PRINCIPLES OF WEB SLITTING

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ABSTRACT

The slitting arrangements used in the paper, plastic film, and metal industries have evolved into machines that use a variety of principles to sever the webs longitudinally. This presentation looks at a variety of ways for accomplishing this task, pointing out problems that are sometimes generated by these solutions. Such difficulties range from the tendencies of the cutting members to become dull, to the production of undesired dust and slivers, or the failure to maintain accurately trimmed widths. Wherever possible the reasons for the defects are explained with recommendations for avoiding further difficulty.

INTRODUCTION

In the manufacture of continuous web materials, it is usually necessary at one or more times in the process to cut the material into strips by severing it along its machine direction. This may be to remove irregular edges generated by the process, to cut it to an accurate overall width more suitable for the next phase of the process, or to produce the width desired for use by the consumer.

In some machinery, such as the package-size sheeters used in the paper industry, both machine-direction and cross-direction cuts are made in one machine, resulting in letter-size sheets of paper which are collected in piles of 500 or more sheets and automatically delivered for wrapping. In this presentation the focus will be only upon machine direction cutting, or slitting. The other type of cutting is well differentiated by the German term for sheeter, or *Querschneider*, literally a square or right-angle cutter. As you can well imagine, the problems in obtaining a precise 90 degree cut on a piece of material travelling at high speed require very specialized approaches.

The size range of slit material varies from 10 meter width as sheets are prepared for off-machine coaters in the paper industry to tiny tear tab strips for packaging applications that are barely over 1 mm in width. Other familiar slit products include magnetic tape: 3.2 mm width for audio cassettes, 8 mm for camcorders, and 12.7 mm for VHS tapes, aluminum foil, fax paper in roll form, photographic film, and every roll of paper that ever went into a high speed newspaper printing press. Some rolls found around the home have been made by a process that produces narrow rolls out of one longer wound roll, or log. In this case the material is wound up first, than parted off into narrow form by a sawing motion in the case of bathroom tissue and paper towels, or a plunging sharpened disk used in the manufacture of transparent tape or vinyl electrical tape.

Here we wish to consider the general ways of making one or more cuts in a single layer of web material, so we will put aside dedicated machines such as log saws. By placing slitting devices at precisely controlled distances across the web, constant widths of product can be produced to tight tolerances. This is of particular importance where width control is required for the precise registration of recording, as in the use of magnetic tape and movie film.

SLITTING ARRANGEMENTS

The commonly encountered mechanical means for slitting are shown in Fig's 1 through 5, and include score slitting, Fig. 1, rotary shear or band-and-blade slitters, Fig. 2, slitting disks with zero- or low-clearance on parallel axes, Fig. 3, variations on blade elements for high-bulk slitting, Fig. 4, and razor blade slitting against a slotted mandrel, Fig. 5.

New Developments

Several high tech devices have made inroads into the area of mechanical slitting and are noted here to be inclusive. Their higher costs can be justified if the problems are too difficult to be solve by the more conventional, low cost mechanical devices.

Water jet slitting, Fig. 6, involves a stream of high pressure (300 MPa or higher) water forced through a small diamond or sapphire orifice approximately 0.1 mm in diameter, to emerge as a supersonic cutting tool for delicate or high bulk materials travelling at speeds up to 3000 m/min. There is little or no drag force or reaction on the material, and disposal of trimmed edges is assisted by the jet energy. If the trim breaks or the web moves inward causing loss of trim, the cutting will be reestablished once the material moves into the path of the jet, without a web break or jamming of the trim. The force of the jet will dissipate rapidly in air over a distance of about one meter, and excess fluid is collected when it enters into a simple slotted metal cylinder.

Another potential candidate for high speed web slitting is a high powered sharply focused laser beam, Fig. 7. One important requirement is that the web material must be absorbent, not transmissive, to the wavelength of the laser beam, or else no cutting will take place. There is a practical speed limit for cutting paper webs at around 500 m/min, and there is another problem of maintaining good edge quality if the sheet is not kept at the distance where the beam is in sharpest focus. If the sheet wanders out of the focal plane, the energy is diffused over a larger area, and instead of vaporizing the material, the beam discolors the web edges and produces a poor or intermittent cut. Reflected energy can cause expensive lenses to shatter, and the lenses must be kept cool and free of buildup of condensing material. Laser cutting seems to be more useful at slower speeds on difficult to handle materials, such as ceramics.

