A FUTURE ONLINE CONCEPT FOR ROLL AND SHEET PRODUCTION IN PAPERMAKING TECHNOLOGY AND PROCESS REQUIREMENTS FOR WEB HANDLING

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ABSTRACT

The process of on-line converting is discussed as a chance to increase the productivity and quality in roll and sheet converting in paper mills. In this article the technical and process related prospects will be presented on the basis of an exemplary production line (WFC Paper) and transferred into realizable concepts for continuity paper converting.

In the case of roll production, the segment of large rolls with standard sizes is very suitable for an on-line-production, and in the case of sheet production the segment of larger lot sizes. In both cases a new machine design with altered functions and a higher level of automation and process control is necessary.

These alterations yield diverse requirements for web and sheet handling, which have to be fulfilled for a continuous and high-quality production. All fundamental technologies such as transport mechanics of webs and sheets, winding and stacking mechanics, slitting in length and cross direction as well as measurement and control techniques for the monitoring of converting processes in particular belong to this category. These technologies will be discussed and further tasks for research work will be presented.

INTRODUCTION

During the last two decades, the paper manufacturing industry has achieved a progress in the productivity of their production plants and in the qualitiy improvement of the products manufactured there as nearly no other industrial sector. This progress has been accomplished by employing new technologies for equipment and plants and, on the other and, has been caused by the increasing competition on the international markets for suppliers and customers.

For the continuous search for new potentials of improvement, the question of on-line production, from paper manufacturing to paper converting, currently plays a vital role. In modern paper mills, this change from off-line to on-line production has been realised, including the coating and calendering on a high production level for mass paper. The converting by winder and cross-cutter, however, still happens according to the well-tried technological standard. Here, the tambours are mass-produced off-line to rolls and sheets, and within a continuos converting process. This is particularly connected with the fact that on the one hand the variety of sizes, combined with a limited number of lot sizes, makes the use of technically complex plants compelling. On the other hand, compared to converting plants, paper manufacturing plants play a more important role when it comes to making investment decisions.

In this connection, this paper proposes technical perspectives for on-line converting, and related objectives for research and development are described and discussed.

PRODUCTIVITY CRITERIA IN PAPER CONVERTING

The economic effiency of production processes is connected to the aim to achieve maximal profit from the products produced by employing the minimal amount of resources and means of production. The economic efficiency thus defined depends on a high number of power factors, which charactarise a production process and the necessary means. Thus, besides the exclusive consideration of productivity, the influence of material handling and logistics are vital for travel-through and delivery times, or the availability and flexibility are important for the supply capability. These complex connections of the interrelated power factors cannot be described in detail in this paper. Rather, the criterion productivity is discussed in detail, in order to explain the research and development objectives which are primarily connected with this criterion, in the second section of this paper.

Productivity is a measurement for the efficiency of a production plant. It can be measured by a quantity related coefficient of efficiency η.

$$\eta = \frac{\textit{effective output}}{\textit{theoretical upper output limit}} [\%] \qquad (1)$$

Here, the coefficient of efficiency stands for the effective output by a plant, e.g. measured in tons per day, under consideration of the particular order- and production terms valid. The theoretical upper output limit represents the quantity efficiency, which could be achieved in a continuity-converting process under optimal production terms. The parameters determined by machine, paper, plant, and order terms, which influence the coefficient of efficiency, are shown in figure 1. Here, it becomes evident that the conditions and interactions of these parameters can be employed in a productivity analysis as well for winders as for cross cutters in the same way.

