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Numerical Simulation of Ink Flow Field on Ink Fountain Roller of Offset Printing Machine

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Abstract: The flow characteristics of the ink on the ink fountain roller of offset printing machine is very important for the ink amount control and the ink amount control can determine the color quality of printing products. This study simulates first the ink flow of only one ink area using CFX fluid simulation software, then two situations are simulated to analyze how the ink area is affected by its adjacent ink areas on each side. In the first situation, the adjacent sides of the middle ink area have the same ink key opening size that is larger than that of the middle area. In the second situation, the adjacent sides of the middle ink area have different ink key opening size and each is smaller than that of the middle area. From the analysis it can be seen that, in the printing process, the pressure and speed and ink layer thickness of ink on the ink fountain roller are affected by the interaction between adjacent ink areas. Compared with previous work that is limited to analyze the ink flow characteristics of only one ink area, the study aims to analyze the ink flow characteristics under the interactional effect of adjacent ink areas. The research provides a reference to the mutual influence between ink areas in the actual printing process and it's important for the printing color quality control and has a better application prospect.

Key words: Offset printing machine, ink fountain roller, flow characteristics, numerical simulation

INTRODUCTION

During the actual printing process, due to the limitation of some factors, such as printing technology, production environment and skills of operators, etc., some quality defects may be caused (Li *et al*., 2011). For example, the image of printing product is different and the ink amount to be used is also different. If the ink feeding of offset printing machine can't be strictly controlled, the ink amount can't be ensured. So it's important to research the ink feeding part to control ink amount. The printing sheet is divided into a number of regions in horizontal direction and the region is called ink area. The ink amount of each ink area should be controlled respectively to meet the demand of each region.

In the ink feeding process, ink fountain roller rotates at a low speed and rolls up the ink in ink fountain and ink on the ink fountain roller is in the shape of film. The function of ink fountain is storing ink and regulating ink amount (Sun, 2007). The ink fountain studied in this study consists of twenty ink keys and ink fountain roller is divided into twenty ink areas. Each ink key is driven separately by a motor through transmission and each ink key can move up-and-down independently along the surface of Ink fountain foundation. Consequently, in each ink area, the opening size between ink fountain roller and the ink key can be adjusted separately and then the ink amount control is realized (Ye *et al*., 2010). Ink fountain structure is shown in Fig. 1.

In the previous paper, pilot leak's influences on the performances of extra high-pressure proportional pneumatic valve, the mathematic model of only one ink area was built and the flowing characteristics of ink on this ink area was analyzed (Ahmed and Siores, 2001; Chen and Wang, 2005). But in the printing process, the ink amount to be used in adjacent ink areas is different and the ink key opening size of adjacent ink areas is different as well, then the adjacent ink area will influence each other. So the study adopts fluid simulation software CFX

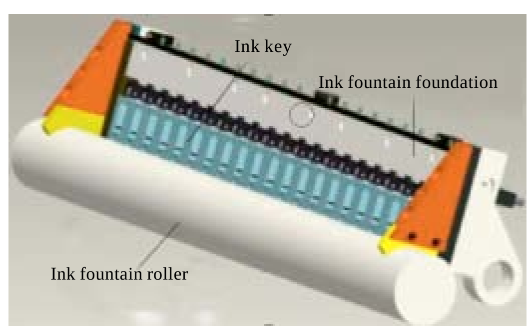

Fig. 1: Ink fountain structure

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to simulate the ink flow on ink fountain roller. According to the simulation, the study analyzes the flowing characteristics of ink and the interaction between adjacent ink areas.