Razor Slitting

The advantage of slitting using industrial razor blades is the simplicity and lack of moving parts, plus the economy of disposable blades. The material to be cut must be soft and free of abrasive inclusions, so plastic film is more frequently slit by this method than is paper. Paper would dull the blades rapidly, and a large amount of dust would be produced, with ragged sheet edges. The precision of width control in slitting will not be great on any material. The minimum slit width will depend on how small the blade holders can be made, plus the problems of entanglement of narrow webs which may drop into the grooves of the backup roll. If the desired slit widths do not match the spacing between backup roll grooves, the backup roll may be made in segments which can be set at any separation.

Score Slitting

Very hard materials are used in score slitting. The backup roll is smooth and ground to a high finish, with hardness Rockwell C62 or harder. The rolling blades pressed against the backup are also very hard, creating extreme pressures at the contact point, sufficient to sever any material passing through. The design of the blade shape to produce the best cutting action while resisting wear is an art. A finite radius must be included at the tip of the blade. If the included angle between the blade edges is too narrow, the blade will be subject to rapid wear. With a high included angle between edges, the wear rate will be low, but the cutting action will suffer, with web material transferred to both the backup and blade causing occasional sticking and the possibility of web breaks. One application of score slitting is to produce tractor-fed computer printer paper. After passing through the printer, the sprocket hole edges of the paper may be torn off leaving a nearly smooth edge on the paper. This is accomplished by cutting grooves of about 0.1 mm width across the cutting edge of the blades, spaced about 1/2 mm apart. This results in cuts through the web about 0.4 mm long, with a bridge of a few fibers about 0.1 mm long to hold the sheet and sprocket feed strip together until it is forcibly separated.

Parallel Axis Shear Slitters

Some stiff materials are readily handled by shear cut slitters that alternately displace one ribbon of the slit web downward and the next upward. In sheet metal slitting, for instance, slitting elements are made the width of the cut strip, Fig. 8a. Those on the top roll shear against similar elements on the bottom roll. If the slit widths must be made adjustable, spacers may be used be fill in the spaces between slitting elements made as adjustable collars, Fig. 8b. The shaft diameters may be made large to resist the high forces required to shear steel strip, and allow both top and bottom rolls to be driven. Similar arrangements may be used for slitting photographic films coated with emulsions, magnetic tape, and cigarette paper. Provisions for forcing the cutting elements against each other include axial springs, Fig. 8c, and individual bevel blades loaded by spiral springs which provide the axial thrust, Fig. 8d. On some of these arrangements, regrinding to resharpen the elements will change the width of slit, unless the regrinding is done only in the radial direction. In this case, the depth of penetration must be adjustable by changing the spacing between the two rolls. Another popular arrangement for flexible webs is to carry all of webs across a mandrel and use many bevel knife blades to slit against the same side of the rings cut into the mandrel, Fig. 8e. In this case, resharpening can be done on the worn edges of the mandrel, with equal amounts ground off to maintain the same spacing between slit widths.

Band and Blade Shear Slitters

These are seen frequently in the paper industry, where one of the elements (usually the bottom one) can be arranged to have its own pancake drive motor, d-c or a-c variable frequency, Fig 9a. When orders require frequent changes in the spacing of the slits, the top and bottom elements are arranged on beams spanning the machinery, with automated positioning controls to quickly reposition all the slitters in the time between the ejection of one wound roll set to the threading up of the web to start the next set. In simpler converting winders, the band elements are often carried as adjustable collars on one driven roll, and the adjustment of slit positions is done manually by locking the collars in place, Fig 9b. The blade members must be correctly located next to the corresponding band elements. They are loaded by a force provided by springs or pneumatic pressure. The penetration, or overlap, between these two disks must be correctly set, as well as any toe-in, or angular adjustment, which reduces or eliminates the contact between the two disks at the back part of the overlap where they are moving away from each other. If the contact is not properly set, or if there is any camber (an inclination of the blade rotation axis toward the band rotation axis) wear rates will soar, or else a clean cut will not be produced.

In the research leading to the development of web-driven slitters with sharpness retention qualities (1), some interesting facts were discovered. For many years it was thought that the surface speed of rotary shear elements had to be equal to or greater than web speed, particularly in the trim slitter positions. However, for fine paper slitting, the sheet will drive the slitters at a close enough speed match if the bearing rolling losses are made small. The 45 degree bevel angle ground into most blade elements is not necessary to the shear action of slitting, and neither is the 3 degree relief angle produced as an undercut on the active face of the band. Two squared-off metallic disks with 90 degree corners will cut fine papers and plastics as well, and are a lot easier to handle with far less risk of finger cuts. There is a point however when cutting thick materials when the material tends to force apart the side-loading pressure of a square band and blade. This tendency can be counteracted by putting a bevel on the blade and band as shown in Fig. 4. This change is not necessary for thin material slitting.