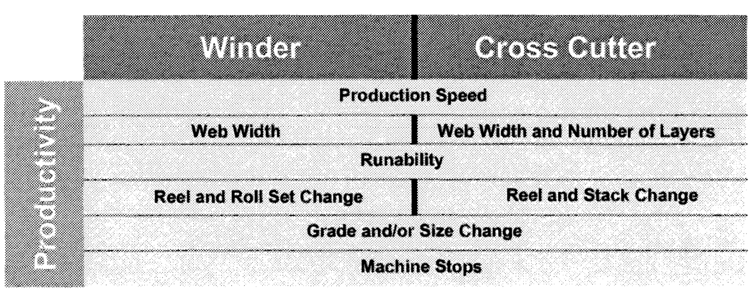


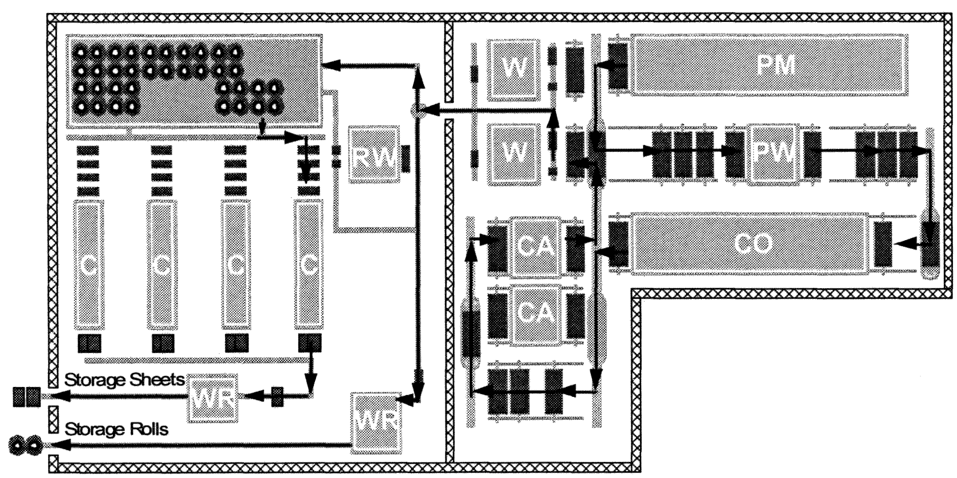
Fig.1: Parameters of productivity in paper converting

This coefficient of efficiency can now be used for evaluating the productivity of paper lines. Due to different questions, it is often necessary to pursue the evaluation within an absolute or comparing criterion, and, on the other hand, to pursue it for a paper line altogether or in sections. In order to answer these questions, the above defined coefficient of efficiency is highly applicable. Thus, e.g. the performance of an existing paper line can be approximated by analysing the actual data and a corresponding final analysis, with a total coefficient of efficiency, based on sectional single coffecients of efficiency. Equally, there is now the possibility, to check new investments for their productivity potentials by using corresponding target guidelines.

On this basis, the current level of technology of paper converting (off-line production with discontinuity-production sections) will be evaluated in the following and, resulting from this, a productivity increasing on-line concept with continuity-production will be developed. As practical example, a paper line for woodfree coated printing papers (WFC-paper) for manufacturing rolls and sheets is used.

OFF-LINE PRODUCTION WITH DISCONTINUITY PAPER CONVERTING

Up to now, the conversion of WFC-papers has taken place mainly in plants which are structured as shown in figure 2. Here, the raw paper is produced in off-line production steps and wound on tambours, then coated in separate coaters, again wound on tambours, and finally, calendered on separate calenders and again wound on tambours. This is followed by paper converting, usually by employing a number of winders and numerous cross cutters. Until now, these machines work to a great extent discontinuously.



PM Paper Machine
PW Prewinder
CO Coater
CA Calender
WR Wrapping Machine
W Winder
RW Rewinder
C Cross Cutter

Fig. 2: Typical off-line layout for a WFC – paper line

These discontinuity-converting processes are characterized by operating the machines dependent on the order, with the partular lot sizes and the resulting grade and size changings. The adjustments of equipment resulting from this have to be undertaken manually during a machine-stop.

The productivity losses of such a paper line result on the one hand from the highly divergent production performances of the respective machinery and, on the other hand, from the paper losses due to the winding and unwinding processes, which are necessary for up to 10 times. The following evaluations of efficiency focus on the machines used for paper converting.

Today, single-drum winders are employed as winders for such papers. They operate with a maximal production speed of approx. 2500 m/min, can wind roll diameters of up to approx. 1250 mm, ensure a roll set change within approx. 40 sec and a reel change within approx. 120 sec during a machine-stop. If one considers besides these performance-determining parameters of the machine further the performance determining parameters of the paper, like paper grade, grammage and size, the productivity can be expressed in a diagram of efficiency. Fig. 3 reveals the efficiency of such a winder for the listed and quantified parameters, reprented by the average production speed. Although the maximal production speed has been conceived to be 2500 m/min, only an average speed of approx. 1600 m/min is reached. This means that, compared to the theoretical marginal efficiency with maximal production speed, a coffecient of efficiency of not more than 64% is achieved.