METHODOLOGY

Basic physics equations: In the actual printing process, generally, the rotation speed of ink fountain roller is 0.4 or even 0.5 times the paper-transferring speed. In normal operation, the paper-transferring speed is 12~15 thousand pieces per hour, so the rotation speed of ink fountain roller is 8.35~13.09 rad sec. In this study, the rotation speed of ink fountain roller is 10 rad sec, then the ink on ink fountain roller is in low speed flow field. So the ink flow can be considered as incompressible viscous flow and the calculation model adopts the incompressible Navier-Stokes equation. And then by consulting relevant literatures, the flow state of the fluid model is laminar (Kuang and Pang, 2012). The incompressible Navier-Stokes equation in the form of rectangular coordinates is as follows (Versteeg and Malalasekera, 1995):

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

$$\rho\frac{Du}{Dt}=-\frac{\partial p}{\partial x}+\mu\left[\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right]+\rho f_x$$

$$\rho\frac{Dv}{Dt}=-\frac{\partial p}{\partial y}+\mu\left[\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right]+\rho f_y$$

$$\rho\frac{Dw}{Dt}=-\frac{\partial p}{\partial z}+\mu\left[\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right]+\rho f_z$$

In the equations, ρ is the density of fluid, V is the velocity vector of fluid its component is (u, v, w) in a Cartesian coordinate system, ρ is isotropic pressure of fluid, f_x, f_y, f_z are the volume forces in three directions, μ is coefficient of dynamic viscosity.

Meshing and boundary conditions: The stroke of the ink key in the ink fountain studied in this study is 0~0.6 mm. The ink key moves when driven by the ink key motor along the surface of ink fountain foundation and the moving distance is the size of the ink key opening. When the moving distance of the ink key is 0 mm, the ink key contacts with ink fountain roller and the ink key opening size is 0 mm, as shown in the part A of Fig. 2.

Three-dimensional geometry model of the ink flow field on ink fountain and ink fountain roller is built using Pro/E. Because of the ink key opening size is only hundreds of microns, in order to improve the calculation speed and precision, the ink field flowing from the ink fountain should be refined grid and the ink field in the ink fountain can be proper larger grid.

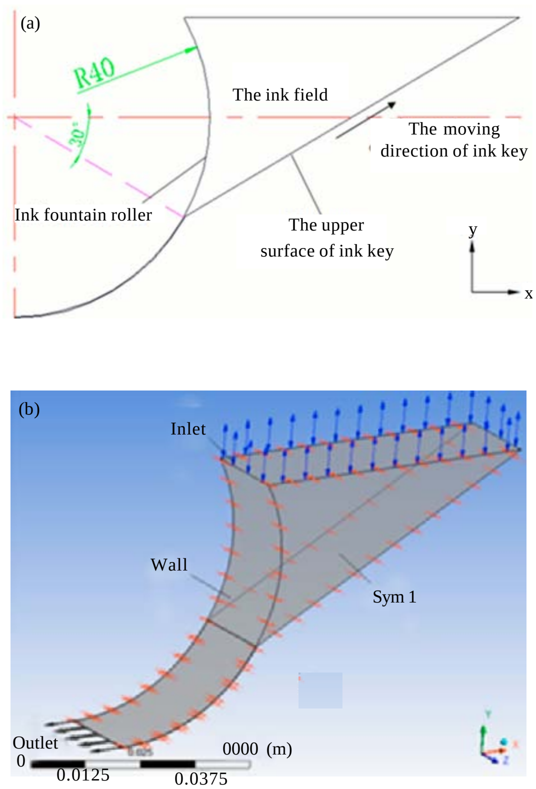


Fig. 2(a-b): (a) Two dimensional model of the ink flow field and (b) Boundary conditions of the ink flow field

Because of ink viscosity, the ink in the ink fountain flows due to the rotational shearing when the ink fountain roller rotates in clockwise. A common high viscosity ink is used in this study and its density is 1012. 985 kg m^{-3}, dynamic viscosity is 1.2 Pa sec. Inlet boundary is set as opening, outlet boundary is set as static pressure 0 pa, Wall boundary is set as no slip, moving wall and its velocity is -10 rad sec. Symmetry boundary is set as the two symmetric planes that are shown in the part b of Fig. 2b and it is the ink flow field for only one ink area which ink key opening size is 0.48 mm. The temperature is 25°C. The upper surface of ink keys need not special designation, the software automatically designates it as no slip and adiabatic wall boundary.

