Software for Quantitative Estimation of Coefficients of Ink Transfer on the Printed Substrate in Offset Printing

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Abstract. In the framework of standardizing the process of offset printing, one of the most important tasks is the correct selection of the printing system components, taking into account the features of their interaction and behavior in the printing process. The program allows to calculate the transfer of ink on the printed material between the contacting cylindrical surfaces of the sheet-fed offset printing apparatus with the boundaries deformation. A distinctive feature of this software product is the modeling of the liquid flow having free boundaries and causing deformation of solid boundaries when flowing between the walls of two cylinders.

1. Introduction
In a number of Russian and foreign papers, various approaches to the mathematical description of ink devices, the transfer and splitting of printing ink. They are mostly based on a system of algebraic equations that reflect the addition and division of ink layers in contact zones, the use of which allows solving the dynamic problem of transferring paint layers on the printout [1-4].

In connection with the computer hardware and software possibilities expansion, which greatly simplified the modeling of hydrodynamic processes, the works of H Rech, John MacPhee, B Patzel and R Ruder, Y Ozaki., M. Kimura and others are of high scientific interest [5-7].

It should be noted that in most papers qualitative analysis of the process under investigation is given. Data on the paint splitting with a simplified half-cleavage with zero absorbency are given. It is conventionally accepted that the paint layer is divided in half along the separation angle. Another drawback of the works published on this issue is insufficient attention to the incorporation of ink absorption into the paper pores, along with its fixation on the surface and taking into account the characteristics of the surface microgeometry.

Along with the experimental methods, theoretical methods are intensively developed. Among them, the use of modern modeling theory, in particular computer modeling, is an important research tool. This approach provides the most accurate and maximum adequate real process to study the change that occur in practice when moving the ink layer between rotating cylinders of the printing apparatus and the interaction of the paper porous structure with the liquid medium.

2. Statement of the problem
When solving the problems defined, it is necessary to overcome significant mathematical difficulties due to both the nonlinearity and complexity of the equations themselves and the need to determine the free surface when solving the system of partial differential equations. The search for new solutions of this problem emphasizes its relevance.
3. The problem solution

To solve the problem, the authors developed an algorithm and its software implementation [8-10]. The program algorithm works with data sets describing the two-dimensional fluid motion and given in the calculated polar coordinate system $\theta$ in the form of a discrete set of points in which we apply the finite-difference equations in the transformed Oxy, coordinate system, which is polar and is presented for a more convenient consideration of the calculation results.

The program calculates the fluid flow between the contacting cylindrical surfaces with the boundaries deformation. A distinctive feature of this software product is the modeling liquid flow which has free boundaries and causes solid boundaries deformation when flowing between the walls of two cylinders. After the file opening and the introducing of data in the input lines of the file with their further preservation, the program allows to make calculations with the preservation of numerical data in a separate file of intermediate and output data and graphical visualization of the described process.

Figures 1-2 present the screen forms of files with input data and the calculation of speed arrays while modeling the transfer of ink from the cylinders of the offset printing machine to the substrate.

Figure 1. Data input interface.

Figure 2. Interface for computing speed arrays when modeling the ink transfer to a substrate.

The algorithm for the numerical modeling of the flow (transfer) of a viscous incompressible fluid with free boundaries between rotating cylinders consists of the following blocks:

Block 1 is responsible for the description of all variables, including data arrays.
In block 2, a number of parameters and initial data, such as pressure values, velocities, cylinder radii, mean pore radii and others are set; the formation of all calculated arrays at time \( t = 0 \) is made.

The input of calculated data from the control point at a certain time point, which was final in the previous calculation or the transition to calculation with all initial data, is carried out in block 3.

In block 4, the values are determined at the time \( t \) and the values from the file are input for all necessary parameters at the modeling start or at the moment of the calculation continuation with the control point. Besides, the parameter for using the control point and the end time of this calculation with the creation of the next control point are set.

Additional arrays formation at the initial moment of time \( t = 0 \) or time instant \( t \) from the control point and transition to data with increment of time by the iteration step \( \tau \) is performed in blocks 5 and 6, accordingly.