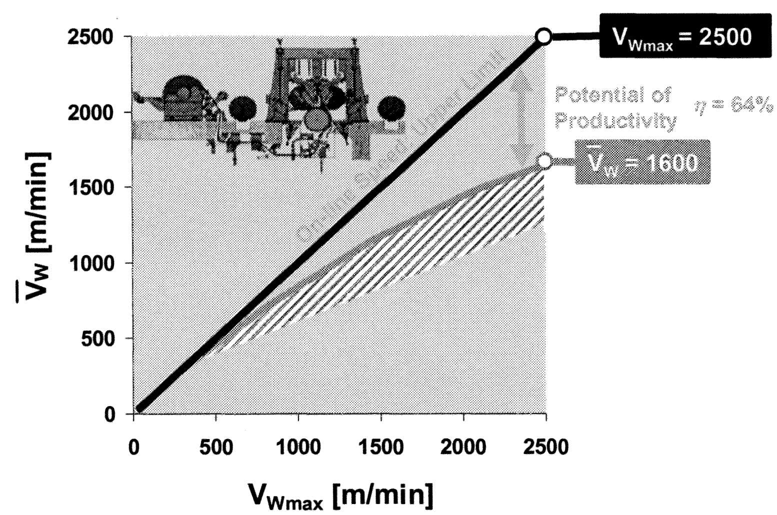


Fig. 3: Productivity of a single-drum winder in a WFC-paper line

In a similar manner, the efficiency of cross cutters in such a paper line was analysed. By considering the same parameters of paper and machinery parameters with a maximal speed of 400 m/min, a stack height of 1200 mm, a stack change within 210 seconds and a roll set change within 420 seconds, a diagram of efficiency as shown in fig. 4 is achieved. This reveals that with manual roll set- and stack changes and machinery adjustments dependent on paper grades and sizes, an average production speed of not more than 230 m/min can be reached. At the same time figure 4 shows the productivity potential, compared to a continuity-production at maximal speed, with approx. 42%.

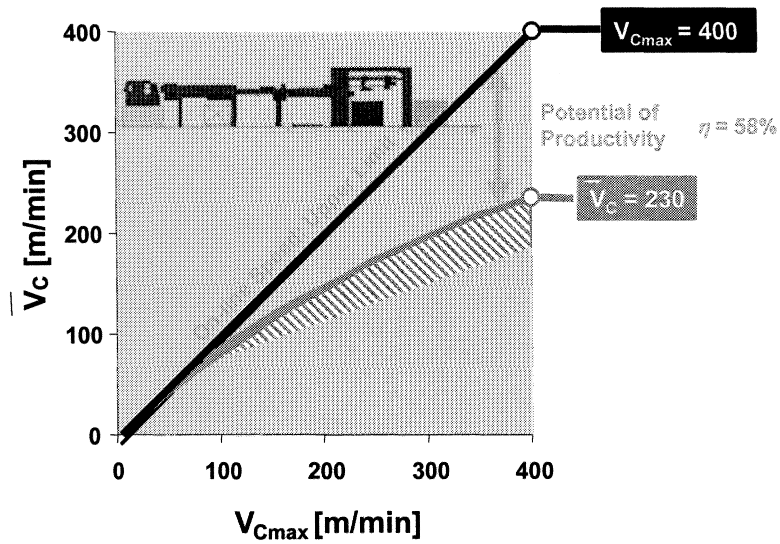


Fig. 4: Productivity of a cross cutter in a WFC-paper line

These results show that the productivity of paper converting alone offers a major potential for improvement. In a more detailed report [1] it could be proven that other relevant parameters for economic efficiency, like investment-, and running costs, availability and flexibility of machinery, materials flow and logistics of rolls and stacks as well as the quality of the roll and stack paper delivered, contain considerable improvement potential.

