A NEW OBJECTIVE METHOD FOR QUANTITATIVE ASSESSMENT OF CUT EDGE QUALITY FOR PAPER AND BOARD

by

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ABSTRACT

In the paper converting and finishing industry the cut edge quality is of particular importance to the manufacturing processes, e.g. the printing process. In this paper an objective method for the quantitative evaluation of the cut quality of thin, plane materials is presented. In a first part of this paper existing procedures for the evaluation of the cut quality are analyzed. Afterwards the own method, consisting of two essential elements, is presented. The first element is the measurement data logging by use of a CCD line camera and the second one, is the measuring data evaluation with a self-developed software. The capabilities of the developed method are demonstrated on evaluating cutting edges of four thin, plane materials. The results show, that the procedure is suitable to differentiate cut results sufficiently and to transfer them into quantified quality grades in reproducible manner.

NOMENCLATURE

c	weighting coefficient
W	total weighted value
Q	quality grade

INTRODUCTION

The quality and in particular the dustlessness of cut edges of paper-, board or foil webs is of particular importance for many converting processes. Statistics show that 25 % of all registered quality complaints are lead back to cut problems in form of dusty and fringed cut edges, e.g. in printing presses, where dusty and fringed cut edges lead to increased cleaning cycles.

Thin, plane materials are produced continuously and converted to webs or sheets. The converting process with the most influence on the cut quality is the slitting process. Running webs are slitted at high speeds with circular knifes into narrower webs or with cut-off knives into sheets. The slitting process, with it's three phases the compression-, the slitting - and the tearing phase, the knife and the cut material geometry and as well as the knife adjustment determine the microscopic appearance of a cut edge. For the third phase of the slitting process it has to be considered that there is no controlled cutting but tearing of the material and this leads to a fringed appearance of the cut edge profile and with that to a cut with low quality. This microscopical appearance of a cut can be used as a dimension of the cut edge quality. The fewer the quantity of fringes or hanging fibers is, the better is the cut quality.

Typical methods used to evaluate the cut quality at this time are based on not standardized, qualitative procedures based on pure optical control. Such evaluations are subjective and don't allow any comparison.

Wise [1] presents an optical off-line method that measures all four edges of a quadratic sheet with the aid of a scanner. The properties measured with this method are format accuracy, parallelism and angularity and cut edge quality of a paper sheet. The separation of the cut edge profile into roughness and curvature are separated by filtering using a high- and a low-pass filter. The evaluation of the cut edge quality is done by an unweighted, statistical evaluation of the roughness deviations from a self-determined ideal cut line.

Feiler [2] introduces a quantitative evaluation method for the cut edge quality for an off-line use. In this method the cut edge profile is measured optically with use of a light source and a transparency unit. In this evaluation method the weighted roughness deviations from the lowest point of the cut edge profile are summed up.

Another objective procedure for the evaluation of the cut quality has been introduced by Szczepaniak et. all [3]. Additionally to the evaluation of the cut edge quality, the length and width of sheets are also measured. This method optically evaluates with the aid of a CCD camera the cut edge quality of only one edge of the sheet sample. The patent specification for this method gives no supplementary information about the evaluation of the cut edge quality.

Based on the presented procedures for the evaluation of the cut quality a new objective method for the quantitative evaluation of cut quality is described in this paper [4]. It consists of two essential elements, the measurement data logging with the aid of a charge-coupled device camera (CCD camera) and the measuring data evaluation with the aid of a self-developed software.

MEASUREMENT DATA LOGGING

Experimental Setup

For the experimental setup an optical measuring apparatus (Fig. 1) was build up for the measurement of the cut edge profiles of the tested materials. This apparatus consists of a high-resolution CCD camera and a mobile sample mount.

The CCD camera consists of an arrangement of photosensitive electronic components, photodiodes, along a straight line. Each photodiode generates an electrical charge which is proportional to the absorbed light quantity. Due to the structure of the photodiodes this charge remains localized, so the electrical profile along the line can be transformed into a brightness profile. By reading the charge pattern along the line with aid of a computer the data can be digitized and made available for further processing. If the line is illuminated and partially covered (Fig. 2), the charge profile corresponds to the degree of covering. The covering of the line is determined by the camera via a software filter that assigns a brightness or darkness value proportional to the charge of the photodiodes.

In order to measure the cut edge profile of a sample on the length of several centimeters, the sample is moved as shown in Fig. 2 at constant speed along the CCD-camera. During the sample motion the CCD camera is periodically scanned. The resolution in direction of the cut can be adjusted either by the sample speed or by the scanning frequency of the CCD camera. The resolution in the direction of the cut edge profile depth can be adjusted by the size and quantity of photodiodes within the camera. The used measuring apparatus reached a resolution in the cut direction 10 μm and 1 μm in the direction of the cut edge profile depth (Fig. 2).

