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Evaluation of tribological properties of pick up roller measured 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

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ABSTRACT

Analysis of contact conditions between rubber rollers and printing paper is important for stable paper feeding operation. Direct observation of apparent contact area is necessary to understand contact conditions, such as distributions of real contact area and micro-slips. However, conventional optical microscopy takes too long to observe the whole apparent contact area because the field-of-view is too narrow. We developed a wide field-of-view laser microscope, and applied it to determine the distributions of real contact area of rubber rollers against glass plates. Critical torques at which micro-slips of the rubber rollers occurred were proportional to total real contact area.

1. Introduction

In printing machines, such as ink jet printers and photocopiers, paper is fed by friction force exerted between rubber rollers. Friction characteristics of the rubber and paper are very important for precise paper feeding systems. Thus, paper-to-paper friction [1,2] and rubber materials for high friction and wear resistance were investigated [3]. There have been many attempts to understand rubber friction mechanisms [4–10], particularly on rubber tire friction [11,12]. In the paper feeding process, micro-slips could occur at the contact interface between them. These micro-slips could induce paper wrinkles or paper jams. As more precise paper feeding is necessary to achieve high precision printing, it is necessary to clarify the tribological properties involved in the contact between the rubber rollers and the printing paper on the microscopic level. Typically, numerical analysis such as finite element method (FEM) is used to analyze the contact conditions [13]. In reality, the apparent contact area between the rubber roller and the printing paper included real contact portions as well as non-contact portions. The total apparent contact area is much wider than the total real contact area. In FEM analysis, however, the friction coefficient is assumed to be constant over the whole apparent contact area regardless of practical contact situations in which the normal load is unevenly distributed over the apparent contact area because of the uneven contact between them. Moreover, the rubber roller deteriorates with age, and the paper debris attached to the rubber roller will alter the friction coefficient between the rubber roller and the paper. Direct observation by optical microscopy is an effective way to gain an understanding of the contact situation. The rubber roller may not make uniform contact with the paper because of the surface roughness and consequent uneven contact between them.

In a previous study, to gain an understanding of the mechanisms of micro-slip initiation and propagation, the processes of micro-slip initiation and propagation were observed at the contact interface between a rubber plate and a glass plate by optical microscopy [14]. The results indicated that the partial slip distribution was affected by contact morphology, such as spherical ball, triangular stamp, rectangular stamp, and concave stamp contact. However, the apparent contact area in this experiment was not large enough to discuss the effects of contact morphology on the contact situation because of the limited field-of-view of the optical microscope used.

If the contact situation over the whole apparent contact area is extrapolated based on the observation results over only a fraction of the apparent contact area, it will vary markedly depending on the observed portions. Thus, the entire apparent contact area of the rubber roller must be directly observed to clarify the distribution of the real contact area. However, the apparent contact area of the rubber roller is too large for direct observation. As it takes a great deal of time, few researchers have directly observed the whole contact area [15].

In this study, the entire contact surfaces of the rubber rollers were directly observed using a laser microscope with a wide field-of-view developed in our laboratory to observe wide areas on a fine scale [16]. The object to be observed was a pick-up roller,

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

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which is the same type of rubber roller used to pick up a sheet of paper from a stocking tray and feed it to the printing component of a printer. The distributions of real contact area were determined from the entire apparent contact area. The distributions of micro-slips over the entire apparent contact area were also calculated from the observed images both before and after application of torque, using an image correlation technique. In addition, the effects of paper debris on the micro-slip characteristics of the rubber rollers were examined by experiments using pickup rollers dredged with paper debris.

2. Experimental procedures

Table 1 shows the basic specifications of the newly developed laser microscope used in this study. Fig. 1 shows an outline of the observation system for the rubber roller. In this figure, 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 to a photodetector (not a CCD sensor) through a pinhole. The magnification of the $f\theta$ is about 7 × in terms of an optical microscope objective lens. 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 specimen attached to the motor-driven stage could 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 1
Specification of equipment.