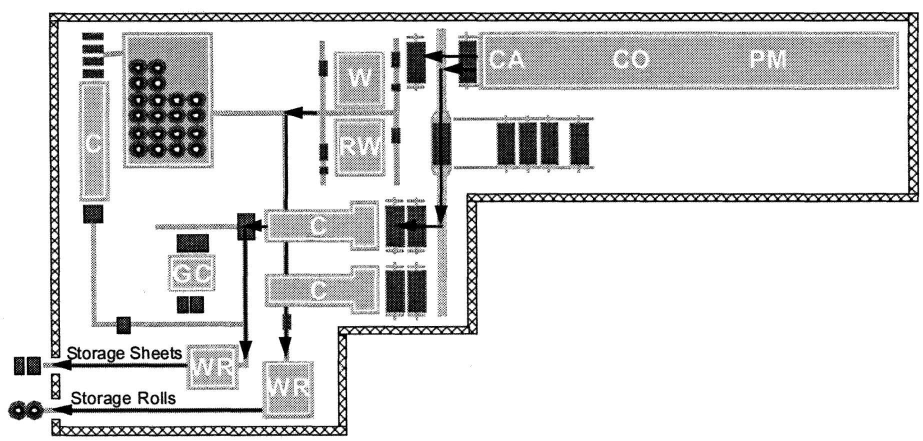
ON-LINE PRODUCTION WITH CONTINUITY PAPER CONVERTING

By on-line production, the integration of coating and calandering into the paper converter is meant. Today, new investments include this integration as well for the production of rotogravure paper as for offset paper. These on-line plants can currently operate with a production speed of nearly 1800 m/min with an expected further increase in speed to 2000 m/min and more. At a machine width of up to 10 m, approximately 400,000 tons of paper can be produced annually on such plants in the sector of rotogravure paper. With offset paper, this efficiency cannot be reached yet due to the smaller machine width. Nevertheless, these on-line plants will lead to new concepts in the field of paper converting.

Based on this context, a concept is developed in the following for future paper converting with continuously operating winders and cross cutters, in order to meet the noticeably increased productivity of future on-line plants.

By the explained results for discontinuously operating winders and cross cutters, it could be revealed that the limits of productivity are fixed through frequent production adjustments during machine-stop. Exactly at this point the concept for continuity-paper converting applies. A first approach to a solution contains the separation of the succession of orders with their high number of variants, according to orders, which contain standard paper grades and -sizes in a higher number and orders, which contain a small number of lot sizes with changing paper grades. The second approach, which concentrates on machine technology, logically focuses on the reduction of stillstand times for machinery. Here, it is aimed at reducing the adjustments of machines for grade and size changes due to changes in purchase order processing, but also at automazation, and further at realising tambour changes as well as roll and stack changes while the machines are operating. To render this approaches valid for sheet production on cross cutters, the tambours with more width, coming from the fore-running on-line plant, have to be directly processed, at least for standard production, without having been cut on the winder.

Fig. 5 shows a factory layout for roll and sheet production of WFC-papers under consideration of the mentioned concept terms. Therein, the on-line plant is followed by a continuously operating winder for standard products, which are processed directly from tambours, then wrapped and transported to storage. A rewinder is located parallel, which produces differing finished rolls from the pre-cut standard rolls. The area of the cross cutter contains two production lines, too, namely that one, which processes the standard products directly from the tambour with following stack wrapping and transport to storage. The second production line is fed by pre-cut rolls from the winder or the re-winder. These rolls are subsequently processed on a cross cutter, which is high-automated for size- and grade changings to the numerous sizes, divergent from the standard. Additionally, a guillotine cutter is intended, with which e.g. for just-in-time deliveries trimmed sizes can be processed from pre-produced standard sizes.



PM	**Paper Machine**	**W**	**Winder**
PW	**Prewinder**	**RW**	**Rewinder**
CO	**Coater**	**C**	**Cross Cutter**
CA	**Calender**	**GC**	**Guillotine Cutter**
WR	**Wrapping Machine**		

Fig. 5: Future on-line layout for a WFC-paper line

Without doubt, such a converting concept includes that numerous problems and questions concerning processes and machinery have to be solved or answered. In the following, the objectives concerning processes and machines will be listed, which have to be fulfilled in order to subsequently fulfil the perspectivally shown increases in efficiency within continuity paper converting.

Within the field of roll production the concept assumes that the winder fulfils the following conditions for standard production with new machine-constructions:

- Flying-splice reel change (at reduced speed)
- Non-stop stack change (at reduced speed)
- Automatical size change (at machine stop)
- Complete process and machine control

Under consideration of the thus achievable effects of increased efficiency, a efficiency diagram has been developed, which is shown in figure 6. Here, one can deduce that a winder thus equipped with a maximal production speed of 2500 m/min can reach an average production speed of 2300 m/min and thus a coefficient of productivity of 92 %. Applied to a winder operating discontinuously, this means an increase in productivity of 28 %.