RESULTS AND DISCUSSION

Figure 3 is the pressure chart of ink flow field on ink fountain roller. Because the ink key opening size is only 0.48 mm, so the maximum pressure is in the ink key opening position and the pressure decreases along the circumference of ink fountain roller on both sides. Figure 4 is the Y direction speed of the ink in the ink key

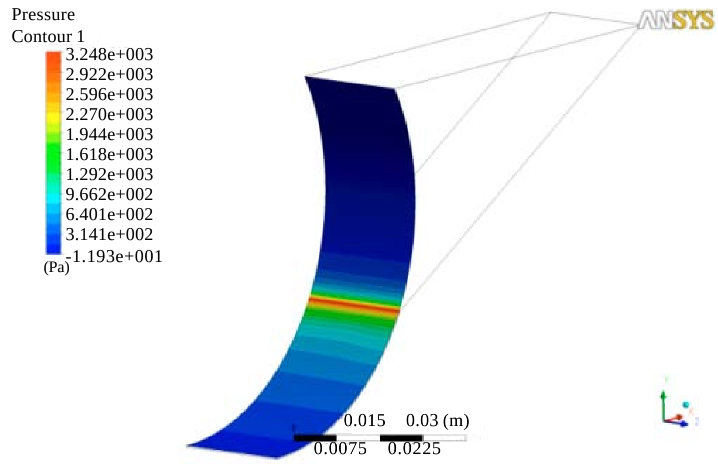


Fig. 3: Pressure chart of ink flow field on ink fountain roller

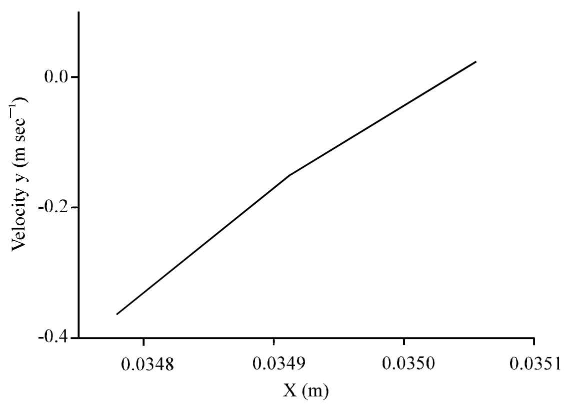


Fig. 4: The Y direction ink speed in the ink key opening position

opening position. Because the ink fountain roller rotates in clockwise direction, ink flows by the rotation of ink fountain roller and the flow direction is the negative direction of Y axis in the ink key opening position, so the speed value in Fig. 4 is negative. As can be seen from Fig. 4, the farther away from the fountain roller, the smaller the ink speed is. The ink is sheared by the rotation of the ink fountain roller and due to the ink's thixotropy, ink's viscosity decreases and fluidity increases. The ink close to the ink fountain roller suffers a larger shearing force and it has good fluidity. The ink far away from the ink fountain roller suffers a smaller shearing force and it has poor fluidity (Tang and Yuan, 2007).

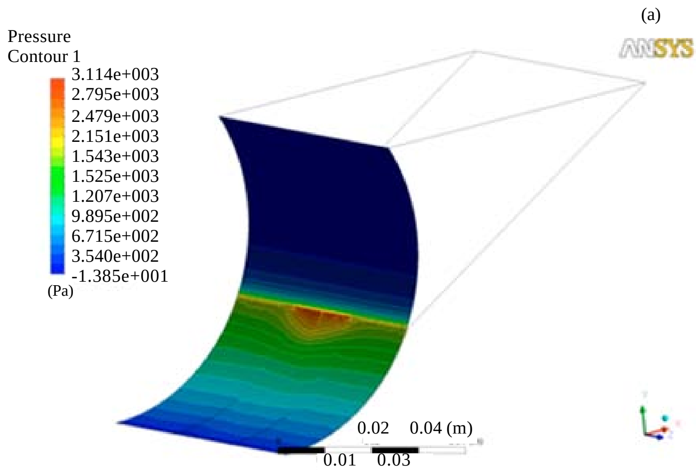
The previously published studies just analyze the difference of the ink pressure and velocity on ink fountain roller, when the ink key opening size is changed. The above result is to study the ink pressure distribution on the ink fountain roller and the Y direction ink speed in the ink key opening position. It is different with the previous work.