DO'S AND DON'TS FOR SLITTING

1. Do apply constant tension, on the basis of force per unit width, to every slit web. This includes the trim. It is often thought that the trim can be allowed to fall free, or be carried into a vacuum trim chute that is operating with low air velocity. This is not the way to have the web behave properly, spread itself to the correct width, and keep the trim from breaking off.
2. Do your slitting where the web run is stable. If the web is jumping up and down, it will likely suffer frequent breaks in the slitter section. Cures that have been effective include the old style of guard board, a slightly curved metal section over which the web slid before entering the slitters. Air flotation was often provided through drilled holes. This tended to spread the web and remove soft wrinkles. Heat and dust produced from the sliding was often objectionable, so grooved table rolls of small diameter are now preferred, before and after the slitters. These rolls are made in segments if the winder face exceeds 4 m.
3. Curved spreader rolls of the Mt. Hope type are often beneficial when used before the slitting section. They tend to stabilize the sheet run, make the web lay flat, and produce a very small amount of cross-directional tension which can aid in keeping some separation between the slits. To be effective, only a small amount of bow should be built into this roll. Any excessive bow will cause slippage between the cover and the web with loss of traction, resulting in the loss of spreading action.
4. Make sure all slit webs are carried away properly. Simple converting winders have slip clutches on two mandrels which allow the individual cores to turn at different rates so slack webs will be tightened up. The threading of alternate webs to wind on each of the shafts in turn makes for complete and non-interleaving slit separation. In general, if a section of web goes slack, it will wander and interfere with the other slits. When using a curved spreading roll after slitting, remember to use only the minimum degree of bow and slit separation required to do the job. The outer slits are the most difficult ones to accommodate in any case. If the spreading causes them to be directed an any angle other than aligned with the winder rolls and winding product roll, some torsional straining will

be built into the end rolls, making them subject to dishing, or collapse in the case of narrow rolls of large diameter.

5. Don't let slitting elements run dry. Trim slitters in the paper industry running at low speed with no paper present will begin to "sing" or emit a screeching sound less than a minute after the paper leaves them. This is due to the dry metallic surfaces welding against each other. Rapid wear is generated when this noise is produced. Just the presence of a few molecules of cellulose on the rubbing surfaces will provide a little lubrication, block the oxidation, and prevent the wear. Soft plastics touched to the surfaces will also remove the noise and wear. Oil will also work, but is considered a contaminant in the paper industry. The best thing is to stop the slitters when there is nothing to be slit.

BY-PRODUCTS OF THE SLITTING PROCESS

Dust and slivers

Slitters are known to produce dust in the paper industry. There is always a trace amount of dust produced when slitting paper because a few of the paper fibers are anchored on only one side of the line of cut. The rate of dust production is worse around dull or poorly adjusted slitters. Even when slitting solid materials such as plastic sheet, slivers and torn-off particles can result from slitting. Before the unsevered web reaches the point of overlap between the top and bottom shear elements, or before reaching the point of contact between score slit blade and the backup roll, the material is first compressed before it is cut. Any material having a Poisson's ratio of 0.3 or more, which applies to almost all plastics, will experience tensile direction straining perpendicular to the compression existing between the cutting elements. Fracture cracks can appear in the plastic material due to this tensile straining, and they will be most prevalent near the center of the web and oriented in the machine direction. When shearing takes place from the top element sliding across the bottom element (or the score cut blade plunging into the backup roll), some of the material split out from the fracture cracks will be cut through as well. Loose needle-like slivers of material will be found, and other crumbs that break out. Some will be attracted back into the winding roll because of electrostatic charge and will be captured inside, while other slivers will remain attached to the sheared edge of the web, only to fall off later. Some of the remedies suggested would be to change the material formulation, and to try slitting at an elevated temperature.

Slitter rings

Wound rolls suffering from slitter rings are sometimes called bullseye rolls. The inference is quite different than when a bullseye is right on the mark and worth a high score. Here the meaning is that the side of the roll resembles an archery target, with lots of concentric rings. The rings result from a wobble or runout in the slitting elements. This produces a long sine-wave pattern of width variation. When the wave pitch becomes an exact multiple of the circumference of the wound roll, there is a beat or interference pattern formed which is quite distinctive (4). Visible patterns can be seen even if the misalignment of elements causes a CD wander of the cutting point of as little as 0.1 mm, so it is important to verify that the mounting of rotating slitter elements is true and square, with low runout.

