

A Non-Contact High-Speed Inspection System for Ink Jet Print Head Nozzles

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Abstract

Ink jet nozzle plate production includes inspection of each nozzle for morphological defects such as nicks, cuts, or blockages. Defective nozzles will result in compromised print quality. Once nozzle plates are integrated into the print head assembly, print testing can be used to verify head performance. However, inspection of the nozzles themselves earlier in the production process will decrease the number of print head failures. 100% inspection of nozzle plates is time consuming and it requires specialized inspection equipment and processes, but is the only guarantee of part quality.

Inspection of ink jet print head nozzles requires high-speed, automated processes to support production volumes. Challenges such as illumination, depth of focus, part orientation, and image capture speed have resulted in falsely inflated part rejection rates when traditional inspection systems are used. To minimize false rejection rates and to minimize the amount of operator intervention required for manual inspection, a more robust inspection system is needed.

This paper will present a novel inspection approach using existing image analysis technology for quantifying nozzle morphology integrated with sophisticated multi-axis motion control, automatic positioning adjustment, and a line scan camera for acquisition of single, non-stitched images.

Introduction

Nozzle plate inspection is a difficult and complicated task. Traditionally either nozzle plates were not inspected directly and only tested through print testing after integration into print head assemblies or a human inspector would view the part under a microscope and decide whether the parts passed or failed based on subjective, visual criteria. More recently, human observers have been augmented by the use of automated inspection methods. However, nozzle plate inspection systems often rely heavily on human observers for final go/no-go determination since there is an inflated false failure rate associated with current automated inspection methods.

Current inspection methods often include the use of a 2-D CCD array camera as the primary image input device. Nozzle arrays are generally long and skinny and require high magnification for adequate assessment. Using a 2-D CCD array camera poses a variety of challenges. Since the captured image size is limited by the size of the array, the camera needs to be stepped across the part surface in order to make a complete assessment of the surface characteristics. This step and repeat method is both time consuming and riddled with potential sources of error from focusing, illumination and placement.

The 2-D CCD array camera needs to be focused at each step since the depth of focus is prohibitively small for high magnification, large field of view circumstances.

There are three major illumination issues that need to be contended with. First, illumination angle is critical since nozzle plate materials are most often highly specular and difficult to image. Second, heat is often an issue which may cause damage to a nozzle plate due to mismatched coefficients of thermal expansion of materials used in head manufacturing. This is an illumination issue since many illumination sources are heat intensive. Third, illumination uniformity is a great challenge for use with large array cameras and illumination levels often fall off toward the perimeter of the array causing undesired perturbations in the resulting data.

Assuming that both illumination and focus are controllable, the composite image is stitched together from the separate images collected at each step and reconstructed in a single buffer in order to be analyzed. Another potential error lies along the stitching boundaries where adjacent fields are abutted. Any variations in placement of part or camera will result in incorrect, partial, or repeated data along the boundary lines, which will confound the measurements.

There are other considerations to be taken into account such as measurement system or component efficiency. Using a 2-D CCD array camera (usually 480 x 640 array elements) is quite wasteful in terms of processing time as only approximately 5% of the usable elements are actually used for the nozzle array inspection. The rest of the array elements image unimportant peripheral areas of the nozzle plate away from the orifices.

Obviously, there is ample opportunity for inspection system improvements both in terms of efficiency and efficacy.

Novel Inspection Approach Purpose

The proposed approach has attempted to address the shortcomings of current nozzle plate inspection equipment and methods. The goal is to more accurately quantify nozzle plate quality and minimize false failure rates. The system will be used to automatically position and inspect magazines of nozzle plates to support production volumes. The inspection system design is patent pending.

System Description: Part Positioning

In order for the parts to be inspected, they need to be oriented such that the part surface is parallel to the sensor array and that the nozzle arrays are parallel to the major axis of motion. Since the system is very high magnification, any skew, pitch and yaw of a part can be independent of the others even within single a magazine. These positional errors need to be accounted for on a part by part basis.

The proposed system uses sophisticated multi-axis (x, y, z, and Θ_x) motion control for automatic positioning adjustment.[1] Although the details of just how the adjustment system is designed is understandably proprietary, one element of the positioning system is a 2-D CCD array camera. The 2-D camera is used to identify and help correct for positional variations.

System Description: Image Acquisition

The system relies on a line scan camera with sub-micron resolution for acquisition of single, non-stitched, high-resolution images.[2] A line scan camera uses a single row of sensors when capturing an image. In order to build up a 2-D image, multiple pictures need to be taken. This requires careful synchronization between part motion and image capture frequency. The proposed system has a very capable motion control mechanism that is perfectly synchronized with the camera exposure frequency. The result is a seamless image of the entire nozzle array.