INTERACTION OF ADJACENT INK AREAS

In order to analyze the interaction of adjacent ink areas, based on the above simulation, two numerical simulations as follows have been done. The first situation is that the ink key opening size of adjacent ink areas are, respectively 0.6, 0.48 and 0.6 mm along the Z axis, the adjacent sides of the middle ink area have the same ink key opening size that is larger than that of the middle area. The second is that the ink key opening size of adjacent ink areas are respectively 0.24, 0.48 and 0.36 mm along the Z axis, the adjacent sides of the middle ink area have different ink key opening size and each is smaller than that of the middle area.

Pressure analysis: Figure 5 are pressure charts of the ink flow field on ink fountain roller. In the figure, along the positive direction of the Z axis (from left to right), they are ink area 1, ink area 2 and ink area 3. The interface of the ink area 1 and ink area 2 is defined as the interface 1 and it's in the plane Z = 20 mm. The interface of the ink area 2 and ink area 3 is defined as the interface 2 and it's in the plane Z = 40 mm:

- The smaller the ink key opening size is, the higher the pressure of the ink flow field is. The pressure difference between the adjacent ink areas causes axial ink flow and the ink flows from the ink area that is of higher pressure to the ink area that is of lower pressure, that is, from the ink area that is of



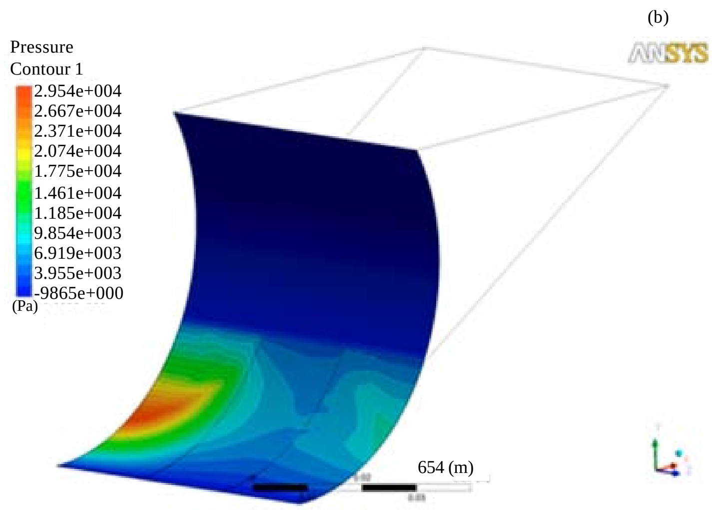


Fig. 5(a-b): (a) For the first situation, the pressure chart of the ink on ink fountain roller, (b) For the second situation, the pressure chart of the ink on ink fountain roller

smaller ink key opening size to the ink area that is of larger ink key opening size

- When the ink key opening size of two adjacent ink areas are larger than the ink key opening size of the middle ink area, the ink of the middle ink area flows to its two adjacent ink areas, so the pressure of the middle ink area decreases. When the ink key opening size of two adjacent ink areas are smaller than the ink key opening size of the middle ink area, the ink of the two adjacent sides flows to the middle ink area, so the pressure of the middle ink area increases. For example, Point A (34.7785, -19.76, 30 mm) lies in the ink key opening position of the ink area which ink key opening size is 0.48 mm. In Fig. 3 and 5, the pressure of point A are, respectively 3251.08Pa, 2883.6 Pa and 3593.04 Pa
- For the first situation that ink area 1 and ink area 3 have the same ink key opening size, they have the same effect on the middle ink area. This is because interfaces 1 and interface 2 have the same ink key opening size difference, then the pressure difference are the same and the axial ink flow are the same
- For the second s ituation that ink area 1 and ink area 3 have the different ink key opening size, ink area 1 has much more effect on the middle ink area than ink area 3. This is because ink key opening size difference of interface 1 is larger than that of interface 2, then the pressure difference of interface 1 is larger than that of interface 2 and the axial ink flow of interface 1 is stronger than that of interface 2
- When the ink key opening size is small enough and the ink key opening size difference between the