Block 7 calculates the movements of the free boundaries of the fluid and the boundaries of the cylinders as a function of the velocity field and the forms computed nodes that fall within the fluid boundaries.

The verification of fluid adhesion conditions on the cylinders is performed in block 8.

In block 9, the iterations begin to calculate the pressure and determine the termination condition for the iterations.

The calculation of velocities, displacements of free fluid boundaries and markers for their geometric determination is performed in block 10.

The calculation of pressure, determination of the adhesion condition in the internal fluid computation nodes, including contiguity to the free boundary, verification of the condition for setting the iteration for the pressure and subsequent exit from the iteration cycle are performed by blocks 11 and 12, respectively.

In block 13, the amount of ink absorbed into the pores of the printed material is calculated.

In block 14, the curvature radii of the fluid free boundaries are calculated together with the determination of the surface tension forces for the boundary nodes.

In blocks 15 and 16, the condition for the termination of the iterative process with respect to time is checked (block 15) and the current lines are determined by the calculated velocity field (block 16).

Block 17 records all calculated data at the final point in time with the creation of a control point for possible subsequent continuation of the calculation.

Block 18 provides additional output of data to files and closing of files.

For numerical modeling, some programs were developed in the Fortran PowerStation v.4.0 software package [11-12].

The results of practical testing of the developed software algorithm are shown in Table 1. Angular rotational velocity of the cylinders is equal to 10 rad / s. \( P = P_{\text{atm}} = 10^5 \) Н / м² is the pressure of the environment, \( \nu = 0.012 \) м² / с is the kinematic viscosity. The initial dimensions of the liquid region were \( \delta L = 4 \) μm and \( \delta S = 2 \) μm, \( \delta = 1 \) μm represents the substrate thickness, the radii of the cylinders are \( r_1 = r_2 = 0.13 \) м.

### Table 1. Numerical modeling results.

| Paper sample number | Paper roughness, \( \mu m \) | Average pores radius, \( \mu m \) | Quantity of paint, transferred onto the paper, % |
|---------------------|-----------------------------|-----------------------------|-----------------------------------------------|
|                     |                             |                             | Penetrated into the paper structure | On the paper surface | Total paint quantity on the printout |
| 1                   | 0.250                       | 60                          | 7.49                     | 47.15          | 54.65                           |
| 2                   | 0.450                       | 110                         | 5.28                     | 47.13          | 52.31                           |
| 3                   | 0.350                       | 1000                        | 37.42                    | 35.07          | 72.49                           |

A uniform grid with the number of computed nodes with two coordinates and equal to 80 was used, which allowed to analyze the convergence and behavior of numerical solutions with an accuracy of 1% for Reynolds numbers about 1. The flow type is laminar.

A fragment of the program for calculating ink absorption into the pores of the printed substrate and determining the boundaries near the cylinders is shown in figure 3.
761 continue
goto 755

    if(krasch1(i,j).eq.1)goto 762
    if((kdisk1(i,j+1).ne.1).and.(krasch1(i,j-1).ne.1))goto 762
    u1(i,j,2)=(u1(i,j+1,2)+u1(i,j-1,2))/2
    v1(i,j,2)=(v1(i,j+1,2)+v1(i,j-1,2))/2
    krasch1(i,j)=1
    ekgr1(1,i,j)=hx/2
    ekgr1(2,i,j)=-hx/2
    ekgr1(3,i,j)=hy/2
    ekgr1(4,i,j)=-hy/2
762 continue
750 continue
755 continue
jn=jdisk1(i)
do 758 j=jn,nj
    v1(i,j,2)= t_v1(i)
758 continue
759 continue
6753 continue

    ybum_d2=dabs(s1) ! maximum ink absorption
do 729 i=2,nim1
    jdisk12(i)=jdisk11(i)
do 730 j=1,njm1
    j1=nj-j
    if(j1.ge.jdisk11(i))goto 736
    if(krasch1(i,jdisk11(i)).ne.1)goto 734
    jdisk12(i)=j1
734
736 continue

Figure 3. Fragment of the program for calculating ink absorption into the printed substrate pores.

