperture stop to allow the image of the surface to be transmitted to the borescope unaffected. Because the hole in the aperture stop had to be small, this arrangement greatly decreased the area that could be examined. In addition, the amount of light reaching the inside surface of the valve housing was greatly lowered. Thus, this arrangement was judged impractical. It could only be done if the aperture stop could be attached to the borescope probe before it is reflected from the mirror in the forward oblique and 90 degree probe. This would be a difficult part to fabricate that would be beyond the scope of this project.

VIDEO PROCESSING OF IMAGES

The borescope images from the three valve samples indicate good contrast between the larger defects and their background when the lighting and borescope positioning can be optimized at each defect. However, in some cases, different parts, or even different areas of the same part, required a re-optimization of examination conditions to identify different degrees or types of defects. To fabricate a flexible automated system to inspect a variety of parts, it is desirable to have a fixed lighting and positioning scheme to minimize the amount of setup required for each part. Given the degree of image variations from the three samples, image processing is a viable approach to attempt to normalize these contrast variables for a constant inspection configuration.

A general-purpose image processing system was used to investigate what requirements an image analysis system might need so that defects could be automatically detected. A Macintosh II computer, with a Data Translation QuickCapture frame grabber board and Automatix Image Analyst image processing and analysis software, was used for this evaluation. A video tape was made of several of the flaw conditions that were observed in these three parts. Various image processing techniques were then used to examine the borescope images from the valve inspection mock-up.

For the inside diameters of the housings, we assumed all the significant defects would be scratches having a long, narrow shape, oriented more or less parallel to the bore of each hole. The borescope was positioned with respect to the valve to provide images with the bore wall aligned vertically with respect to the video image. The flaw detection scheme was to identify a

These were simplified attempts to use a specific general-purpose image analysis software package to determine how some of the borescope images obtained might be processed for automated inspection. Successful image analysis relies on having good contrast between the object of interest and its background in the original images. Whenever the contrast of the defect to background is sufficient, flaw detection can be suitably implemented. However, the contrast of the images obtained with the borescope have a certain degree of gray scale shading and background clutter that made it difficult to reliably make the defects identifiable when scanning over a variety of part surfaces. The images we have thus far obtained from our three samples have not shown to be of high enough contrast to guarantee a defect can always be identified automatically, or that the number of false defects will not be objectionable, using image processing software.

A search among the many image processing vendors available may reveal a more suitable imaging analysis system that can be incorporated into our system with desirable results. The system should be able to enhance image contrast; associate pixels of similar gray levels; individually isolate those with long, narrow characteristics of sufficient length; and/or determine how well an edge or line can be defined within a region of interest.

INSPECTION SPEED

One of the questions that needs to be examined if this process were to be automated is the time it will take to inspect a surface. As discussed previously, this is dependent on the field of view of the borescope and the region of interest that can be reliably examined in the video processing technique. During the testing, it was determined that the field of view of the probe in a 6.147 mm diameter hole was 32 degrees vertically and 17.6 degrees horizontally. If we assume that the hole is 5 mm deep and that we will want to overlap the region of interest by 50% (so that a defect area would be seen at least twice on any horizontal plane), then it will take approximately 3,300 frames to scan this bore. If the images could be processed at 30 frames per second, then it will take approximately two minutes to inspect this size of surface. Additional time will be required to load and unload the part from the fixture.

CONCLUSIONS

- The borescope approach is a viable method for inspecting the valve housings for defects. All of the defects that were identified in the parts were detected, as well as scratches that were not observed by the present method of observing the parts under a microscope.
- The best images occurred using the forward oblique probe on the borescope. Less glare occurred in the image, and flat counterbore area could be inspected.

- The second parallel activity in Phase I will be to continue to look into methods to automate the inspection process by examining more sophisticated methods for diffusing the light from the borescope and using commercially available software to process the image.

Phase II

- If a better method is found in Phase I for diffusing the light or processing the images, then the work will continue into Phase II for automating the inspection process.
- If a better method for diffusing the light or processing the images is not found, then PNL recommends skipping Phase II.

Phase III

- The fixture developed in Phase I and associated documentation for operating the system will be delivered. If Phase II is implemented, the system will automatically detect defect areas. If Phase II is not implemented, the system will automatically display the images of the inside surface of the valve housing, which will aid the manual inspection of the valve housings.

By performing this type of program, ASAC can be assured that at the end of the program, they will at least have a system that will improve their present inspection process, although it may not be as automatic as originally desired.

**DATE
FILMED**

8/25/94

END