Laser source	Laser diode (650 nm)
Field of view	10 mm × 8 mm
Resolution	2.5 (μm)
Number of pixels	20,000 × 16,000 (pixels)
Speed of observation	9000 (Lines/min)

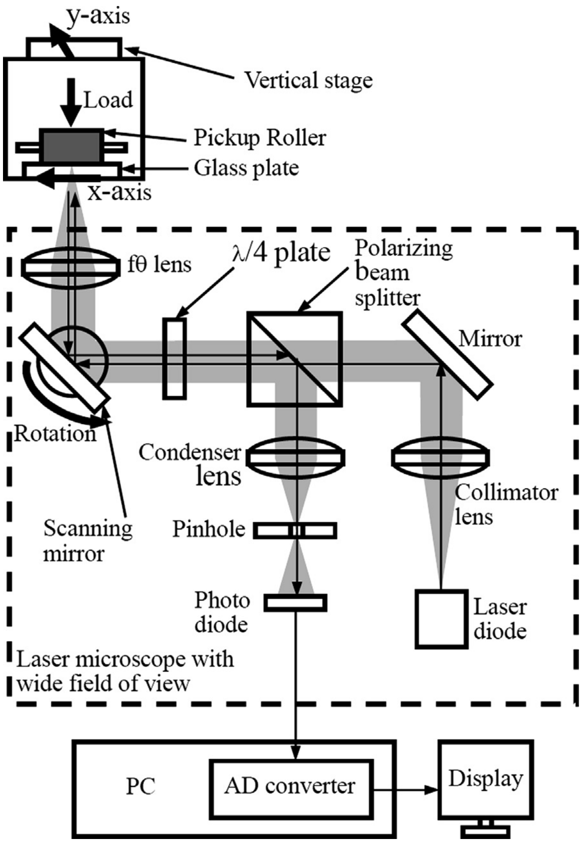

Fig. 1. Outline of observation system.

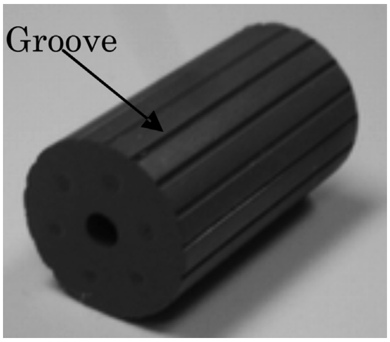

Fig. 2. Pickup roller.

The rubber pickup roller was set on a special jig that could be moved in the y direction and pressed against the glass plate. The normal load applied to the pickup roller was measured with a load cell. In this study, printing paper was not used and the contact situations between the rubber pickup roller and the glass plate 3 mm thick were observed from the glass plate side. When observing local micro-slips on the contact surface, some torque was applied to the steel shaft of the pickup roller. Fig. 2 shows the rubber pickup roller used in this study. The pickup roller measuring 12.4 mm in diameter and 22.5 mm in length had evenly spaced grooves along a generatrix of the cylinder surface. This groove greatly affected the contact situation. Thus, two different contact patterns with or without grooves were observed.

3. Experimental results

3.1. Observation of the real contact area

The rubber pickup roller was not expected to show even contact with the glass plate over the whole apparent contact area. Thus, the real contact area distribution without torque was observed over the apparent contact area in a short time. The apparent contact area was defined as the largest possible area detected. The normal load applied to the pickup roller lay in the range from 1.0 N to 5.0 N. Figs. 3 and 4 show the observed contact images without and with grooves. The black portions in these images represent the real contact area between the rubber and the glass plate. This measurement method is based on two-beam optical interferometry. The real contact area where the interstice between two surfaces makes zero-order dark interference based on the optical path difference of reflected light from the lower surface of the rubber and the glass plate. Thus, the real contact area appears dark in these images [15,18–20]. The observation area was 3.5 mm × 24 mm. As these images were thresholded, the