Modelling the Ink Current in the Screen Presses Using the Roller Squeegee

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The usage of a roller squeegee instead of a flat roller in screen printing devices is proposed in this paper. It reduces image distortion on impressions and increases printing speed. The ink pressure caused by the movement of the roller squeegee forces ink through the screen until contact is made between the cylinder and the printing substrate. It results in the print definition loss. The model of ink current in the working layer in the screen printing devices with the roller squeegee was developed to determine the range of the roller squeegee applicability. The model is described by Navier-Stokes equation in a system with the continuity equation. The flat case of the stationary viscous liquid motion which is due to a large length of the roller squeegee is considered. A computer program has been developed to solve these equations. Despite an assumption of the stationary fluid motion the equations are solved with the technique of the time definition to get better stability of the solution. The calculations obtained with the help of the computer program for different ink quantities in the space between the roller squeegee and the screen are represented. The calculations have shown that the ink current depends on its quantity that is confirmed by experience. Over time some whirlwinds appear in the ink and determine the pressure distribution on the screen. In the first approximation it is agreed that when the ink is moving it does not get into the gap between the roller squeegee and the screen. Therefore, the pressure in the gap between the roller squeegee and the screen base tends to infinity which is not the case. We have defined the main areas for further development of the ink current model to get better matching between the calculations and the experimental results.

Introduction

The basic tendencies of the development of the printed matter market are directly connected with screen printing (continuous and selective varnishing, metallized, fluorescent, light-reflecting inking, etc.). The wide application of this printing method allows to receive steady growth of a screen printing share in the market of graphic arts services up to 4-6 % a year. At the same time the drawbacks of the screen printing are well-known and the main of them are – low speed and great geometrical image distortions on a print when using flat-bed presses and impossibility to use plates of the big diameter in rotary screen printing. The reason of it is the plate deformation that is caused by the classical squeegee. The specified defects constrain the development of screen printing. The problem solving of screen printing development we see through applying printing devices with a roller squeegee that will allow to expand essentially technological opportunities and to eliminate the reasons interfering its development. On fig. 1 the ink current in a working layer is schematically shown when using the roller squeegee.

Statement of a problem

Owing to the big extent of the roller squeegee with regard to its diameter we can pass on consideration of the flat current that is schematically shown on fig. 1 where the roller squeegee 1 is sliding along a surface of the plate 2. Under the action of the roller squeegee 1 the ink paint from a working layer 4 is pressed through the screen basis of the plate 2 and passes to a printed material 5 creating the image 6. The ink consumption through printing elements of the screen printing plate is insignificant concerning all volume of the working layer.

In the simplified kind the scheme of the printing device is shown on fig. 2. The section of the roller squeegee is a circular cylinder. The printing plate can be presented as a flat surface which we shall name a rolling level. We consider that the cylinder 1 slides without slippage along a motionless flat surface 5. The cylinder 1, the rolling level 5 and the working layer 4 have significant extent in a direction that is perpendicular to the plane of the figure.

As a first approximation we consider that the ink consumption from the working layer 4 is absent and all liquid moves inside of it. The cylinder 1 rolling along the rolling level 5 forces all volume of the liquid in the working layer 4 to move ahead of itself

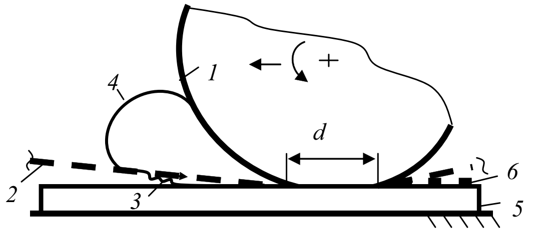

Fig. 1. The scheme of ink current in a working layer:

1 – roller squeegee; 2 – plate;
3 – the ink in the working layer pressed through the plate;
4 – ink working layer;
5 – printing material;
6 – ink layer on a print;
d – contact zone

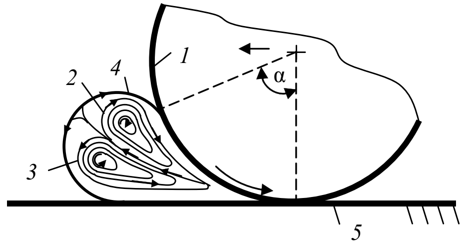

Fig. 2. The simplified scheme of the printing device:

1 – cylinder;
2, 3 – circulating streams;
4 – working layer;
5 – rolling level

in a direction of a travel. It is supposed that when the cylinder moving along the rolling level, two circulating streams noted on fig. 2 in figures 2 and 3 are formed in the working layer.