DEVELOPMENT OF THE WEAR ANGLE IN SHEAR SLITTERS

Fig. 10 shows a typical band with 3 degree relief and a bevelled blade top element that have experienced some wear while running at the penetration depth shown and about a 1 degree toe-in. Fig. 11 shows the cross-sectional view of this pair taken at two points, Section

A-A at the tip of the overlap where the web enters, and Section B-B through the location where actual rubbing or wear between the elements is taking place. Note that both members are worn to the same slope, here shown as about 5 degrees. At the location A-A, where the web is supposed to be severed by the shear action, the cut point is open, allowing many small paper fibers to pass through. This analysis and the physical measurement of worn slitter blades and bands was carried out in the late 1960's by the author and David Daly (2.)

When the band and blade pair were new or freshly sharpened, the view of the band seen in the machine direction, Fig. 12, does not allow the cut point to be seen. It is obscured by the toe-in of the blade. If the viewing point is shifted to bisect the toe-in angle, a line of sight is opened up into the cut point. Seen at this angle, the outer rings of both the band edge and the blade edge become narrow ellipses, tangent to each other at the cutting point, Fig. 13.

The slope of the line which is tangent to both ellipses at the cutting point describes the **wear angle**, which will be transferred to both elements as the edges deteriorate. If the penetration of the blade and band is decreased, the wear angle is increased, Fig. 14. This can be useful to reestablish contact at the cutting point in a pair of elements which experienced wear earlier at a smaller angle of wear. Use caution when lessening the penetration, as machinery vibration or heavy loads moving across the floor may cause the blade to jump up onto the band, with disastrous results. Using a smaller toe-in angle will cause the initial wear angle to be decreased, as shown in Fig.15. If the toe-in angle is adjustable, it makes sense to start a newly-reground slitter pair with the minimum toe-in, ensuring that a little clearance exists at the back of the overlap between band and blade.

REFERENCES

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2. Daly, D.A. "The shear slitter yields to laboratory study," presented at the Canadian Pulp and Paper Association annual meeting, Jan. 23-26, 1968.
3. U.S. Patent No. 4,157,672 "High Bulk Slitter," June 12, 1979
4. Pfeiffer, J.D. "Analysis of the ring patterns formed when periodic disturbances affect roll edges," Tappi Journal, 72(10):59 (1989)

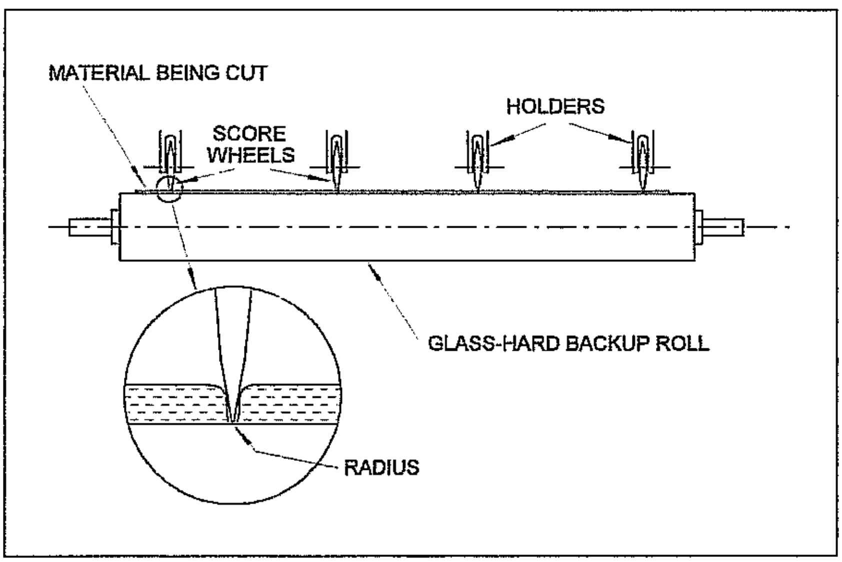

Fig. 1. Score slitting arrangement. Also known as crush slitting.