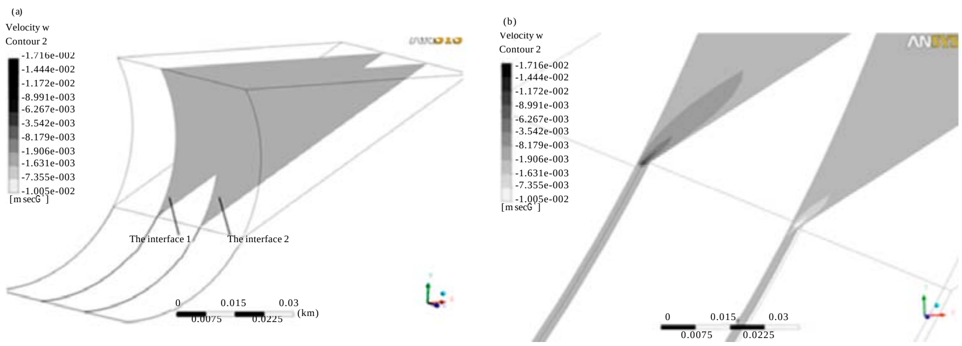


Fig. 6(a-b): (a) The axial ink flow speed chart of two ink area interfaces and (b): The partial enlarged view

adjacent ink areas is large enough, the maximum pressure is no longer in the ink key opening position and it moves down

Velocity analysis: As known from the above pressure analysis, when the ink rotates in clockwise along the circumferential direction of the ink fountain roller it also flows along the axial direction of the ink fountain roller and the axial ink flow at the junction of ink areas is most obvious. Figure 6 are the axial ink flow speed charts of the two ink area interfaces for the second situation. In the figures, the positive numbers represent that the ink flows to the positive direction of Z axis and the negative numbers represent that the ink flows to the negative direction of Z axis.

It can be seen from above figures that the ink flows from the ink area that is of smaller ink key opening size to the ink area that is of larger ink key opening size and the axial ink flow is the strongest in the ink key opening position. This is because the ink key opening size is very small and the mutual compression of the ink is very strong, the maximum pressure of each ink area is in the ink key opening position. So the axial ink flow is the strongest in the ink key opening position and the axial ink flow is very weak when flows out from the ink fountain. As shown in Fig. 6b, the maximum axial ink flow speed of interface 1 is 0.01716 m sec and the maximum axial ink flow speed of interface 2 is 0.01008 m sec, so the axial ink flow of interface 1 is stronger than that of interface 2. But for the first situation that ink area 1 and ink area 3 have the same opening size, the ink of the middle ink area flows to its two adjacent ink areas and the axial ink flow speed in the two interfaces are the same.

Figure 7a is, for the second situation, the Y direction speed chart of the ink in the middle of ink key opening position of the three ink areas. As shown in the figure, the larger the ink key opening size is, the higher the speed of the ink flowing from the ink key opening position is.

