Simulation of Paper Transport to Design the Paper Path of a LBP

Chunghwan Kim and Douksoon Cha
Digital Printing Division, Samsung Electronics Co., Ltd.
Suwon City, Korea

Abstract

The paper path of a laser beam printer (LBP) is an important factor which can affect jam, skew and acoustic noise due to paper transport. As the process speed of the printer is increased and the changing cycle of a model is reduced, the prediction of paper transport is required. Until now, the design of a paper path has been relied on the sense of a designer. But as the process speed of the printer increases, the inertia of paper, which affects the behavior and deformation of paper, also increases, which makes it difficult to predict paper transport and to apply the existing results achieved in other applications to new application. Thus, there have been many trials to predict paper transport using simulation tools. In this paper, the dynamic behavior of paper of a LBP is investigated using RecurDyn, which is a dynamics analysis software, to suggest a design method of a paper path. There showed some examples; applications of the ADF path design of a multifunctional LBP (MFP), the exit path design of a LBP, the paper guide design of a LBP for low acoustic noise and so on.

Introduction

Recently, the performance of office automation (OA) machines such as printer, facsimile and copier is on a rapid increasing trend. In special, the technical development speed of resolution, printing quality, speed and price for needs of customers is very amazing. Thus, the capability of a company to catch up with these needs is the very competitiveness of the company. In the LBP including the MFP, successful transport of paper can be achieved under the conditions of jam free, skew free and double-feeds free. These conditions are the necessary ones that must be achieved for the least needs of customers and mainly affected by the paper feeding based on a paper path. Thus, it is not too much to say that the design of a paper path is the fundamental technology of the design of the printers. Specially, in the recent trend in which the LBP and MFP are speeding up and spreading over home, not only paper feeding problem but also acoustic noise due to paper transport and scanning quality of the MFP are rising to be important problems.

But until now, the design of a paper path has been relied on the sense and experience of a designer. Moreover, a development procedure is consisted of the repeat process of design, manufacturing of a prototype, test and modification of the design, which takes a long time to develop a product and accompanies with the increase of cost. In addition, it is very difficult to find the causes of problems and to modify the design because in the most cases, we should modify the layout to modify the paper path. As the process speed of the printer increases, the inertia of sheet which affects the behavior and deformation also increases, which makes it difficult to predict paper transport and to apply the existing results achieved in other applications to new application. Thus, there have been many trials to predict paper transport using simulation tools. In this paper, the dynamic behavior of paper of the LBP is investigated using RecurDyn, which is dynamics analysis software, to suggest a design method of paper path.

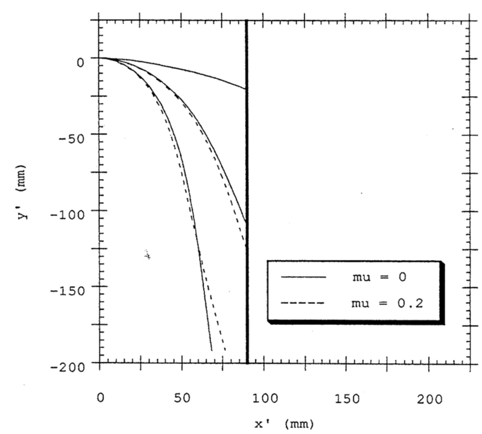

Figure 1. Result of Stolte and Benson[1,2]

Simulation of Paper Transport

Examples of Simulation of Paper Transport

Paper transporting in the LBP undergoes large deformation and has nonlinearity due to it. The contact and the collision with a guide are also nonlinear problems, which make it difficult to analyze the behavior of paper. Different types of paper differ in density, thickness, friction coefficient and Young's modulus. In addition, the material properties change largely according to temperature and humidity, which makes different behaviors of paper for different conditions. The contact between rollers and paper varies with time, which makes paper have a time-varying boundary condition. Thus, it is impossible to find an analytic solution of paper transport. In general, FDM (finite difference method) is used to find the numerical solution.[1,2] Stolte and Benson[1,2] analyzed paper transport using FDM by quasi-linearization; modeling of paper as two degree-of-freedom beam using plate theory considering the bending rigidity. Figure 1 is the result of Stolte and Benson, which is the behavior of paper after paper collided with the guide for the two cases of friction coefficient between paper and the guide: 0, 0.2.