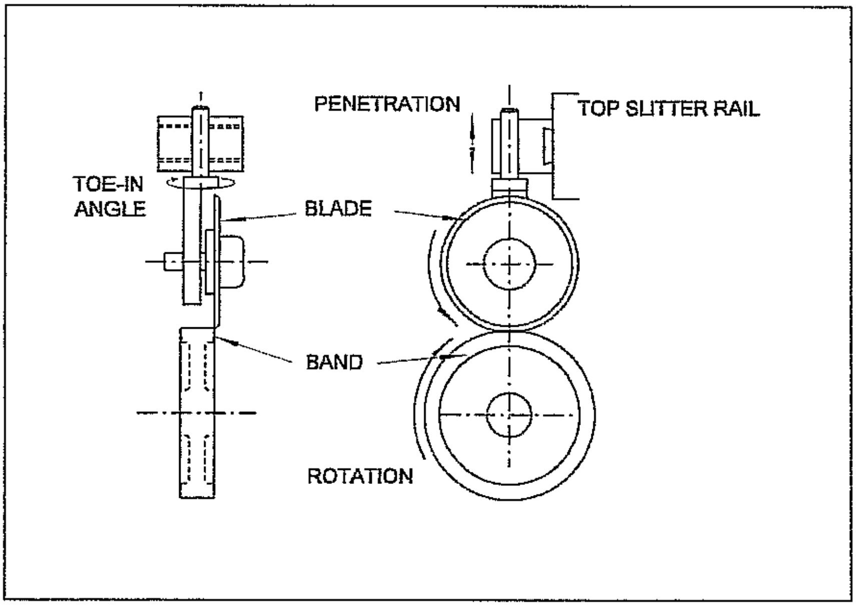

Fig. 2. Rotary shear slitter. Penetration adjusts amount of overlap between blade and band. Toe-in adjusts contact at entrance point of web.

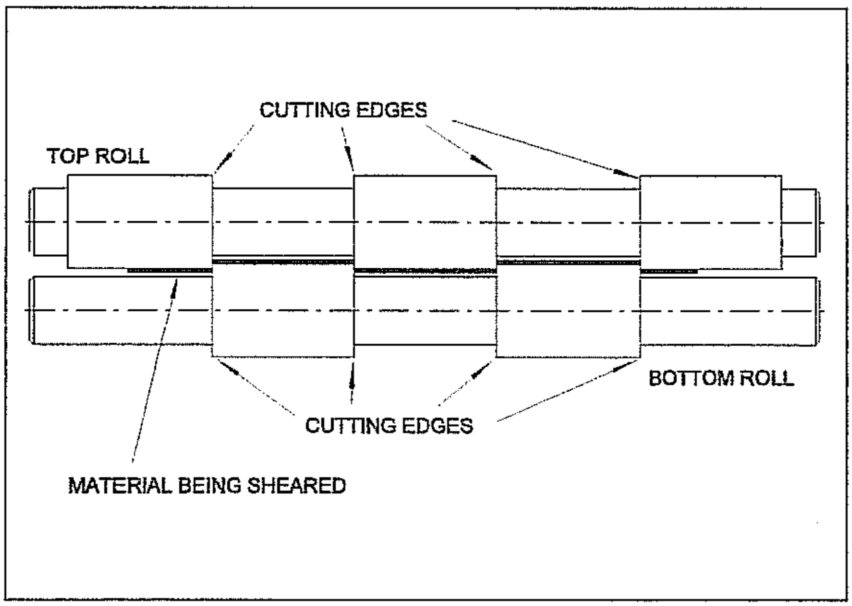

Fig. 3. Parallel-axis slitter where shearing rolls force slit webs to move alternately up or down. To slit metals, both rolls may be driven.