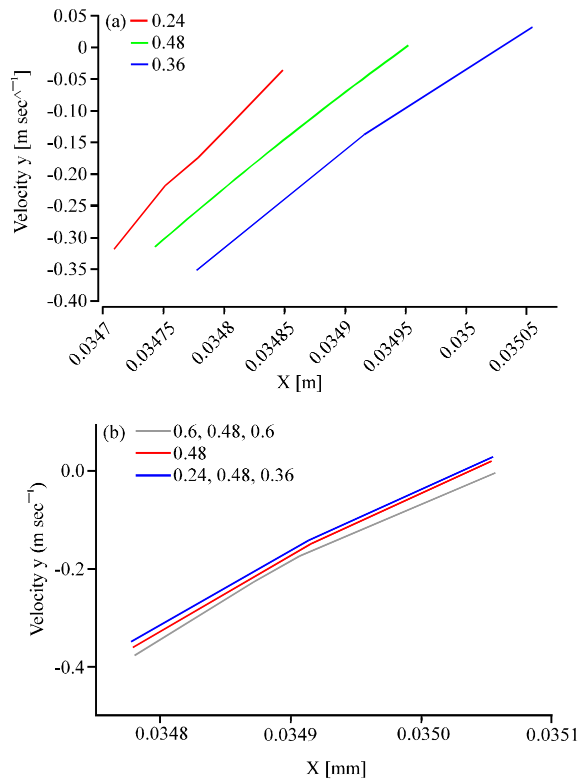


Fig. 7(a-b): (a) The Y direction speed of different ink areas and (b) The Y direction speed of ink area 2

Figure 7b is, for the different situations, the Y direction speed chart of the ink in the middle of ink key opening position of the middle ink area and the ink key opening size of the middle ink area is 0.48 mm. when the ink key opening size of the two adjacent ink areas is the same as that of the middle ink area, the curve of the Y direction ink speed is the red line in Fig. 7b When the ink key opening size of the two adjacent ink areas is larger than that of the middle ink area, the speedof the ink flowing from the ink key opening position of the two adjacent ink areas is higher than that of

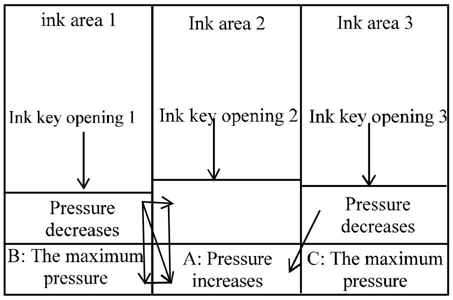


Fig. 8: The analysis of the maximum pressure value

the middle ink area and it leads to the Y direction speed in the ink key opening position of the middle ink area increases. When the ink key opening size of the two adjacent ink areas is smaller than that of the middle ink area, the speed of the ink flowing from the ink key opening position of the two adjacent ink areas is smaller than that of the middle ink area and it leads to the Y direction speed in the ink key opening position of the middle ink area decreases.

The above ink speed analysis can explain why the maximum pressure moves down Fig. 5b. As shown in Fig. 8, the axial ink flow is the strongest in the ink key open position, then the pressure in the ink key opening position of ink area 1 and ink area 3 decreases which makes the maximum pressure move to the region B and region C. In the ink key opening position of ink area 1 and ink area 3, the Y direction ink speed is much larger than the axial ink speed, so the synthetic speed is in the direction shown by arrows in Fig. 8. As a result, the pressure of region A increases and it becomes the maximum pressure position.

Figure 5a is the situation that the ink of the middle ink area flows to the two adjacent ink areas. Because the ink key opening size and the pressure difference don't reach a certain degree, the axial ink flow is too weak to change the maximum pressure position.

THE INK LAYER THICKNESS

The ink layer thickness in the circumferential direction: For the middle ink area that the ink key opening size is 0.48 mm, taking a plane through the arc center that is 30° to the XZ plane and the plane is called plane 30°. The plane 30° intersects the lower ink layer of the middle ink area in a section and the section intersects the center plane (Z = 30 mm) of the middle ink area in a line, as shown in Fig. 9. Extracting the X-axis coordinate values, Y-axis coordinate values and speed values of the intersection line, an example as shown in Fig. 10. The ink layer thickness is calculated according to the ink

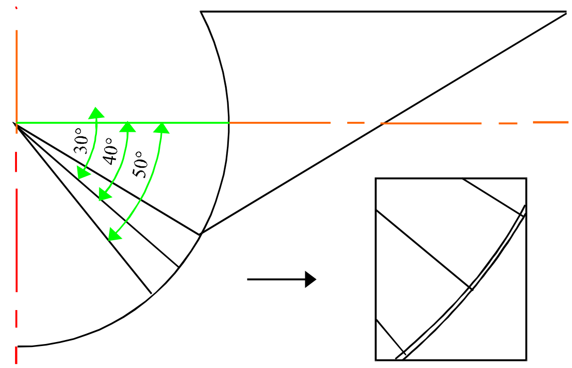


Fig. 9: Intersection lines on the center plane (Z = 30 mm) of the middle ink area