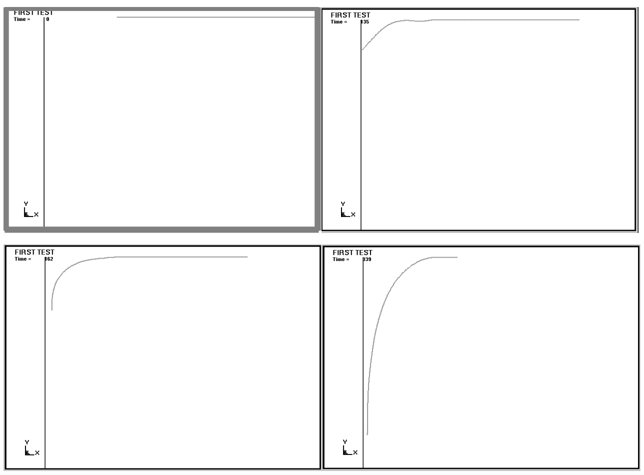

Figure 2. Result using LS-DYNA [3]

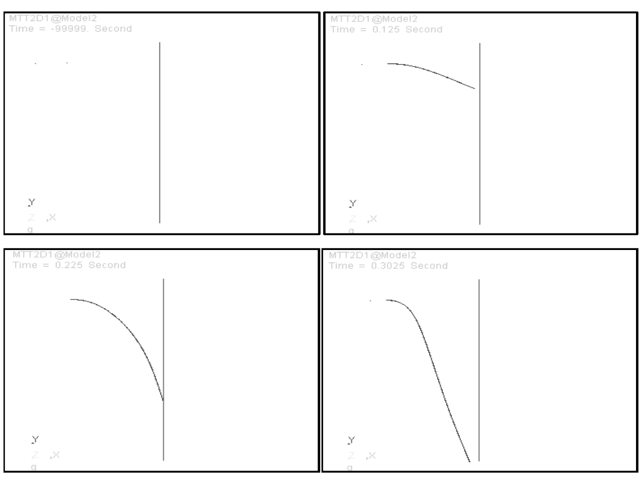

Figure 3. Result using RecurDyn

Cha[3] analyzed the behavior of paper which is modeled by three degree-of-freedom linear elastic shell element using FDM commercial code LS-DYNA and compared with the result of Stolte and Benson. Figure 2 shows the result of Cha, which is alike to Figure 1. Preceding works are mainly about the behavior of the leading edge of paper to investigate jam effect. But there is little work about the behavior of the end edge of paper which can affect the acoustic noise due to paper transport. In special, LS-DYNA is suitable for the analysis of the problem happened in very short time such as collision and drop, and so takes several hours to analyze paper transport.

Table 1. Values of Simulation Parameters of Paper

Parameter	Value
Density	7.5E^{-7} *Kg/mm*^{2}
Young's modulus	2.36 *Gpa*
Thickness	0.1 *mm*

Simulation of Paper Transport Using RecurDyn

However, since RecurDyn, which was developed recently, uses recursive formulation[4] in solver, it reduces solving time greatly. Moreover, it offers a MTT2D module which is a media transport analysis tool kit, which makes it easy to use. Figure 3 is the simulation result using RecurDyn for the same model with Figure 2 and shows the same result with that of Figure 2. LS-DYNA, the nonlinear dynamics analysis software, is the popular commercial code of which accuracy is verified by many applications. The identical results shown in Figure 2 and Figure 3 mean that DecurDyn offers a reliable result.