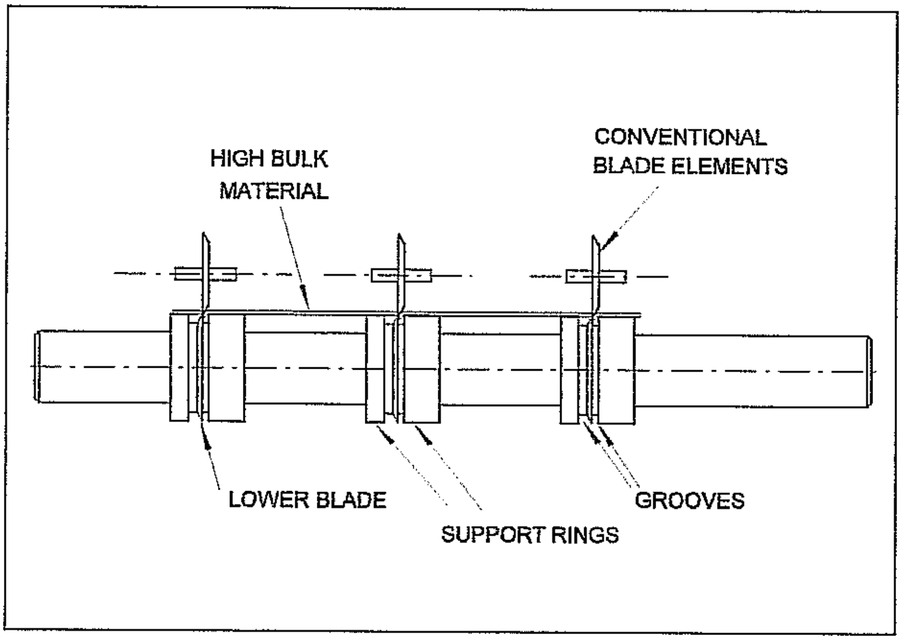

Fig. 4. High bulk slitter for thick, soft materials or multiple paper webs (3).

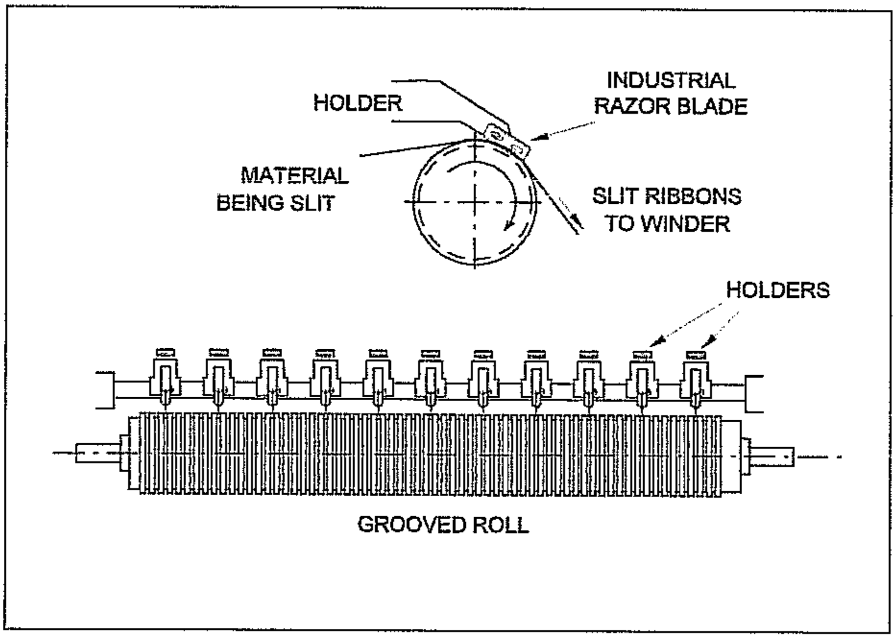

Fig. 5. Razor slitting. Material is allowed to wrap the grooved roll for stability. Disposable blades save on regrind expense.