Experimental Results

The described experimental setup was used for the scanning of the cut edge profiles of four different thin, plane materials. Especially paper, board, plastic foils and aluminum films from different manufacturers and with different cut directions were examined. Figures 3 to 6 show examples of cut edge profiles taken from the examined samples.

This cut edge profiles show that the measurement data logging is able to reproduce the microscopical geometry of a cut.

MEASUREMENT DATA EVALUATION

The digital cut edge evaluation method

The measurement data evaluation in the form of a self-developed software takes the raw digital data of the CCD camera and converts them to a "quality grade", representing the cut edge profile of the measured samples. The evaluation of the calculated quality grade itself is done by classification it into a determined quality scale. The objective evaluation of the cut edge profile takes place in 4 steps:

- separation of the cut edge profile in a roughness- and a curvature profile
- judgement of the roughness profile
- conversion of the weighted roughness profile into a quality grade
- classification of the quality grade into a quality scale

Since the size and the number of fringes of a cut edge is the only parameter we use for the determination of the cut edge quality, this method analyses only the roughness profile. The separation of the cut edge profile into a roughness- and curvature profile is done in accordance to the testing standard EN ISO 4287. The roughness profile is extracted from the cut edge profile by subtracting the trend of the cut edge profile from the measured data. The trend is calculated by a linear regression in a least square sense (Fig. 7) for all measured data. In a further step the trendfree roughness profile is displaced to the point of lowest value of the cut edge profile. By this way a baseline is received, from which the roughness profile can be evaluated. During this evaluation the distances of every individual measurement point from the baseline are multiplied with the corresponding weighting coefficient's and added the so computed single weights to one total weighted value representing the cut edge profile. The weighting function can be individually determined according to requirements. The weighting function chosen for the developed method (Fig. 9) is computed according to formula (1).

$$c_i = 2^{\frac{i-1}{4}} \quad \text{with } i \geq 1 \tag{1}$$

The advantage of the chosen exponential function is the stronger evaluation of the measured data in a longer distance from the baseline and the weaker evaluation of the measured data near the baseline. Transmitted on the examined cut edge profiles this means, that a bad cut characterized through long hanging fibers differs in his evaluation from a good cut that shows only small deviations from the baseline.

The assignment of the total weighted value to a corresponding tolerance grade Q is carried out logarithmically and determined by the series of preferred numbers R40, whereby the tolerance grade is stepped by 0.05. Figure 10 shows this assignment for the first decade of the series of preferred numbers R40. A fringe-free and with that an theoretically ideal cut receives the total weighted value of 1 and a tolerance grade of 1. If a total weighted value of a cut edge profile corresponds exactly to the amount of an interval limit of preferred numbers series, so the lower tolerance grade is assigned to it. From that the range of the tolerance grade can be concluded. The range begins with the minimum value of Q = 1 and is open to the end. (viz. Fig. 11).

The tolerance grades determined with the developed evaluation method evaluate for themselves in a quantitative way the quality of a cut edge. A quality evaluation can result only in connection with an evaluation of quality ranges. In practice subjective terms or definitions for the quality of cut edges as good cuts, acceptable cuts, bad cuts or formulations as marketable cuts and/or not marketable cuts can be found. With this background is proposed, to determine quality scales which agree between suppliers and customers. On the one hand the quality scales can be oriented on the material grade and on the other hand on the product to be converted. Furthermore it is recommended to specify three ranges of the tolerance grades with the label: good cut, acceptable cut and bad cut. In Fig. 12 this recommendation is shown as a matrix with the dependence between board grades and product to be converted.

Application of the digital cut edge evaluation method

On the basis of the presented evaluation method a software was developed, which was integrated into the measurement data processing system Matlab, version 5. The program is used by a graphical user interface that is presented in Fig. 13. The graphical user interface manages three central program units: the input of the CCD camera signals, the processing of the measured data in accordance to the described evaluation method and the output of the results as the cut edge profile with the relevant tolerance grade Q and the entered additional cut parameters. These additional cut parameters allow a differentiation of the cut edge profile according to cut direction, cut material and other further process parameters.

In application the developed cut edge evaluation method shows its capability concerning the quantitative differentiation of cut edge profiles. Two cut edge profiles cutted at same conditions are presented in Fig. 14. The manufacturers evaluated the profiles as a good and a bad cut. These figures show that the good cut differs clearly in his cut edge profile as well as in his tolerance grade from the bad cut.

Furthermore the evaluated tolerance grades of the tested materials are shown in Fig. 15 to 18 representing the cut edge profiles from Fig. 3 to 6. That is acceptable until badly evaluated cut edge profiles have only tolerance grades between 2 and 3 and deviate with that clearly from the ideal value of 1. The special quality requirements, which are set up for photo paper, show tolerance grades near the ideal value of Q =1 (Fig. 19 and 20).

