Tribology International 79 (2014) 162–173

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Measurement of real contact area on thermal print head using a laser microscope with a wide field of view

Isami Nitta*, Yosuke Tsukiyama, Tsuyoshi Tsukada, Hirotoshi Terao

Niigata University, Department of Mechanical Engineering, 8050 Ikarashi-2-nocho, Nishi-ku, Niigata-shi, Niigata 950-2181, Japan

ARTICLE INFO

Article history:
Received 8 April 2014
Received in revised form
31 May 2014
Accepted 9 June 2014
Available online 20 June 2014

Keywords:
Laser Microscope
Dye sublimation printer
Real contact area
Thermal print head

ABSTRACT

In a dye-sublimation printer, a thermal print head presses and heats a dye-based ribbon to diffuse ink dyes to the desired positions into the receiving layer of paper. The print quality will deteriorate if the contact condition between the thermal print head and the paper is insufficient. Thus, it is necessary to analyze the contact condition for finer printing. Direct observation of the contact area with an optical microscope is effective to clarify the contact conditions of the thermal print head. However, conventional optical microscopes take too much time to observe the whole apparent contact area, because their fields of view are not sufficiently wide. Previously, we developed a laser microscope with a wide field of view and applied this laser microscope to observe the whole apparent contact area of rubber elements. In this study, we examined the contact conditions between the thermal print head and the paper. In general, when we observe the contact area of two solid surfaces, one is restricted to a transparent material such as a glass plate. Instead of the thermal print head, a glass head of the same shape as an existing thermal print head was pressed on the paper and observed through the glass head. This allowed us to clearly determine the contact situations of the interface and measure the contact widths and distributions of real contact area. In this method, it was confirmed that the contact width and the real contact area changed in accordance with the type of paper used, steps of the printing process, and density of color printing.

1. Introduction

With the widespread adoption of digital cameras and personal computers, there is an increasing demand for printers capable of high-quality printing. Dye-sublimation type thermal transfer printers are superior to inkjet printers in terms of size reduction of printers and quality of printed images because it can produce continuous-tone images and has fewer moving elements that can break down. Dye-sublimation printers are considered the most promising type of printers for mobile use, and this would require that the printer can be battery powered. Therefore, reducing friction is important to reduce power consumption and provide long operating times for such printers. To reduce friction, the load applied to the thermal print head must be lowered.

A thermal direct printer that can print on heat-sensitive thermal paper with the use of a print head made from numerous small pins has been developed [1,2]. However, the image on the heat-sensitive thermal paper was sensitive to incidental heat, abrasion, friction, and light, which can cause printed images to fade, as well as water. Thus, a thermal transfer printer was developed that uses wax-based ink on a ribbon, which is melted by heating using a thermal print head, and the ink is transferred onto ordinary paper where it becomes permanent after the ink cools. The dye-sublimation printer is a type of thermal transfer printer.

Fig. 1 shows the printing unit of a dye-sublimation printer. The printing method used by dye-sublimation printers is to push and heat a dye-based ribbon with the thermal print head, and transfer the dyes to desired positions on special sublimation paper. Thus, the sublimation printer has tribological problems with regard to contact, friction, and wear of the thermal print head. Despite the name, most dye-sublimation printers actually work by dye diffusion rather than by sublimation; early in the development of these printers, it was mistakenly believed that the dyes were transferred by sublimation, but the dyes are actually transferred by diffusion from the ribbon to the paper.

There are a number of numerical simulations of contact pressure exerted on the roller [3] and the thermal head [4], and of thermal diffusion coupling problems [5,6]. Numerical simulation is a powerful method that can precisely predict the contact pressure and contact width of the thermal print head where experimental methods cannot measure. However, it is still important to measure the contact pressure and contact area to improve sublimation printers, although an attempt to develop a contactless thermal printing system has been proposed [7].

---

* Corresponding author. Tel./fax: +81 25 262 7271.
E-mail address: nitta@eng.niigata-u.ac.jp (I. Nitta).

http://dx.doi.org/10.1016/j.triboint.2014.06.005
0301-679X/© 2014 Elsevier Ltd. All rights reserved.

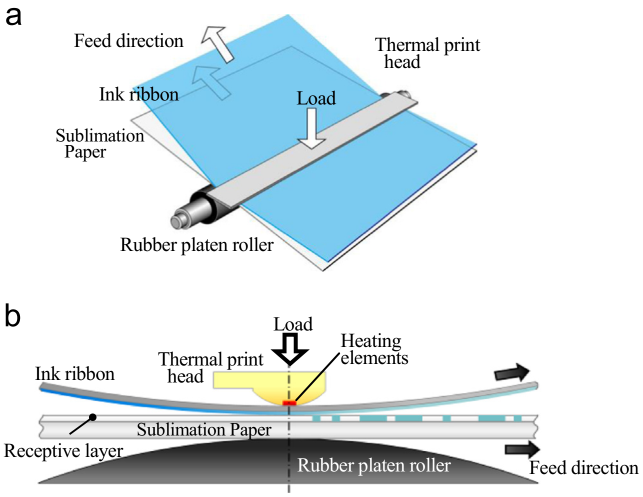

Fig. 1. Principle of dye sublimation printing: (a) a schematic diagram of a printing unit and (b) thermal bye transfer printing process.