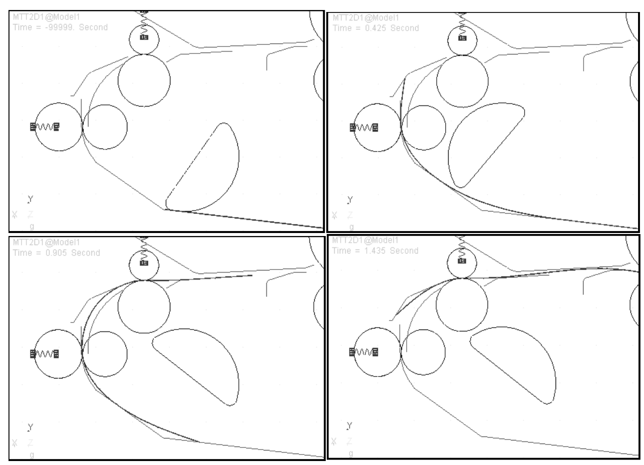

Figure 4. Simulation result of paper transport of the model

Figure 5. Photograph of paper transport of the model

For a more verification of RecurDyn, we compared the simulation results from RecurDyn with actual paper transport of the LBP in production. Figure 4 shows the model and the simulation result of the paper transport of the LBP from pick-up roller to feed roller and registration roller. Table 1 shows the parameter values of paper used in the simulation. Paper is modeled as 100 links with the length of 1mm for the reduction of solving time. Figure 5 is the photograph of the same part as in Figure 4 and shows the similar result with that of Figure 4 in the respect of the leading edge of paper, paper path and the position of the end edge of paper.

Paper Path Design of a LBP Using RecurDyn

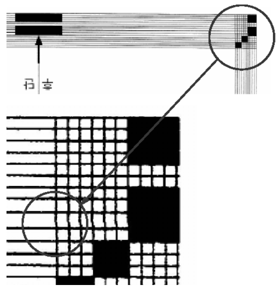

Figure 6. ADF scanned image of the MFP before improvement

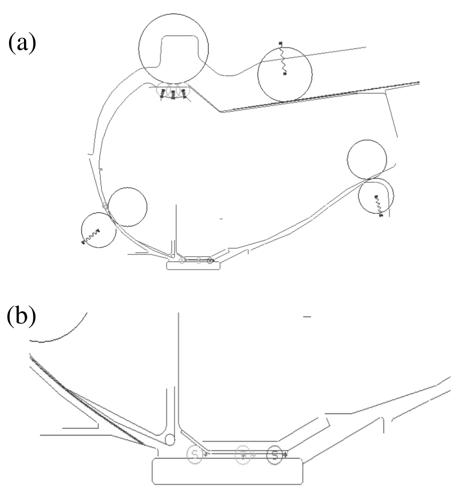

Figure 7. a. ADF paper path model of the MFP and b. Zoomed picture of scanning position

ADF Path Design of the MFP

On the state of the development of the MFP, we found that there was an expansion of ADF scanned image in the vicinity of leading edge of it like Figure 6. To find the cause of the expansion, we modeled the ADF path like Figure 7a and performed a simulation. Figure 7b shows the zoomed picture of the neighborhood of scanning position and Figure 8 shows the velocity of paper at scanning position. In this graph, the perturbation of velocity is due to a numerical error. As shown in this figure, there is the decrease of velocity at about 0.47 seconds. From the moving picture generated in simulation, we found that the decrease of velocity is caused by the movement of paper between two guides at scanning position and brings the expansion of scanned image. After modification of the shape of the guide and simulation, we found the shape of the guide that reduces the decrease of velocity as shown in Figure 9. Figure 10 is the result of the scanned image of MFP to which the modification of the guide is applied. As shown in this figure, the expansion of scanned image disappears.