X [m]	Y [m]	Velolcity [m sec^{-1}]
0.034641	-0.02	0.409911
0.034664	-0.02001	0.363634
0.034688	-0.02003	0.318225
0.034711	-0.02004	0.272595
0.034734	-0.02005	0.227076
0.034758	-0.02007	0.181254
0.034781	-0.02008	0.134991
0.034804	-0.02009	0.088826
0.034827	-0.02011	0.0427503
0.034851	-0.02012	0.0027756

Fig. 10: The extracted speed values of an intersection line

on the intersection line flows or not. At the point (0.034851, -0.02012), the speed value changes in magnitude, so the point can be seen as a boundary point. Another boundary point is the intersection point of the intersection line with the ink fountain roller. The distance between the two boundary points is the effective ink layer thickness.

Twenty-one intersection lines that have different angles to XZ plane are acquired and a set of ink layer thickness are obtained by extracting the relevant data from these intersection lines. Then by using origin data processing software, the curve of ink layer thickness along the circumferential direction of the ink fountain roller is acquired, as shown in Fig. 11.

Because the ink key opening size is very small, the ink accumulates and the ink layer thickness is relatively larger in the ink key opening position. Then along with the ink rotating with the ink fountain roller, the ink distributes evenly and quickly and the ink layer thickness decreases rapidly to a stable value with minor fluctuations.

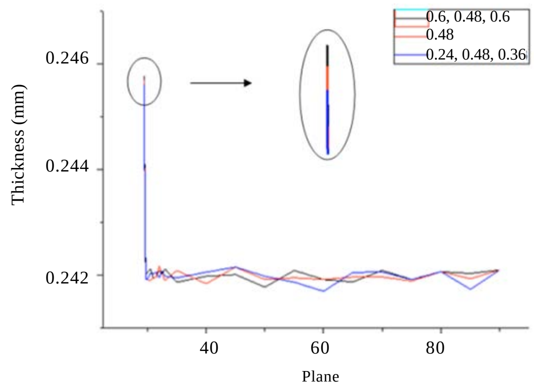


Fig. 11: The ink layer thickness in the circumferential direction

As shown in the partial enlarged region of Fig. 11, when the ink key opening size of the two adjacent ink areas are larger than that of the middle ink area, the speed and the ink amount flowing from the ink fountain of the middle ink area increase, then the ink layer thickness increases in the ink key opening position. When the ink key opening size of the two adjacent ink areas are smaller than that of the middle ink area, the speed and the ink amount flowing from the ink fountain of the middle ink area decrease, then the ink layer thickness decreases in the ink key opening position.

The ink layer thickness in the axial direction: Extracting the effective ink layer thickness on the intersection lines where the plane 30° intersects with the XY planes that have different Z coordinate and the curve of the ink layer thickness in the axial direction is shown in Fig. 12.

As shown in Fig. 12a the larger the ink key opening size is, the larger the ink layer thickness is. The interaction of the adjacent ink areas has a little effect on the ink layer thickness and especially has a little or even no effect on the middle position of ink area. The partial enlarged region of the part a is shown in the part b.

For the first situation that the ink key opening size of two adjacent ink areas is larger than that of the middle ink area, the ink of the middle ink area flows to its two sides which leads to ink accumulation at its two sides. As shown in the partial enlarged region 1 and 3, the ink layer thickness decreases firstly in the internal region of ink area 2, then begins to increase near to the junction of ink areas, while the ink layer thickness of ink area 3 increases slightly near to the junction of ink areas (interface 2).