From the viewpoint of energy saving, a normal load as low as possible is desired for dye-sublimation printers because a lower normal load reduces total friction in the printer. The image quality on the paper will, however, decrease when the applied load is reduced because close contact between the ink ribbon and the paper will no longer be maintained. In reality, the optimal normal load and shape of the thermal print head were determined by arduous experiments with a number of prototype thermal print heads. Thus, a simple estimation method for determining the optimal normal load should be established. The real contact area is an important factor for the optimal normal load because sublimation printers are based on solid contact, unlike the inkjet printers.

In a previous study [8], the dyes on the ribbon were assumed to be transferred and diffused onto the paper at the real contact area. The real contact areas of three different papers against an optical prism were measured at a variety of applied normal loads with a contact microscope. The distributions of contact pressures applied to the thermal print head were also simulated by finite element analysis (FEA). In addition, the effects of the real contact area of the paper on the optical density were examined. Thus, the correlations between the optical density and the real contact area were determined experimentally. The optimal normal loads for the thermal print head were predicted from the viewpoint of the real contact area.

The method used for measuring the real contact area mentioned above is different from contact configurations of the existing thermal print heads and some errors may be introduced when the optimal normal load is predicted based on these measurements. Thus, direct observation of the contact interface between the thermal print head and the paper is necessary to examine the effects of normal loads applied to the thermal print head on print quality. However, there have been no reports of such investigations.

In the present study, a thermal print head made of phosphate glass [9] identical in shape to the existing thermal print head was applied to directly observe the contact area against sublimation paper. A laser microscope with wide field of view developed in our laboratory [10] was used because conventional optical microscopes have a short working distance and cannot be used to observe the contact area in focus, even for a very small area. We examined the effects of the normal load and sublimation paper on the contact widths and contact situations with this laser microscope.

2. Experimental procedures

Table 1
Specification of equipment.

Laser source	Laser diode (650 nm)
Field of view [mm^2]	10 × 8
Resolution [μm]	2.5
Number of pixels [pixels]	20,000 × 16,000
Scanning line [lines/min]	9000

Table 1 shows the basic specifications of the laser microscope with wide field of view used in this study. Fig. 2 shows an outline of the observation system for the contact area between the phosphate glass print head and the sublimation paper, the configuration of which is indicated in Fig. 2(b). In Fig. 2(a), the region within the dashed line represents the laser microscope with wide field of view based on confocal optics. First, a laser beam emitted by a laser diode is made as parallel as possible through a collimating lens. In addition, the collimated laser beam, which is linearly polarized, is transformed into a circularly polarized beam by a quarter wave plate. The laser beam is scanned by a rotating flat mirror at a rotational speed of 9000 rpm and passes through an $f\theta$ lens unit to focus the laser beam on the contact surface. The reflected laser beam becomes polarized at right angles to the outgoing laser beam from the $f\theta$ lens unit, which allows good separation at the polarizing beam splitter. Finally, the reflected laser beam passes through a pinhole to a photodetector. The intensity of the reflected laser beam is transformed into digital data with a 12-bit A/D converter at a conversion rate of 100 MHz. The rotating flat mirror scans the laser beam in the horizontal direction (i.e., the x direction), and the specimens, i.e., the phosphate glass print head and the sublimation paper, attached to the motor-driven stage can be moved in the vertical direction (i.e., the y direction) at a constant speed controlled by a microcomputer. Thus, the contact surface to be observed could be scanned by the fine laser beam and the image of the surface is made by arranging the signals of the reflected laser light in the horizontal and vertical directions.

Table 2 shows performance comparisons between the laser microscope with wide field of view and a typical microscope with similar magnification. A long working distance of 27 mm was needed to observe the nip part of the rubber roller. In addition, as the nip part is too long in the transverse direction, a number of measurements were necessary to cover the whole part with a conventional optical microscope. The telecentric lens provided constant magnification, meaning that object size did not change, over a range of working distances, virtually eliminating perspective angle error. Thus, object movement did not affect image magnification, which allowed for highly accurate measurements.

The phosphate glass print head was fixed on the large glass plate 3 mm thick by the adhesion force of vegetable oil the refractive index of which is almost the same as that of the large glass plate (i.e., 1.5). The presence of the vegetable oil between the phosphate glass print head and the large glass plate made the contact interface invisible. The rubber platen roller with a metal shaft was pushed against the phosphate glass print head through the sublimation paper as shown in Fig. 2(b). This configuration was used to simulate the actual contact state of the dye-sublimation printer except for heating. The ink ribbon was also removed because it prevents clear observation of the contact interface due to its opacity. However, the very thin ink ribbon, with a thickness of only about 5 μm, may not greatly affect the contact situation. The material of the platen roller was natural rubber, CR50, and its inner and outer diameters and length were 6 mm, 12 mm and 100 mm, respectively.

Fig. 2(c) and (d) shows the sizes of the phosphate glass print head: 15 mm wide × 75 mm long × 1.1 mm high at the top of three protrusions or bumps [9]. In the experiment, only the middle of the three protrusions was used. The radius of curvature of the protrusion is 2 mm, which is the same as that of the existing thermal print head. The normal load applied to the platen rubber