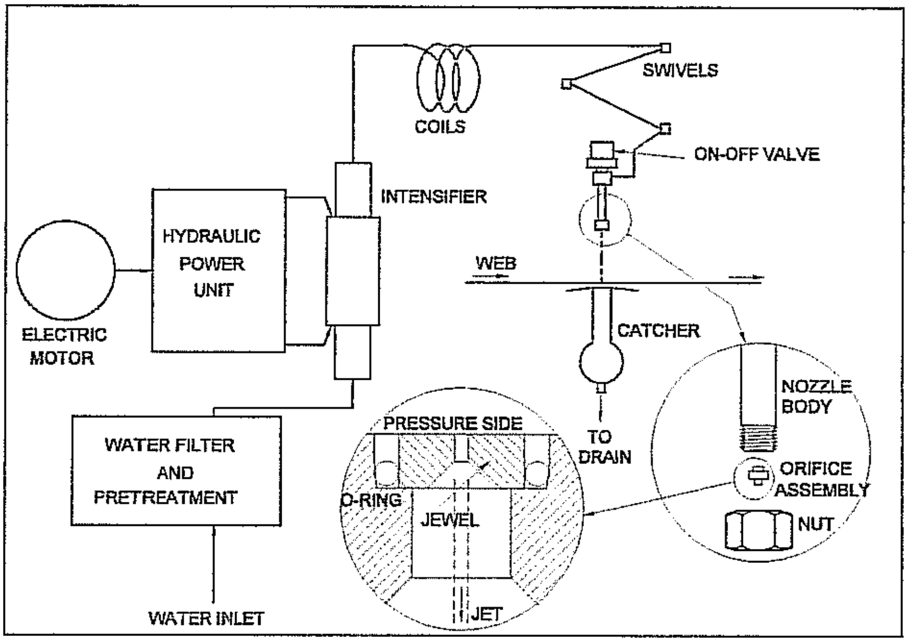

Fig. 6. High pressure water jet slitting. The orifice is formed in a jewel, either sapphire or diamond. Adjustment of the position of the cutting jet is through a system of coils and high-pressure swivels. (Flow International Corp.)

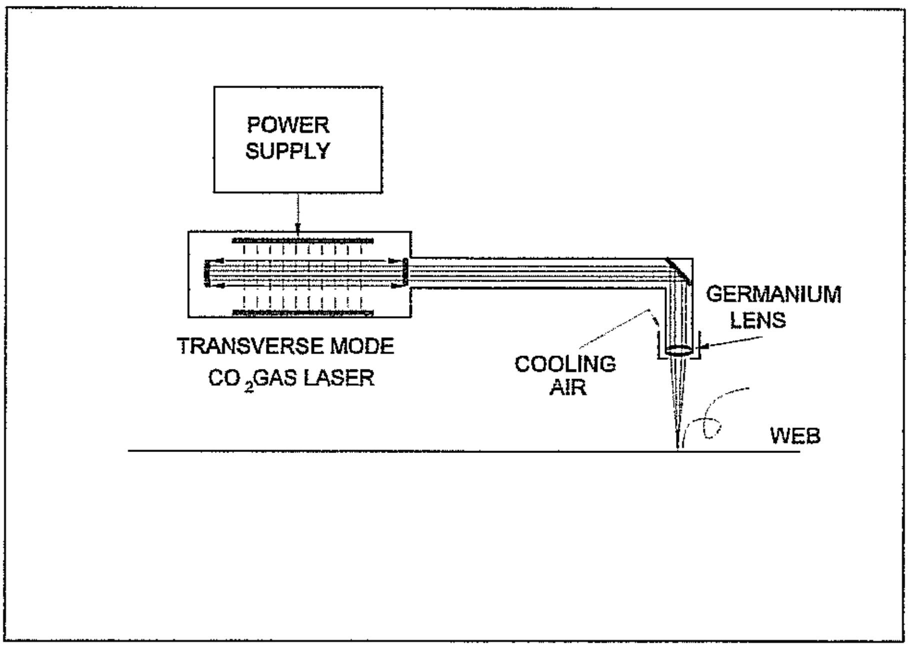

Fig. 7. Laser slitting. Speed is limited by the power density at the focal point for cutting by vaporization rather than burning.