CONCLUSION

A new method for the objective evaluation of the cut quality of thin, plane materials was presented in this paper. The measurement data logging with the aid of a CCD camera proved as strong in the characterization of fringed cut edges. The application of the cut edge evaluation method shows that the procedure is suitable to differentiate cut results sufficiently and transform these into quantified tolerance grades in reproducible manner. With the classification of the determined tolerance grade into a grade- and converting-dependent quality scale the method can be established as an objective method of evaluation in customer-supplier-relationships. The potential of the developed cut edge evaluation method consists in the fact, that upgrading in a machine-independent measuring device is possible and with that the method can be used place independent. Furthermore it is possible to implement this method to a stationary machine installation in order to check slitting processes online.

ACKNOWLEDGEMENTS

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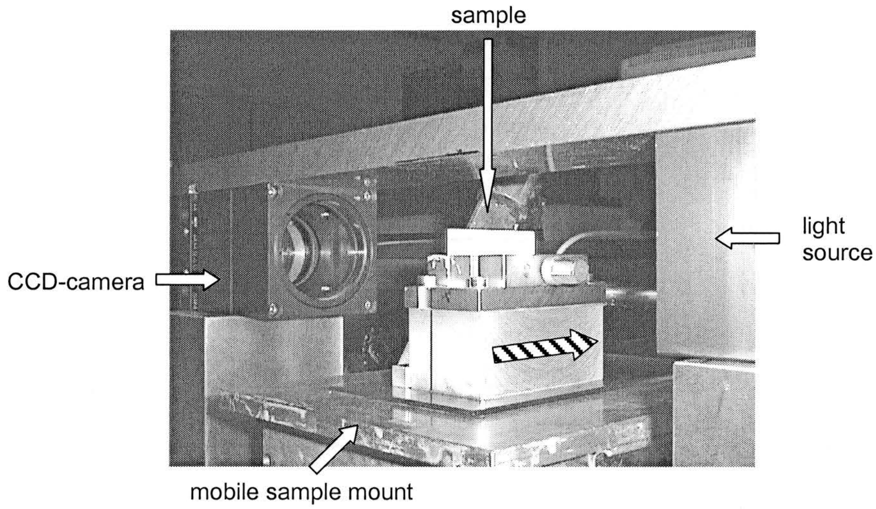