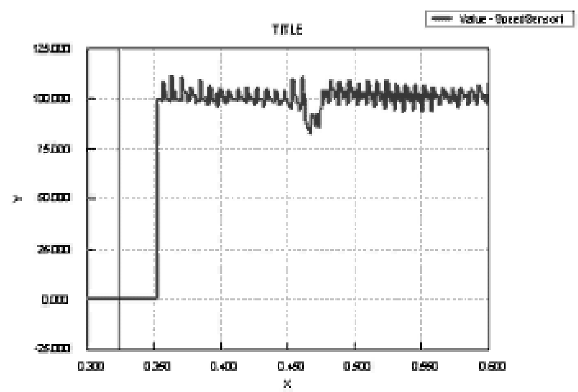

Figure 8. Velocity of paper at scanning position before improvement

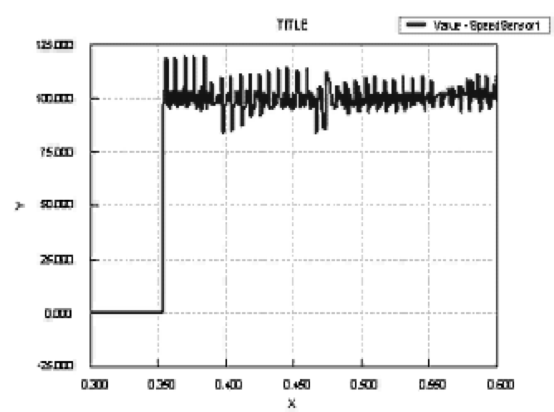

Figure 9. Velocity of paper at scanning position after improvement

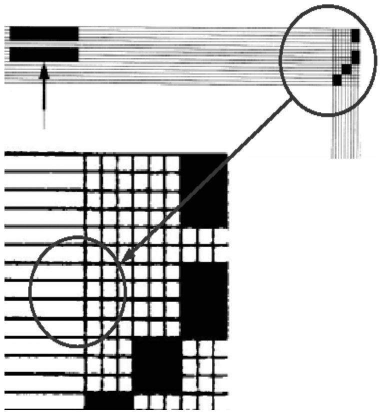

Figure 10. ADF scanned image of the MFP after improvement

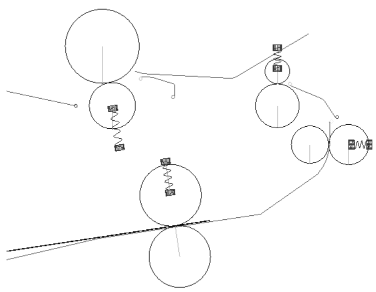

Figure 11. Paper path model of the LBP

Reduction of Acoustic Noise Due to Paper Transport

Figure 11 is the model of the paper path of the LBP. The paper path is very short. In special, the path from feed roller to registration roller is very short and has the path change at right angle. Due to this rapid change of the path, there are loud instant acoustic noises about 62~65dB caused by the collision of paper with guides and the contact of end part of paper with guides. In the advanced model modified from the LBP mentioned above, the length from feed roller to registration roller is extended. To reduce the acoustic noise due to paper path, several designs of guide between feed roller and registration roller are proposed and simulated by RecurDyn. Figure 12 shows three design samples. RecurDyn calculates the contact force between paper and a guide. The contact force relates with the acoustic noise due to the collision of paper with the guide. Table 2 shows the maximum values of contact force for four models shown in Figure 11 and Figure 12. As shown in Table 2, the maximum contact force of case B was reduced to about one-fifth of the case before modification of the guide. The measured acoustic noise due to the collision of paper with the guide was almost removed in the advanced design or case B of Figure 12, which confirmed the modification of the guide design proposed.

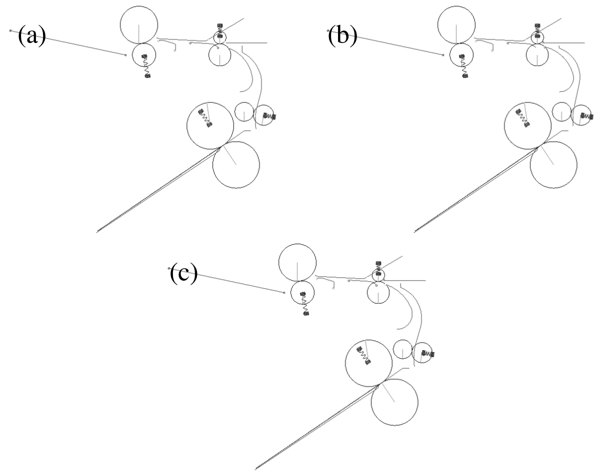

Figure 12. Advanced paper path models of LBP

Table 2. Maximum Contact Force for Four Models Shown in Figure 11 and 12

Cases (Before/After modification)	Maximum contact force (*mN*)
Before modification (Fig.11)	3.20
After modification-A (Fig.12a)	0.59
After modification-B (Fig.12b)	0.57
After modification-C (Fig.12c)	0.63