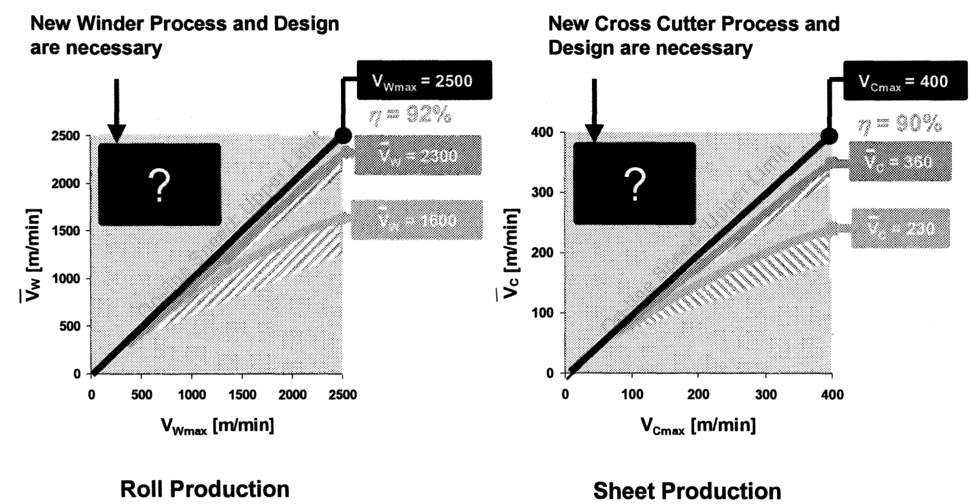


Fig. 6: Productivity of continuity - paper converting

In the field of sheet production, the following process- and machinery related demands are applicable for cross cutters, which operate in standard production processes. :

- Flying-splice reel change (at full speed)
- Non-stop stack change (at full speed)
- Automatical size change in lenghts direction (at machine stop)
- Automatical size change in cross direction (at reduced speed)
- Automatical pass-over of longwise cut sheets in multi-layer cross cutting
- Complete process and machine control

Upon fulfillment of these demands and the quantitative evaluation of the productivity increase, one can deduce via a corresponding computation of efficiency the result, as well shown in figure 6. Here, one can perceive that the productivity compared to a discontinuously operating cross cutter with a coefficient of 58 % increases to 90 %. This remarkable increase in productivity by 32 % will naturally only then become effective in an overall examination, if the amount of standard sheets produced is high enough.

This examination of a nearly achievable on-line concept shows a way with which future demands on efficiency can be fulfilled and which at the same time proves valid upon an economic evaluation by employing issues of investment- and running costs. A qualitative comparison of all relevant factors between discontinuity- and continuity-production is shown in figure 7. Here, it is evident that besides the increase in production with continuity-concepts, the production quality as well can be improved, investment- and running costs can be reduced, and noticeable improvements in logistics and material flow can be accomplished.

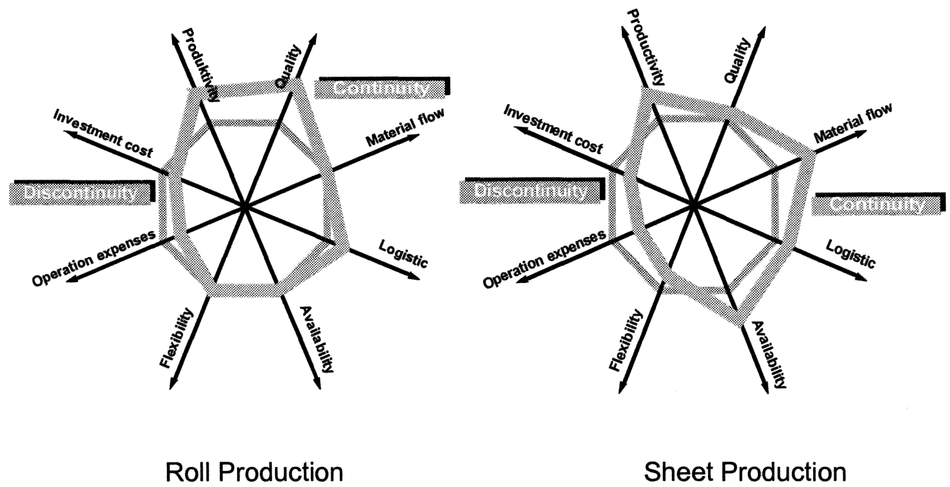


Fig. 7: Economical assessment of continuity- paper converting

This result of the examination of productivity is not only a challenge for new machine designs, but poses numerous questions for research and development, relating to converting functions for roll and sheet transport, winding and stack technology and especially for cutting technology. As well as the questions as the research areas resulting from these, are discussed in the following.