When calculating fluid flows between the contacting surfaces, the deformation of the surface layers of rubber and paper resulting from the change in pressure in the fluid contacted with them was recorded. Taking into account the smallness of the relative motion velocities of the compression surfaces with the difference between the internal and external pressures \( P_1 - P_0 \) with the time-dependent deformation of the boundary \( \Delta r \) for the thickness of the paper or rubber layer \( H \) of area \( S \) having elasticity modulus \( E \), the changes in the center \( x_c \) of the layer thicknesses were calculated according to the following equation:

\[
\rho H S \ddot{x_c} / 2 = -\frac{E}{H} \left( \Delta r / 2 + x_c \right) \cdot S + (P_1 - P_0) \cdot S
\]

Program implementation on calculation the deformation values was carried out according to the algorithm written in Fortran (Figure 4).

c Calculating the boundaries deformation for the 1\(^{st}\) and the 2\(^{nd}\) disk
do 442 i=1,ni
    r1i00(i)=r1
    r2i00(i)=r2
do 442 j=1,nj
    dtxy1(i,j)=0
\[ dtxy2(i,j) = 0 \]

442 continue

do 127 i=2,nim1
kdisk1(i,nj)=1
kdisk1(i,1)=2

do 127 j=2,njm1

\[ dtxy1(i,j) = 0 \]

\[ x3 = r1i(i) \]

\[ x4 = r2i(i) \]

\[ x1 = \text{dabs}(p0 + dobpw(j)) \]

\[ x12 = \left( p1(i-1,j,2) + 2*p1(i,j,2) + p1(i+1,j,2) + p1(i,j-1,2) + 2*p1(i-1,j-1,2) + p1(i+1,j-1,2) \right) / 8 \]

if ((kdisk1(i,j).eq.0).or.(kdisk1(i,j).ne.0).or.(kdisk1(i,j+1).ne.0)) goto 311

\[ x5 = \text{cnatrez}/\text{plt} \times \text{rom1}(3,i,j) \]

\[ x71 = \tau \times \tau \times (x12 + x5 - x1) \times \text{plt} / (\text{tlrez} \times \text{pltr}) \]

\[ x81 = \tau \times \tau \times \text{un1rez} / (\text{tlrez} \times \text{tlrez} \times \text{pltr}) \]

\[ x83 = x81 \times (r1 - x3) / 2 \]

\[ x85 = (x71 - x83) \]

\[ x87 = \text{dsqrt}(x85 \times x85 + \tau \times \tau \times \text{dt_v1}(i) \times \text{dt_v1}(i) \times \text{coefs3}) \]

if (x85 lt 0) x87 = -x87

\[ r1i00(i) = x3 - x85 + x87 / (1 + x81) \times \text{crez} \]

if (r1 - r1i00(i) gt r1 - tlrez/2)

if (r1i00(i) .gt. r1)
r1i0(i) = x3

\[ dtxy1(i,j) = (x3 - r1i(i)) \]

311 continue

if ((kdisk1(i,j).eq.0).or.(kdisk1(i,j+1).eq.0).or.(kdisk1(i,j-1).eq.0)) goto 312

…….

312 continue

127 continue

do 443 i=2,nim1

do 443 j=2,njm1

\[ * \text{dt_v1}(i,j) = (r1i0(i) - r1i(i)) \]

if ((kdisk1(i,j).eq.0).and.(kdisk1(i,j+1).eq.0).and.(kdisk1(i,j-1).eq.0))

\[ * \text{dt_v1}(i) = (r1i0(i) - r1i(i)) / \tau \]

443 continue

**Figure 4.** Fragment of the program for calculating the deformation boundaries.

For the considered modeling parameters for sample number of paper 1 in figure 5, the calculated visualization picture of the paint splitting cavity formation and growth at the initial stage with the appearance of strands and dusting.

**Figure 5.** The ink splitting cavity appearing.
4. Conclusion
Software implementation of the developed algorithm allows:
• to calculate the transfer coefficients of ink on the substrate to be printed under offset printing, taking into account the deformation of the printing system components;
• to calculate the absorption of the paint in the porous surface of the printed material;
• to help automating the control of print quality indicators.
All the factors mentioned confirm the practical and scientific significance of this development and contributes to its improvement, taking into account the further evolution of computer technology.

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