Fig. 1 Optical measurement apparatus

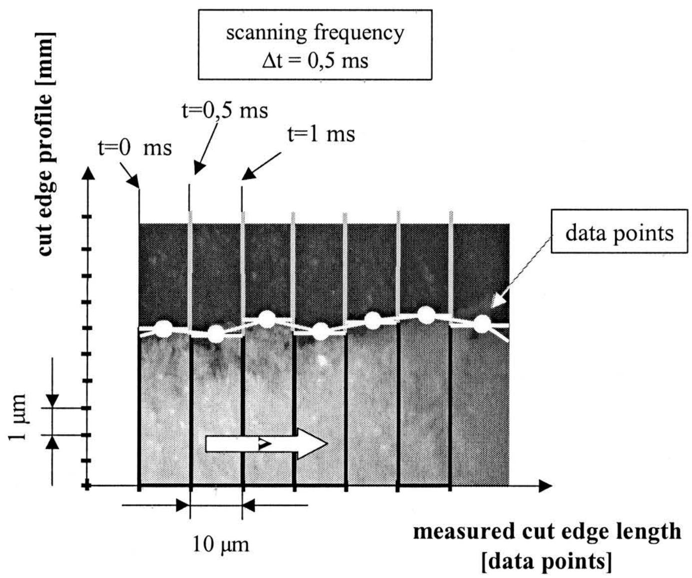

Fig. 2 Measurement data logging with the aid of a charged-coupled device camera

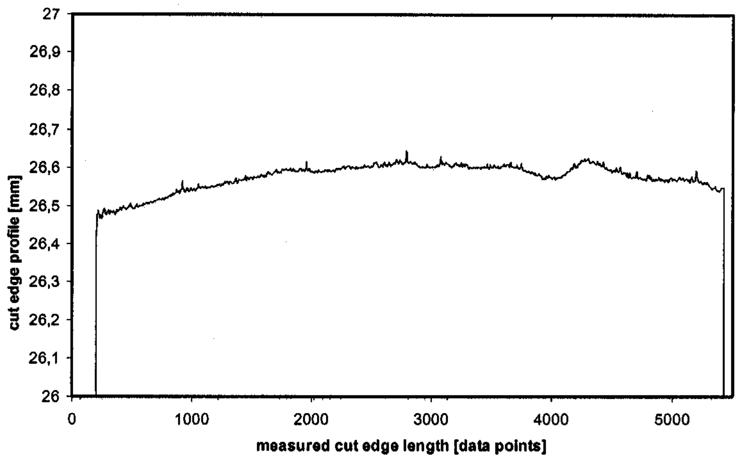

Fig. 3 Cut edge profile in MD-direction of paper 80 g/m^2

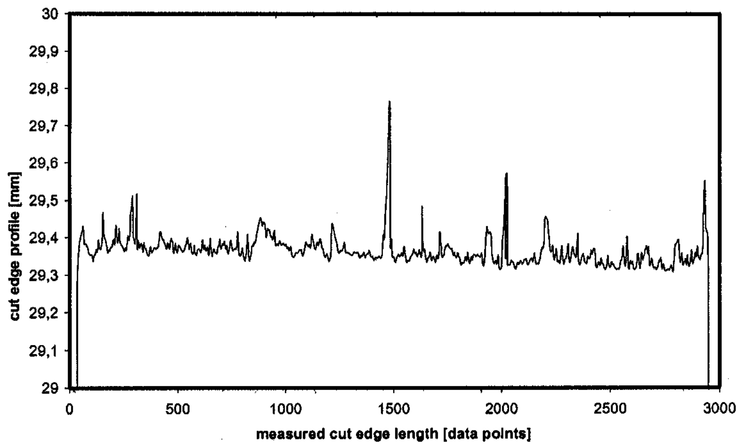

Fig. 4 Cut edge profile in MD-direction of board 300 g/m^2

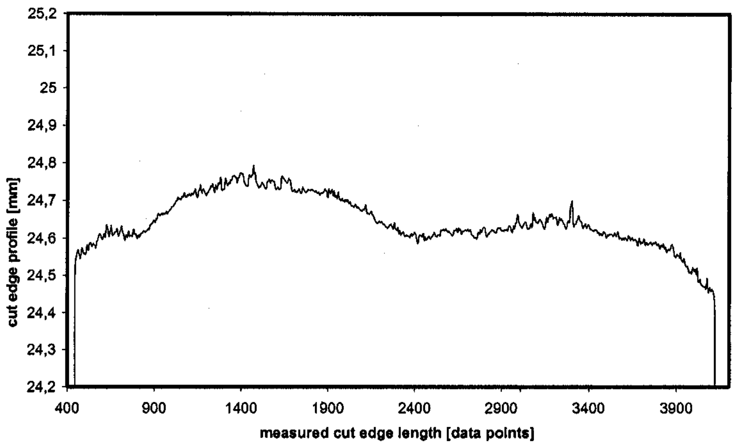

Fig. 5 Cut edge profile in MD-direction of plastic film, thickness 43 µm

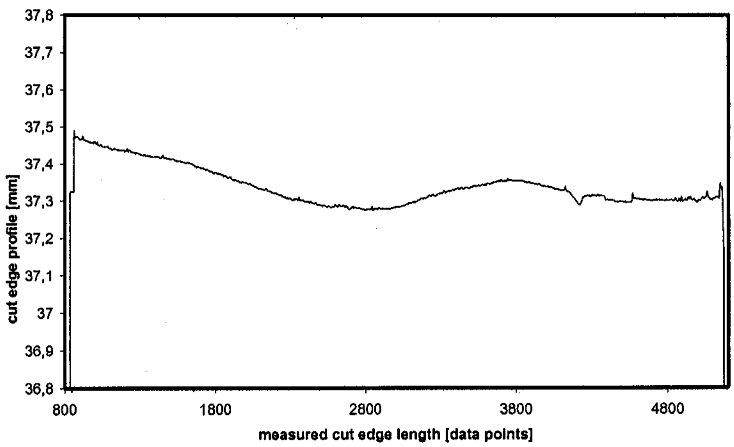

Fig. 6 Cut edge profile in MD-direction of aluminum foil, thickness 13 µm

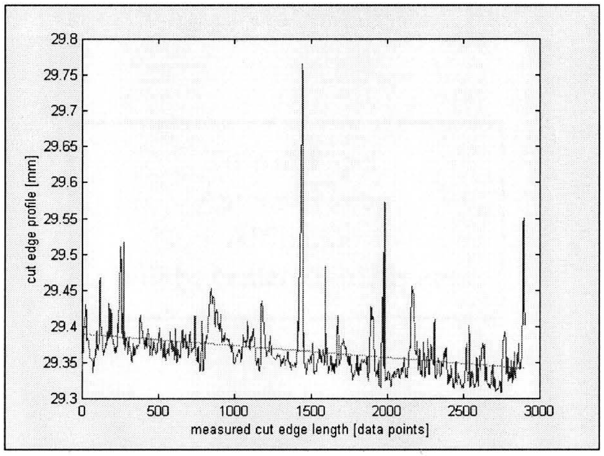

Fig. 7 Trend of the measured cut edge profile

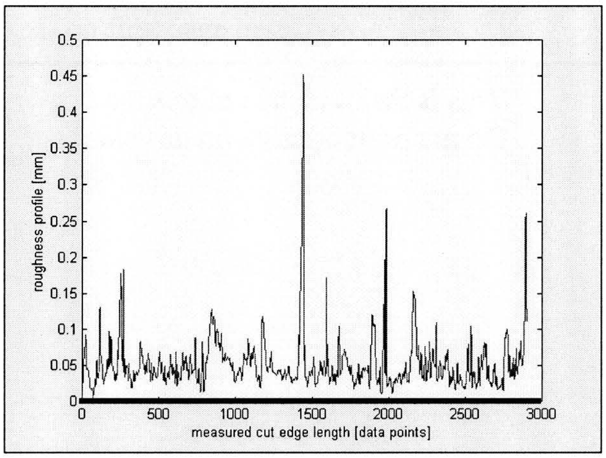

Fig. 8 Weighting of the roughness profile from the determined baseline

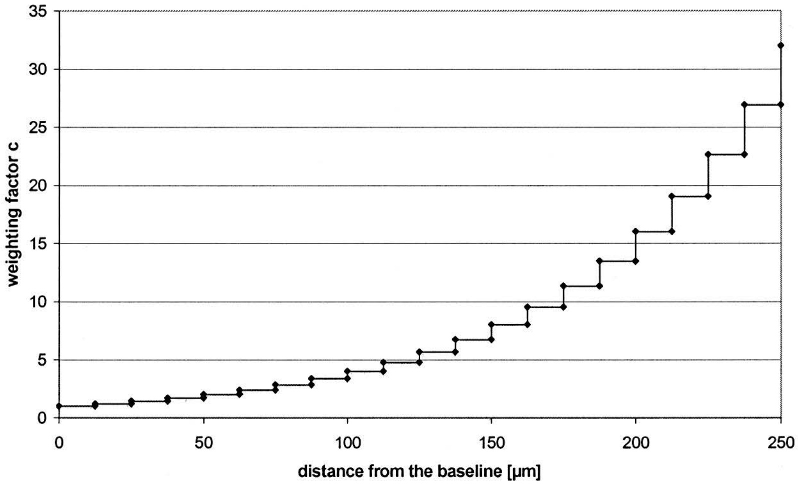