REQUIREMENTS FOR WEB HANDLING

On-line production processes will only then catch on, if besides the presumed increase in productivity, supply capability and the total availability of the plants can be maintained or even improved. As stated above, the mastering of production processes is decisive. In the area of paper converting discussed here, this means that the basic technologies in paper converting are controlled and that these can be applied for principles of converting processes and for the design of converting machines.

Based on this knowledge, fields of research and development for paper converting can be listed and concrete perspectives for research activities in the area of web handling can be formulated. Besides the draft of the total interconnection, fig. 8 shows the following fields of research

- Paper Physics
- Process Modeling and Simulation
- Measuring Methods and Sensors

- Control and Process Flow Systems

as guidelines. These fields of research are connected and will be intepreted under the special aspect of future on-line production.

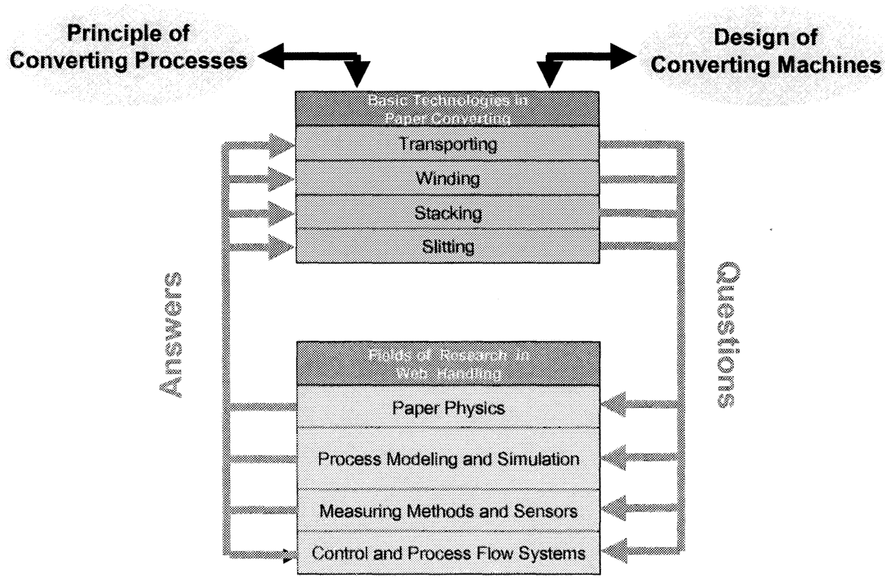


Fig. 8: Fields of research in web handling in dependence on converting processes

The close connections between the areas of research result from the general thought that control and process flow systems cannot function without measuring methods and sensors, and without process modeling and simulation. Furthermore, neither the conception and realization of measuring methods and sensors, nor process modeling and simulation of converting processes are possible, if the basics of paper physics are not known. This thesis can be formulated in reversal as follows: only with the knowledge of paper physics can process models be developed and simulated and can measuring methods and sensors be concepted. With these, control and process flow systems can be configurated with sufficient reliability for plants for continuity-paper converting.

Now, research activities and objectives which are currently important and relevant for the future, can be assigned to this systematic classification of the fields of research.

From the perspective of paper converting, the focus in the first field of research "paper physics" is on the material behaviour under predominantly mechanic loading. For this, a comprehensive material law is necessary in order to understand the complex and numerous phenomena of converting processes. A special challenge poses the fact that this material law has to be developed for process-dependent dynamic loading in order to be able to consider creep- and relaxation behaviour. Further, material parameters are necessary, which are not available (e.g. shear moduli and Poisson's ratios), because no measurement techniques exist. With a comprehensive material law, converting processes can be modelled and simulated upon the transfer on the mechanic behaviour of webs and sheets.

Besides the material law to describe the load-deformation behaviour, the surface properties of webs and sheets are of special importance in paper converting, since in the converting process, loads are introduced through these. To clarify the corresponding stresses, an understanding of the surface property of paper is vital.

Fig. 9 illustrates objectives for research in an exemplary manner. On the one hand the question is posed, how stress-strain-property under cyclical load (load and unload) has to be interpreted for converting processes, and, on the other hand, the question, how the surface property of paper influences the stick-slip-effect, which occurs in a disturbing way at the contact surface of paper webs and sheets under particular load.