While the cylinder moving in a working layer, there is a hydrodynamic pressure that forces ink to pass through the screen until the reliable contact between the cylinder and a printing material that is noted on fig. 1 with figure 3. Thus ink runs are formed on a print and cause the incorrigible defects. However there are modes of printing process when pressure in a working layer does not exceed pressure of ink passing through the screen that allows to print without defects. A problem of the given work is developing to a first approximation the ink current model in the working layer that could become a tool for searching printing process parameters allowing to receive qualitative prints by means of the roller squeegee.

Development of the ink current model in the working layer

Screen printing ink is a viscous liquid with dynamic viscosity of the order 15-20 Pa•s. The ink current in view of its viscosity is described by Navier-Stokes equation in a system with the continuity equation [5]:

$$\frac{\partial \overline{V}}{\partial t} + (\overline{V}, \nabla)\overline{V} = -\frac{1}{\rho}\, grad\, P + \overline{F} + \nu \nabla^2 \overline{V} \qquad (1)$$

$$div\, \overline{V} = 0,$$

where: $\overline{V}$ – speed; P – pressure;
ρ – density of a liquid;
$\overline{F}$ – mass forces; t – time;
∇^2 – Laplace operator;
ν – factor of kinematics viscosity.

For formalization of the problem we shall make following assumptions:

- we consider ink as viscous incompressible liquid;
- we consider stationary current in a plane is perpendicular to axis of the roller
- we consider the roller surface and the rolling level are absolutely rigid;
- the ink consumption from the working layer is absent.

Then the system (1) becomes:

$$\begin{cases} \dfrac{\partial u}{\partial t}+u\dfrac{\partial u}{\partial x}+v\dfrac{\partial u}{\partial y}=-\dfrac{1}{\rho}\dfrac{\partial p}{\partial x}+\dfrac{\mu}{\rho}\left(\dfrac{\partial^2 u}{\partial x^2}+\dfrac{\partial^2 u}{\partial y^2}\right) \\ \dfrac{\partial v}{\partial t}+u\dfrac{\partial v}{\partial x}+v\dfrac{\partial v}{\partial y}=-\dfrac{1}{\rho}\dfrac{\partial p}{\partial y}+\dfrac{\mu}{\rho}\left(\dfrac{\partial^2 v}{\partial x^2}+\dfrac{\partial^2 v}{\partial y^2}\right) \\ \dfrac{\partial u}{\partial x}+\dfrac{\partial v}{\partial y}=0, \end{cases} \qquad (2)$$

where: u, v – speed components of the liquid point moving towards axes x, y accordingly, p – liquid pressure, μ, ρ – kinematical viscosity of the liquid and its density.

To solve bidimentional Navier-Stokes equation the optimal is the approach with use of coordinates «whirlwind – stream function» [1, 2] according to which the replacement of variables is done passing from the speed component to the whirlwind and the stream function which is defined by the following ratio

$$u=\frac{\partial\psi}{\partial y},\qquad v=-\frac{\partial\psi}{\partial x} \qquad (3)$$

and automatically satisfies to the continuity equation. The whirlwind is defined by the following ratio:

$$\xi=\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}. \qquad (4)$$

Using new independent variables the initial system of the equations (2) is reduced to two equations:

$$\frac{\partial\xi}{\partial t}+u\frac{\partial\xi}{\partial x}+v\frac{\partial\xi}{\partial y}=\frac{\mu}{\rho}\left(\frac{\partial^2\xi}{\partial x^2}+\frac{\partial^2\xi}{\partial y^2}\right) \qquad (5)$$

$$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}=-\xi. \qquad (6)$$

Expression (5) refers to as the whirlwind transport equation, and expression (6) – Poisson equation. As a result of such replacement the mixed elliptic and parabolic system of Navier-Stokes equations for incompressible liquid is transformed to one parabolic equation (the whirlwind transport equation) and one elliptic (Poisson equation) [4].

Despite of the assumption about stationarity of the movement these equations usually are solved with the pseudoviscosity time method that explains the presence of the time component in the equation (5). It is explained that solving stationary Navier-Stokes equation without taking into account the time component leads to instability [1, p. 618].

The pseudoviscosity time method consists of following steps.