Fig. 9 Weighting function according to formula (1)

W =	1.00	1.06	1.12	1.18	1.25	1.32	1.40	1.50	1.60	1.70	1.80	1.90	2.00	.....	9.00	9.50	10.0
Q =	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	.....	2.90	2.95	3.00	

Fig. 10 Assignment of the total weighted value W to the quality grade Q

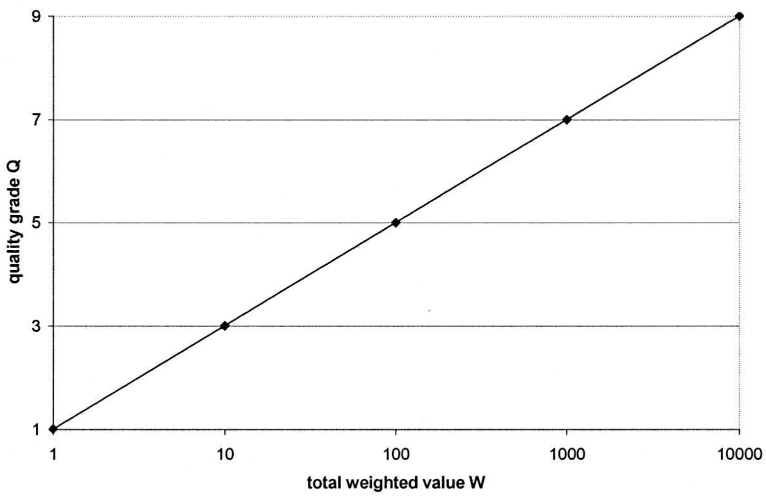

Fig. 11 Range of the quality grade Q

		converting to		
		covering boxboard	folding boxboard	photo colour board
board grade	GC			1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 good cut / acceptable cut / bad cut
	GT		1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 good cut / acceptable cut / bad cut	
	GD		1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 good cut / acceptable cut / bad cut	
	GK	1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 good cut / acceptable cut / bad cut		