For the second situation that the ink key opening size of two adjacent ink areas is smaller than that of the middle ink area, the ink of the two adjacent ink areas flows to the

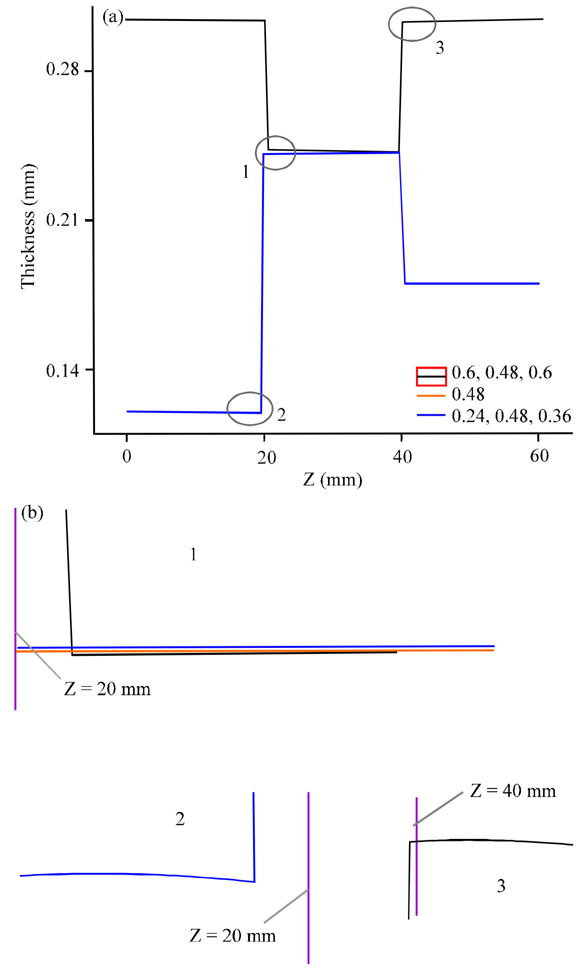


Fig. 12(a-b): (a) The ink layer thickness in the axial direction and (b) The partial enlarged view of region1/2/3 in part A

interfaces which leads to ink accumulation at the two interfaces. As shown in the partial enlarged region 1 and 2, the ink layer thickness decreases firstly in the internal region of ink area 1, then it begins to increase near to the interface 1, while the ink layer thickness of the middle ink area increases slightly near to the two interfaces.

CONCLUSION

Though the ink key opening size can be adjusted separately to control the ink feeding of each ink area it is still affected by the interaction of adjacent ink areas.

There is axial ink flow between ink areas and the ink flows from the ink area that is of small ink key opening size to the ink area that is of large ink key opening size and the axial ink flow is the strongest in the ink key opening position.

The larger the ink key opening size is, the larger the speed of the ink flowing from the ink key opening position is and the lower the pressure of the ink field is. When the ink key opening size of the two adjacent ink areas is larger than that of the middle ink area, the speed of the ink flowing from the ink key opening position of the middle ink area increases but the pressure of ink field decreases. When the ink key opening size of the two adjacent ink areas is smaller than that of the middle ink area, the speed of the ink flowing from the ink key opening position of the middle ink area decreases but the pressure of ink field increases.

For the middle ink area, when its two sides adjacent ink areas have the same ink key opening size, the axial ink flow in the two interfaces are the same and the two adjacent ink areas have the same effect on the middle ink area. When its two sides adjacent ink areas have the different ink key opening size, the axial ink flow in the interface that is of larger ink key opening size difference is stronger than that of the interface that is of smaller ink key opening size difference and it also has much more effect on the pressure of the middle ink area.

The maximum ink layer thickness is in the ink key opening position. Away from the ink key opening position, the ink layer thickness decreases rapidly to a stable value along the circumferential direction with minor fluctuations.

For the ink area that has smaller ink key opening size, the ink layer thickness decreases firstly in the internal region of ink area, then begins to increase near to the junction of ink areas. For the ink area that has larger ink key opening size, the ink layer thickness increases slightly near to the interface.

Above conclusions provide a reference to the mutual influence between ink areas in the actual printing process and it's important for the printing color quality control and has a better application prospect.

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