1. At the moment of time $t = t_0$ initial values of a whirlwind and stream function are set.
2. The equation (4) for ζ in each internal point of the loading diagram during the moment of time t+Δt, where Δt – a step of time integration is solved.
3. Solving the Poisson equation (6) new values ψ in all points of the screen on new values ζ in internal points are found.
4. The speed components from the equation (3) are defined.
5. Values ζ on borders according to values ζ and ψ in internal points are counted.
6. If the solution does not converge come back to the step 2.

Having finished this procedure the speed components are defined in each unit of a computational screen. To determine the pressure in each screen unit is necessary to solve one more equation called as the Poisson equation for pressure which is received by differentiation of the first system equation (2) throughout x, and the second – throughout y. Then these results are summed up and using the continuity equation it is reduced to the following type:

$$\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 p}{\partial y^2}=2\rho\left(\frac{\partial u}{\partial x}\frac{\partial v}{\partial y}-\frac{\partial u}{\partial y}\frac{\partial v}{\partial x}\right). \qquad (7)$$

In a case of a stationary problem the Poisson equation for pressure is solved only once after the established values of the whirlwind and the stream function have been calculated. Considering (3) we shall write down expression (7) through the stream function:

$$\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 p}{\partial y^2}=2p\left(\left(\frac{\partial^2\psi}{\partial x^2}\right)\cdot\left(\frac{\partial^2\psi}{\partial y^2}\right)-\left(\frac{\partial^2\psi}{\partial x\partial y}\right)\right). \qquad (8)$$

Boundary and entry conditions are set according to the sticking condition of the liquid to the stream border. On surfaces 1 and 2 speed that is directed on a tangent to them is set. A return stream is assumed to exist inside of a computational field and participate in forming two circulating currents.

Speed that is directed as shown by arrows on fig. 2 and the pressure equal atmospheric are set on a free surface. The speed on a return current line is equal to the linear speed of borders 1 and 2.

According to the described algorithm the computer program in language C++ is developed. When starting the program the raw data are entered: radius of the cylinder, circumferential speed, a backlash between the roller and the rolling level, the angle φ, the ink density, the kinematical factor of liquid viscosity, the quantity of cells into which the computational field is broken. The result is deduced in the form of a field of speeds and distribution of pressure.

Results of calculations

On fig. 3A-D results of calculations for the following raw data are given: kinematical ink viscosity 20 Pa•s; the density 0,00128 g/mm3 (corresponds to the viscosity and density of many kinds of screen printing ink), the radius of the cylinder of 50 mm, a backlash between the cylinder and the rolling level 0,01 mm, angular speed 10 rad/s. The ink quantity is defined by the angle between a horizontal and a line connecting the center of the cylinder and the top edge of a free surface. On fig. 3A distribution of a field of speeds for the minimum ink quantity that is α=30° is shown. The direction of whirlwinds rotation is shown with arrows. The work-