Fig. 12 Recommended quality scales

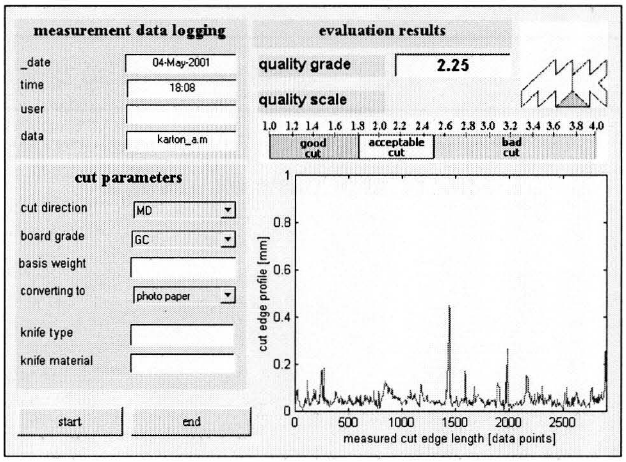

Fig. 13 Graphical user interface of the developed evaluation method

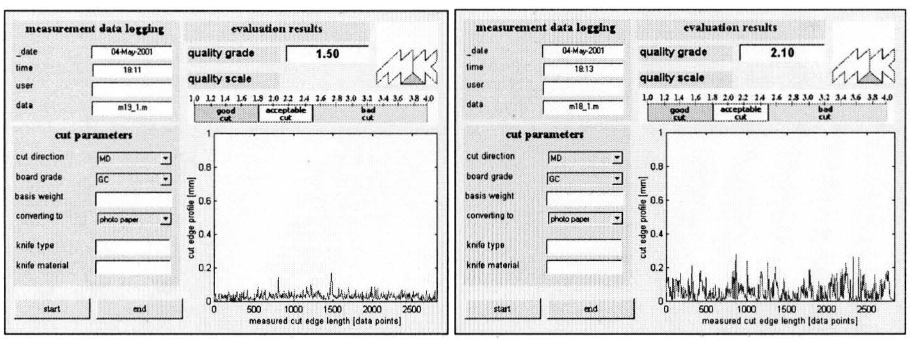

Fig. 14 Comparison "good cut" Q = 1.50 – "bad cut" Q = 2.10

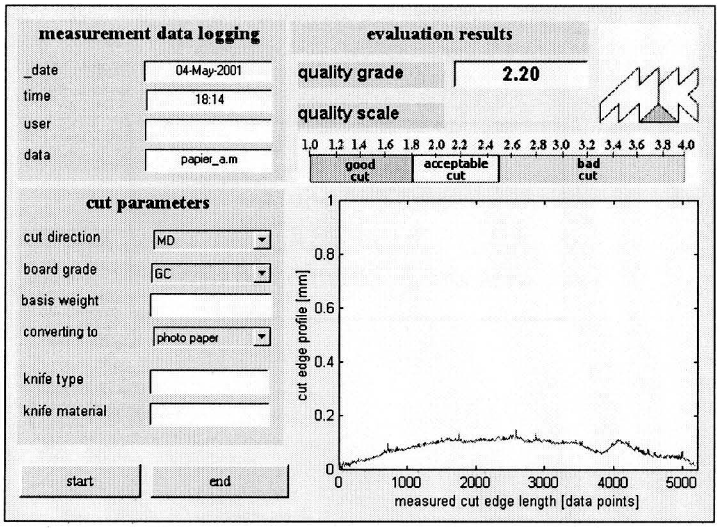

Fig. 15 Results of the evaluation method for paper 80 g/m^2 (viz. Fig.3) with Q=2.20

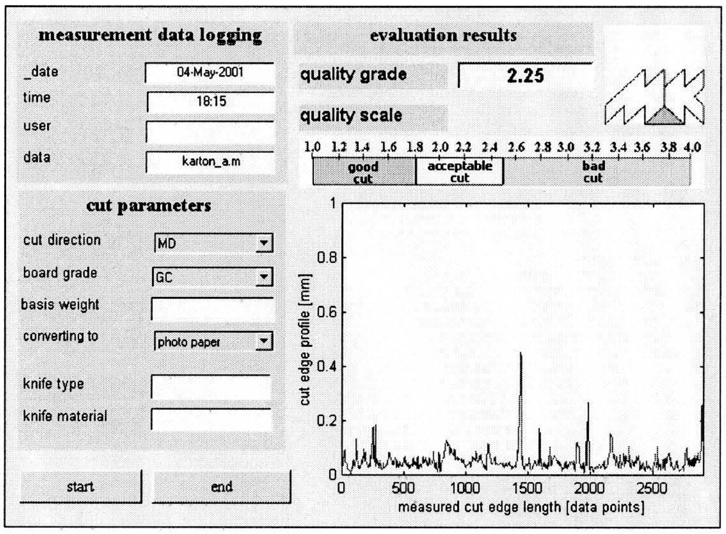

Fig. 16 Results of the evaluation method for board 300 g/m^2 (viz. Fig.4) with Q=2.25