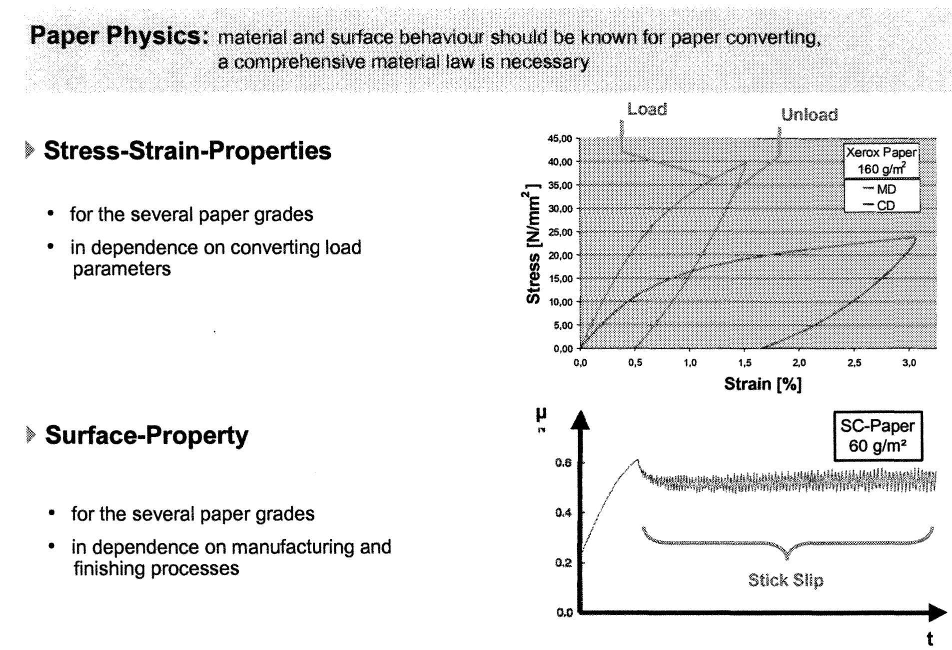


Fig. 9: Research topics in paper physics

For the second field of research "Process Modeling and Simulation" the focus is on close-to-reality models of the four basic technologies of converting processes with subsequent simulation. Here, the challenge lies in connecting the four basic technologies transporting, winding, stacking and slitting with the the particular special conditions of the process section or operational state like traction, spreading, flattness, fluttering, slippage etc. to be examined. On employing standard numerical systems, processes and process-phenomena can be pictured on the computer, in order to evaluate process results on the one hand, namely the webs and sheets produced, and on the other hand, to deduce modules for control and process flow systems from these. The fields, which in this context are relevant for modeling and simulation, could be marked individually in a connection-matrix in figure 10.

Measuring Methods: for all physical paper and process parameters

Sensors: for on-line measuring of the most important process parameters and web, sheet, roll and stack defects

	Stress/ Strain	Friction	Traction	Spreading	Flatness	Fluttering	Slippage	Splicing	Hardness	Exactness	Wear and Tear	Cut Edge	Defects	and others
Transporting Web: Sheet:														
Winding Roll: Wounded Web:														
Stacking Stack: Stacked Sheet:														
Slitting Slitter: Web and Sheet:														

Fig. 10: Connection-matrix to find research topics in process modeling and simulation

The advancement of knowledge in paper physics will decide, in which quality this modeling can be further developed. To emphasize this connection, the example of slitting webs and sheets will be used.

At the current state of research, the slitting process for the most frequently employed method of shear slitting can only be partly described and thus not yet modelled coherently near-to-reality. This means that neither the slitting result (cut edge quality) can be interpreted, nor can advice be presented concerning optimal cutting tool geometries or slitter adjustments. In relation to the issues/questions arising from this, figure 11 shows exemplary an approach to modelling, in which the state of stress and strain was simulated during the compression phase of the shear slitting process with FEM [2, 3].