System Description: Image Analysis

Once the image has been captured, nozzle quality needs to be inspected. To fully automate the inspection process, the hardware is integrated with a powerful image analysis package to inspect nozzle morphology. A currently commercially available image quality inspection software package, ImageXpert™, is used for the part inspection. ImageXpert's powerful image processing and image analysis algorithms are used to inspect nozzles for a variety of attributes and defects. These results can be compared against tolerances for pass/fail determination. This data can be used to determine which parts proceed into print head production and which are discarded. Failure modes and results can be stored for offline failure analysis or they can be used to feed SPC software in real-time.

Challenges: Materials

Silicon and electroplated metal (the most commonly used materials for nozzle plate fabrication) are highly specular. This presents significant illumination challenges for both automated and manual inspection. This is confounded by the fact that the nozzles are holes in the material so the edges must be well defined optically in order to inspect nozzle quality.

The following figure shows examples of two different nozzle plates. The images were captured using a 2-D CCD array camera. The top image shows a portion of a defect-ridden nozzle plate while the bottom image shows a portion of a nozzle plate with no apparent defects.

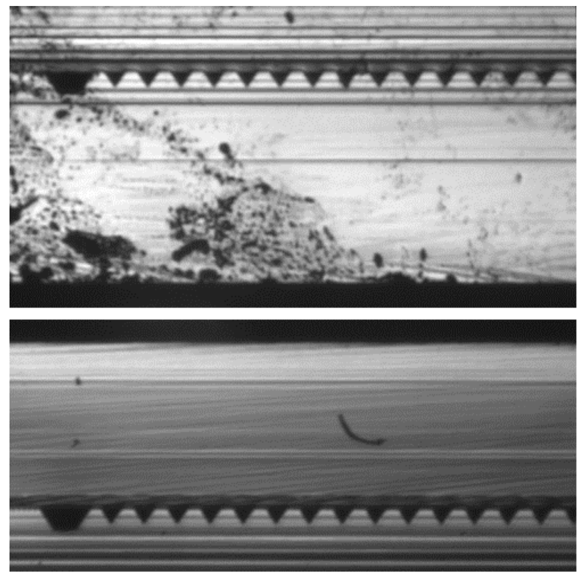

Figure 1. Comparison of two nozzle plates of differing quality

The nozzles themselves are being inspected for defects that can negatively impact print quality. The inspection system needs to detect the presence of plugged orifices, occlusions, orifice size variations, alignment and orientation variations, and fissures since these defect types will impact droplet formation. As inkjet technology advances, ink droplet sizes being deposited approach smaller and smaller volumes (typical numbers today are in the12-23 pico-liter range and the industry is quickly driving toward 6 pico-liters and smaller). Therefore, orifice size will decrease accordingly and minor defects will have a greater effect on proportionally smaller orifices.

The following figure shows some common defects and morphological perturbations.

Figure 2. Common morphological nozzle defects including fissures, occlusions, erosion, and misalignment

Cost Benefit Analysis

Manufacturing and assembling print heads prior to nozzle plate inspection is both time consuming and risky.

Failed print heads require re-assembly with new parts or they are discarded or reworked. Each of these outcomes is costly and requires re-inspection. Inspecting the nozzle plates prior to assembly into print heads can greatly minimize manufacturing costs while increasing output quantity and quality.

Both working parts that are failed and defective parts that are passed result in increased costs. An optimized automated inspection system calibrated for peak performance can minimize errors of omission and commission and thereby maximize productivity and quality control. Limiting the need for human intervention is also a cost saver. Automated inspection machines can measure production volumes without the human limitations of fatigue and de-sensitization.

Conclusion

Feasibility of the design of the new nozzle plate inspection system has already been proven and the first industrial installation has been scheduled for late summer. Results have proven to be more reliable than those of other automated inspection systems

References

1. US Patent # 5,532,815
2. Yair Kipman and Scott Cole, *Test & Measurement World*, October, 1998 pp. 19-24

Biography

Mr. Kipman is the founder and president of KDY Inc., an industry leader in automated image quality inspection and developer of ImageXpert™ a powerful, automated image quality measurement system that can automatically assess the image quality performance of imaging devices. Prior to founding KDY in 1989, Mr. Kipman worked at Xerox for six years where he developed an optical scanner that was the basis for an automatic reading device for the visually impaired. Mr. Kipman holds a M.S. in mechanical engineering, with a major in electro-optics from the University of Connecticut and a B.S. from the Technion Institute of Technology.