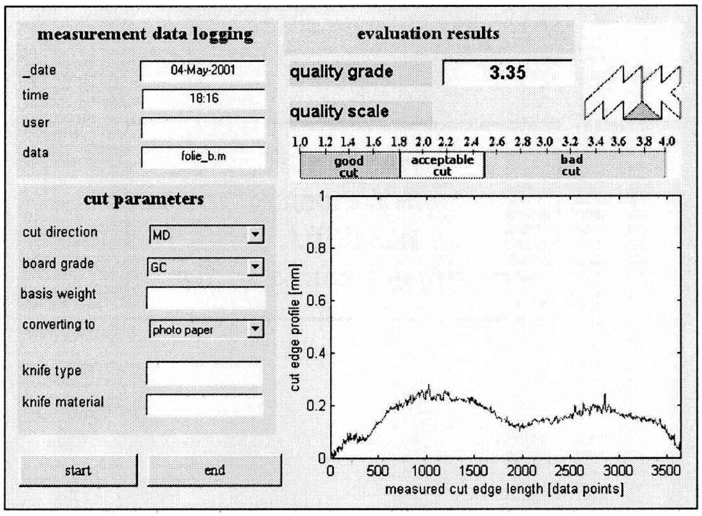

Fig. 17 Results of the evaluation method for plastic film, thickness 43 μm (viz. Fig.5) with Q=3.35

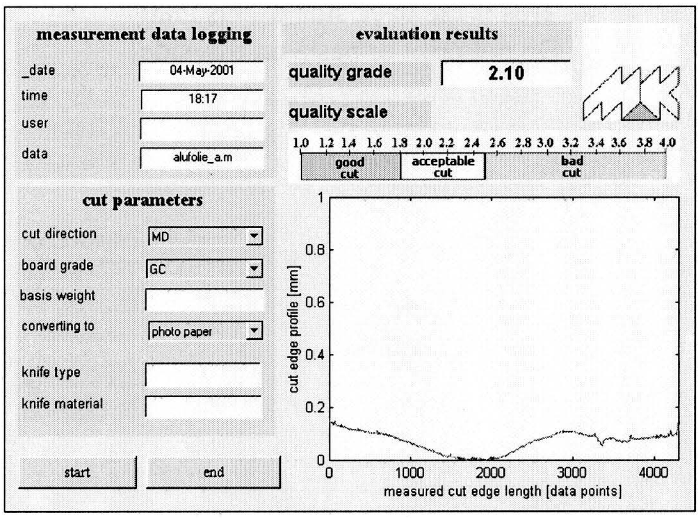

Fig. 18 Results of the evaluation method for aluminum foil, thickness 13 μm (viz. Fig.6) with Q=2.10