Improvement of the Exit Path of the LBP

Figure 13 shows the paper path of the LBP from OPC to fuser and two exit rollers. In the case of duplex printing mode after 170 thousands of pages of printing, the upper guide between fuser and the first exit roller is contaminated by toner. This occurs because the curls of paper make paper contact with the upper guide, which is caused by the decrease of linear velocity of the first exit roller due to the wear of roller. Therefore, the contamination can be eliminated by the increase of the radius of the first exit roller which has original radius R=6.65*mm*. But the excessive increase of roller radius brings the excessive increase of the linear velocity of roller and the excessive contact of paper with the lower guide between fuser and the first exit roller. We simulated paper transport for four cases of roller radius as shown in Figure 14 and chose the best one.

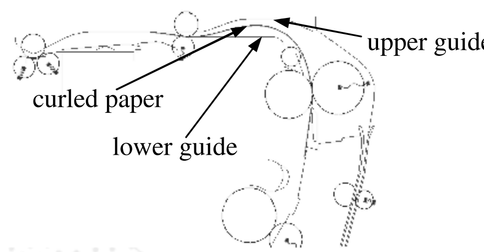

Figure 13. Paper transport of LBP with exit roller radius R=6.65 (original)

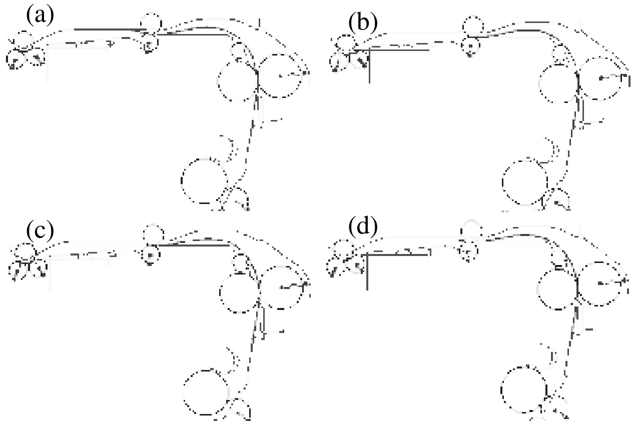

Figure 14. Paper transport of LBP with exit roller radius. a. R=6.70, b. R=6.75, c. R=6.80 and d. R=7.00

Conclusion

In this paper, the paper transport of the LBP is investigated using RecurDyn to suggest a design method of paper path. Some applications with verifications by experiments are shown for examples. The comparison of simulation results and experimental results verified the reliability of RecurDyn. The simulation of a paper path using RecurDyn at design step help the designers catch the behavior of paper and verify his design. Thus, the designers can make a stable and reliable paper path, which make it possible to reduce cost and time. For more accurate and reliable simulation results, we need more accurate experimental values of material properties of paper, rollers and so on.

References

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Biographies

Chunghwan Kim received his B.S. degree, M.S. degree and Ph. D in Mechanical Engineering from Korea Advanced Institute of Science and Technology (KAIST) in 1996, 1998 and 2003, respectively. Since 2003 he has worked in Digital Printing Division at Samsung Electronics Co. Ltd. His work has primarily focused on the paper path design and the reduction of acoustic noise.

Douksoon Cha received his B.S. degree from the Kyungpook National University in 1991, M.S. degree from the Pohang Institute of S & T in 1993 and a Ph.D. from the Pennsylvania State University in 1999 with a major of Mechanical Engineering. Since 1999 he has worked in the Digital Printing Division of Samsung Electronics Co,. He is interested in the acoustic noise reduction, banding artifacts of image and paper handling issues.