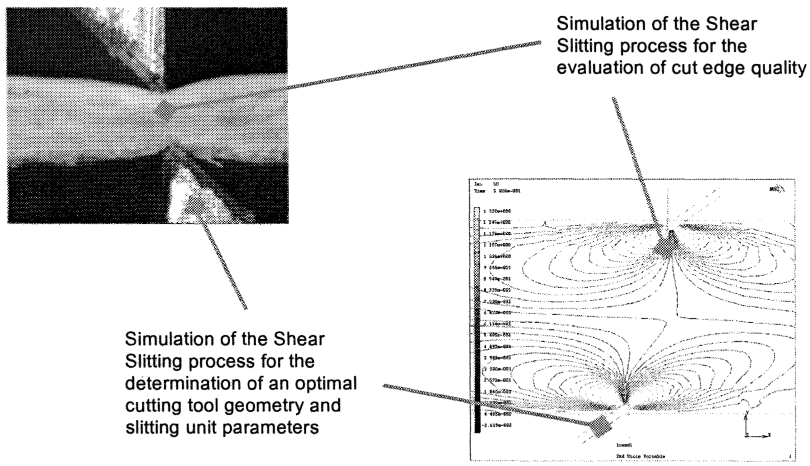


Fig. 11: Example for process modeling and simulation

On the further progress of these research activities, criteria for selecting optimal slittng parameters should be developed, hints for the interpretation of slitting results should be named and a concept for the control of slitter adjustments should be developed.

The classification and definition of the third field of research "Measuring Methods and Sensors" and the fourth "Control and Process Flow Systems" result as well from the interdependencies of the four basic technologies and the special phenomena of the particular process sections in web- and sheet processing. In fig. 12, the interdependencies are marked, which represent problem areas and pose objectives for research in relation to continuity-converting.

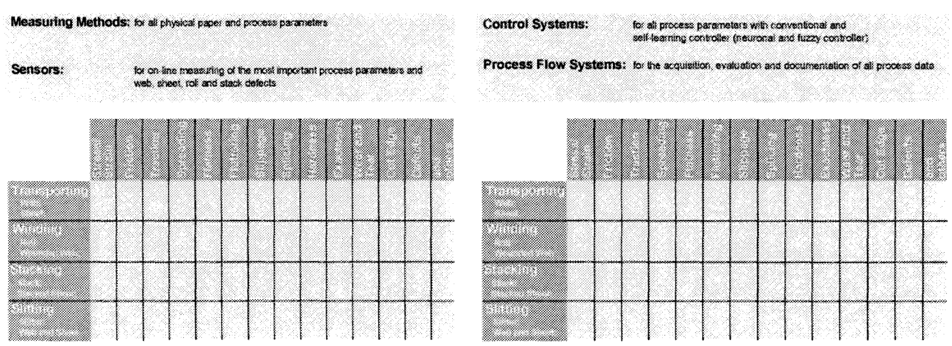


Fig. 12: Connection-matrix to find research topics in measuring methods and sensors (left figure) and control and process flow systems (right figure)

Within the third field of research, these objectives focus especially on measurement methods and sensors, which are suitable for or which allow the record of the traction between sheet and roll or the layer slippage in winders, or to record the wear and tear of the slitting tools in the cross cutter or the cut edge quality. Up to now, no measurement techniques are available for these issues for the contactless detection at high production speed. The development of those measurement techniques is vital for operating control-and process flow systems, which comprise the focus of research within the fourth field of research.

Comprehensive control- and process flow systems are prerequisites for on-line production plants, and especially for continuously operating machines. Here, numerous research tasks arise, since for the converting machines currently available, no control systems except the machine parts responsible for drive are used, but only control (without feedback). It is obvious that the basic technologies have to be fitted with feedback control systems to fulfill the conditions of maximal availability of machines. Today, the controlled winding- or slitting process is listed on the agenda of future developments in machinery. On the path to solution, as long as the physical connections in production processes are not clarified entirely, it becomes necessary to employ self-learning control systems.

Process Flow Systems are vital for the continuous control of plants and the monitoring of the processes involved. This means that a minimum equipment for recording, analysing and documentation of all process data should exist, to optimize machines and processes in a continuous improvement process.

The reader is left to identify interesting and future-oriented fields of research on the basis of the connection-matrix, which are closely connected to continous or even on-line converting processes.

CONCLUSION

This paper undertook to show the development in the paper industry, to realise on-line production lines, in the area of paper converting. Within a comparative analysis of discontinuity paper converting machinery used today, and concepts for continuously operating machines, the potential for productivity increases could be revealed. An increase in efficiency, expressed by a quantity-related coefficient of efficiency, of approx. 30%, can be achieved, if corresponding developments in processes and machines are implemented, which, however, depend on major efforts which have to be undertaken. For this development, numerous basic research efforts are necessary in the field of web handling.

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