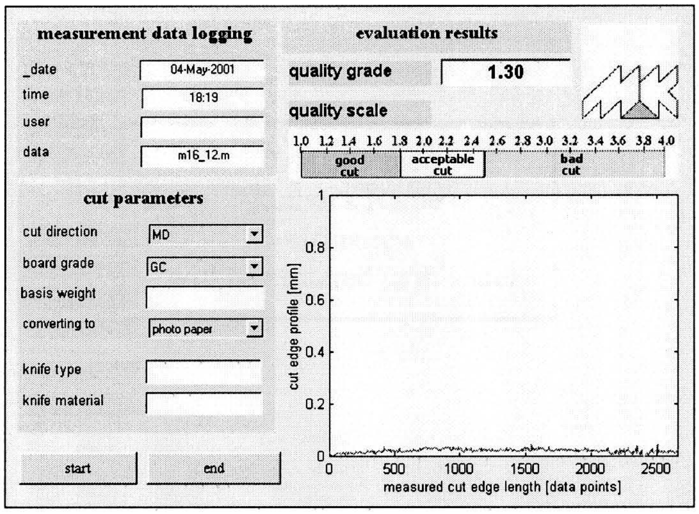

Fig. 19 Results of the evaluation method for photo paper

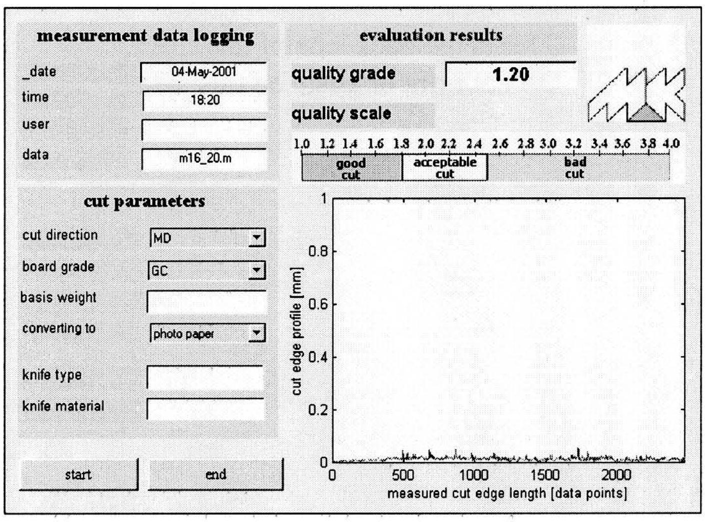

Fig. 20 Results of the evaluation method for photo paper

E. G. Welp, E. Wolf, and J. Heindl – Ruhr-Universitaet Bochum, Germany

Name & Affiliation	**Question**
M. Jorkama – Metso Paper	Do you see any speed limitations for online installations?
Name & Affiliation	**Answer**
E. Wolf – Ruhr-Universitat Bochum	Yes, the speed limit is adjusted on the measurement data logging. We used a charged coupled device that is four years old. We had a scanning frequency of about 2 kHz and with that we can only use this evaluation method up to speeds of 2 or 3 meters per minute, which is insufficient for an online process. I have reviewed current charged coupled devices and actual cameras with scanning frequencies ranging from 50 to 80 kHz with different vendors. This would allow us to study speeds of 50 to 80 meters per minute but that still would not be sufficient for an online evaluation. The camera can be moved with the web or we can change the whole measurement data logging system. We do not have to use a charged coupled device. We are considering digital still imaging. We can take a digital camera and shoot photos of the cut edges and then prepare the data for the evaluation method as well but this would be a further implementation.
Name & Affiliation	**Question**
M. Jorkama – Metso Paper	We will have to wait for a while for you to achieve speeds of 30 meters per second?
Name & Affiliation	**Answer**
E. Wolf, Ruhr – Universitat Bochum	Yes.
Name & Affiliation	**Question**
D. Jones – Emral Ltd.	Concerning your technique and your way of analyzing the data to present a single quality number. Do you see this being translated into a standard that companies could log on the specifications sheets for their products? If so, how do you propose to achieve this if this is your long term goal?

Name & Affiliation	Answer
E. Wolf – Ruhr-Universitat Bochum	We are preparing this evaluation method to make it to a standard. But, each manufacturer or vendor has his own requirements on his product. Manufacturers of photo paper plastic films have their own requirements on cut edge quality. It would be difficult to set a standard for all web products. The evaluation method itself can be established as a standard, but the assignment of the quality grade into an overall or general quality scale would be not so easy.
Name & Affiliation	**Question**
D. Jones – Emral Ltd.	The different quality numbers yielded by different materials would be similar to a modulus. Some would have a high modulus, some would be a low modulus. Nevertheless there will be bounds that each web product would fall within.
Name & Affiliation	**Answer**
E. Wolf – Ruhr-Universitat Bochum	Yes.
Name & Affiliation	**Question**
Gary Holman – Westvaco	You indicated that you have found that only 3-5 cm lengths would give you suitable information. Am I correct?
Name & Affiliation	**Answer**
E. Wolf – Ruhr-Universitat Bochum	That's correct.
Name & Affiliation	**Question**
G. Homan – Westvaco	I would challenge you to perhaps expand that. Depending on how well your slitter system is set up you will observe a tremendous amount of variation. Your sample size can be too small to record the variations that occur. I have witnessed this personally and I'm sure others have seen similar things under actual operating conditions as opposed to a laboratory environment.
Name & Affiliation	**Answer**
E. Wolf – Ruhr-Universitat Bochum	Yes, we have thought about that. In the process of our development we considered what is a minimum length to create a quality grate that is reproducible. The result was a 3 cm length. It depends on the data logging, how long the lengths could be, and what you can measure. The data has to be stored and so it depends on the hard disk drive storage capacity and how much data you can observe.
Name & Affiliation	**Comment**
R. Lucas – GL&V	I would think that a minimum length would be in excess of the circumference of your slitter band otherwise you might never distinguish a nick in one of the cutting blades. So I agree with Mr. Holman. If you were to take a 3 cm sample you might be able to characterize that sample but that may not be representative of the cut edge of a roll.
Name & Affiliation	**Question**
D. Wager – Dupont	I was wondering if the scanning system can discern

	detached particles because the thing that we don't like is slitting dust.
Name & Affiliation	**Answer**
E. Wolf – Ruhr-Universitat Bochum	We have tried to detect the ability of a cut edge to build dust up. First, we measured a defined cut edge length and then we tried to get dust out of the cut edge. We tried first a non-impact process. We put a sample, for example, on a shaker. We shook it up 3000 times per minute and measured the same length again, but we had no change in the quality grade. We also submitted cut edges to ultrasonic waves and again the quality grade was not effected. I do not think you can detect particles with this system.
Name & Affiliation	**Question**
D. Wager – Dupont	I agree with Mr. Lucas, you need to sample at least over the circumference of the cutting tool. In addition when you're evaluating the quality you are often looking at the finished side of a roll. This is the only way you can make a total evaluation of the edge. You may only get particles going away from plastic film maybe only 2 or 3 times throughout the whole roll. So is there a way to actually scan the whole of the side of the roll as well?
Name & Affiliation	**Answer**
E. Wolf – Ruhr-Universitat Bochum	That is an interesting idea. I will test it.