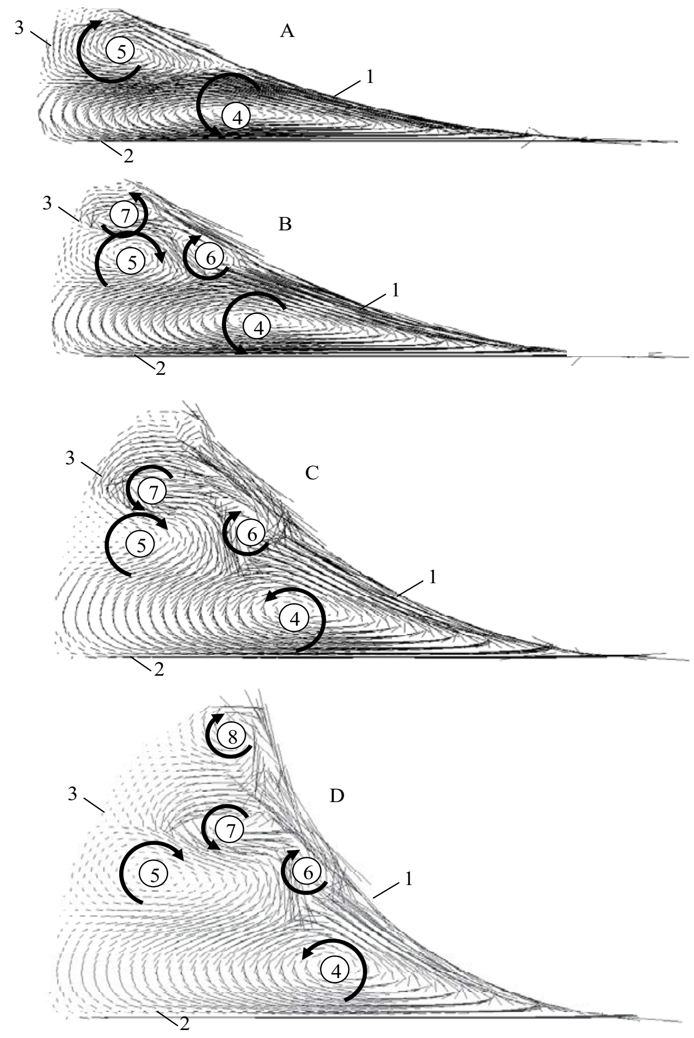

Fig. 3. Change of a field of speeds depending on a corner defining quantity of a paint in a working layer: A – $\alpha=30^0$; B – $\alpha=40^0$; C – $\alpha=60^0$; D – $\alpha=80^0$;
1 – a surface of the cylinder; 2 – a plane качения the cylinder;
3 – a free surface; 4, 5, 6, 7, 8 – whirlwinds

ing layer is borrowed with two alternate whirlwinds 4 and 5. At α=40° (fig. 3B) appears a pair of alternate whirlwinds 6 and 7 located in the top part of a working layer that becomes more appreciable on fig. 3 C at α=60°. Thus the distance between whirlwinds increases and intensity of the bottom pair whirlwinds is less than intensity of the top pair about that is seen through the sizes of speed vectors. Current with the maximum ink quantity in the working layer (α=80°) is characterized by occurrence of one more whirlwind 8 (fig. 3 D) located in the top corner of the working layer. The length of speed vectors shows that the intensity of the whirlwind 5 is the lowest and whirlwinds 7 and 8 – the highest. Thus, with increasing ink quantity in the working layer the current becomes more complex and the alternate whirlwinds with different intensity are appearing in it.

Trends of the further researches

Using the developed model the computational pressure upon the rolling cylinder line is equal to infinity. It mismatches the validity and does not allow to use the model for calculating printing devices using the roller squeegee. Therefore one of the primary goals the decision of which is necessary to develop the current model is the account of the ink consumption through printing elements. It is possible to assume that the small ink consumption from the working layer will not essentially influence the speeds distribution but obviously will make the pressure in the working layer to be final. Further, the deformation of an elastic environment by which the surface of the roller squeegee is covered will affect the pressure volume, therefore the next step in developing the specified model is calculating the deformation of an elastic environment

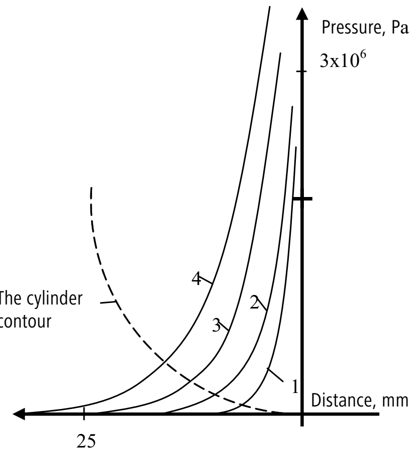

Fig. 4. Pressure distribution in the working layer:

1 – α=30°;
2 – α=40°;
3 – α=60°;
4 – α=80°

On fig. 4 the pressure distribution in the working layer for different ink quantity is shown. As the ink consumption from the working layer is not stipulated so in the point of the minimal distance between the cylinder and the rolling level the ink speed becomes equal to zero, and pressure – infinity. The resulted schedule allows to make only qualitative pressure assessment in the working layer as for the exact quantitative estimation it is necessary to consider the ink consumption through printing elements of the plate.

under the action of hydrodynamic pressure in the working layer.

Conclusions

1. The ink current model in the working layer of a screen printing device with the roller squeegee was developed. As a basis for the model the Navier-Stokes equation in the system with the continuity equation was used. All results were solved numerically.
2. Calculated results in the form of the speeds field and the pressure distribution to the rolling level were derived. It was established that when ink is quantity increased in the working layer there are additional whirlwinds that are absent in entry conditions and their movements are more complex. If the ink consumption is absent the pressure in the working layer becomes equal to infinity.
3. On the basis of this data, further steps in developing the ink current model in the working layer of a screen printing device with the roller squeegee are determined.

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