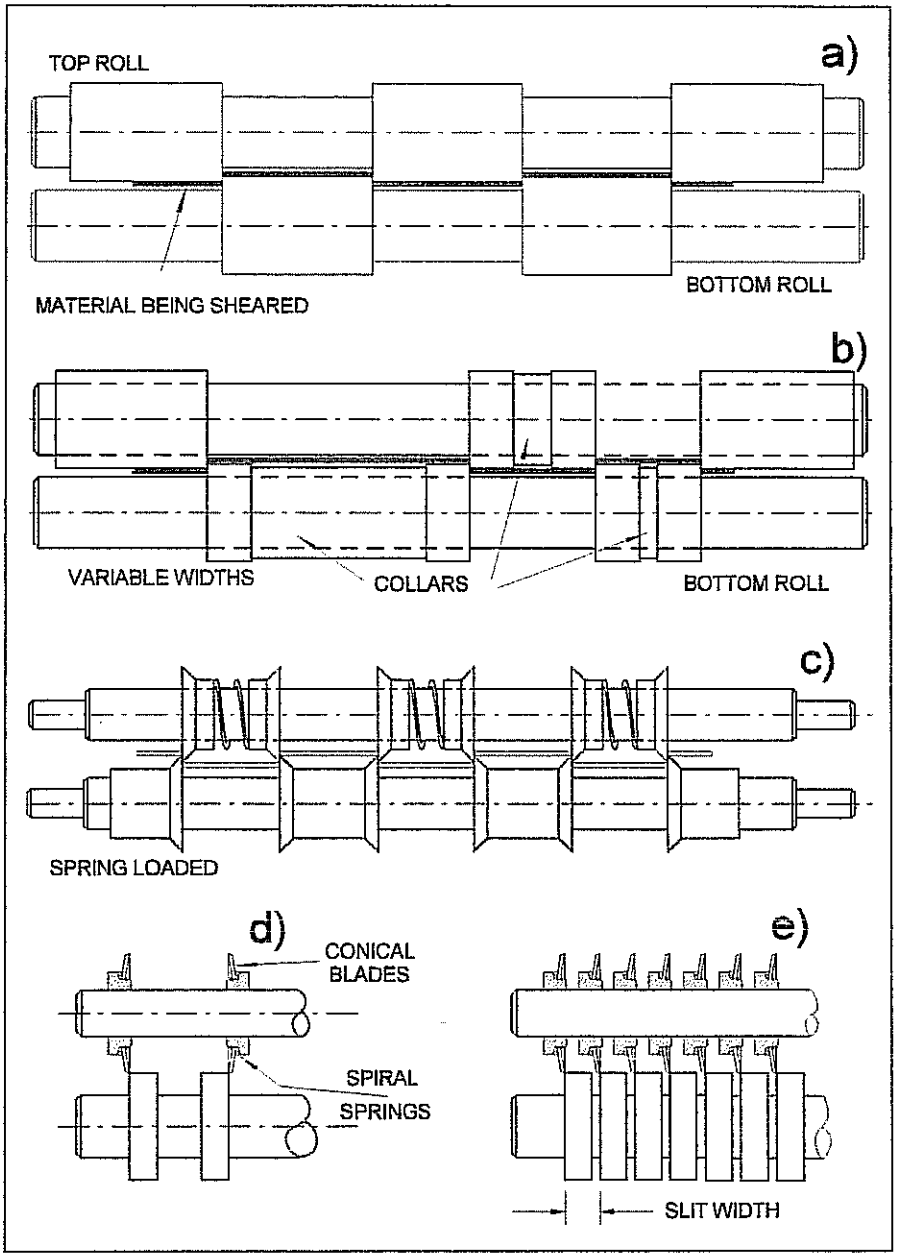

Fig. 8. a) Parallel axis slitter for cutting constant widths. **b)** Use of collars to space slitters for variable width slitting. **c)** Coil springs provide axial thrust. **d)** Springs wrapped around hubs push cupped blades axially. **e)** Slit width accuracy maintained by grinding the same side of all bands. (Dienes Werke)

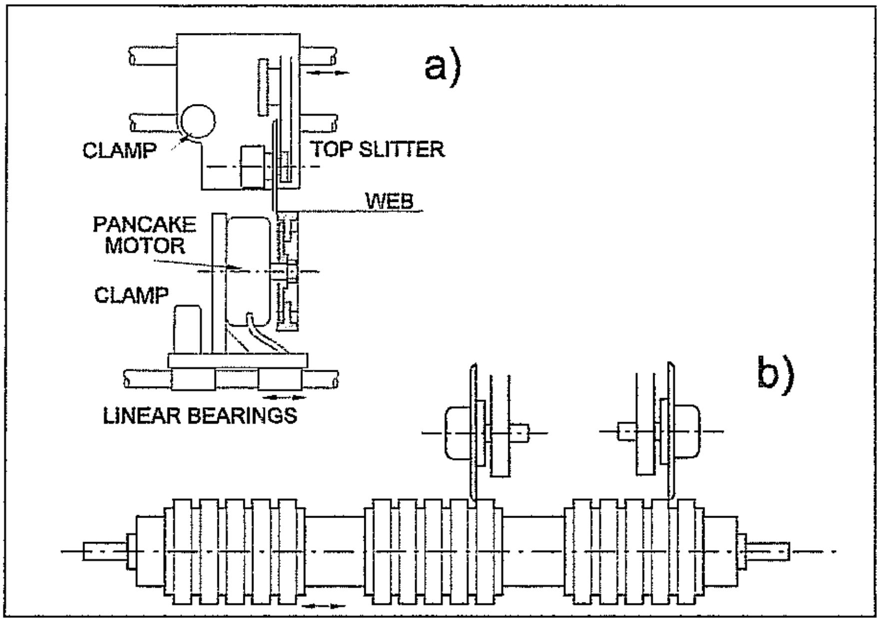

Fig. 9. a) Pancake motor (a-c or d-c) for driving band. Linear bearings and clamps allow rapid manual adjustment. (Beloit Corp.) **b)** Ganged slitter band assemblies on a common mandrel. Sleeves are adjustable.

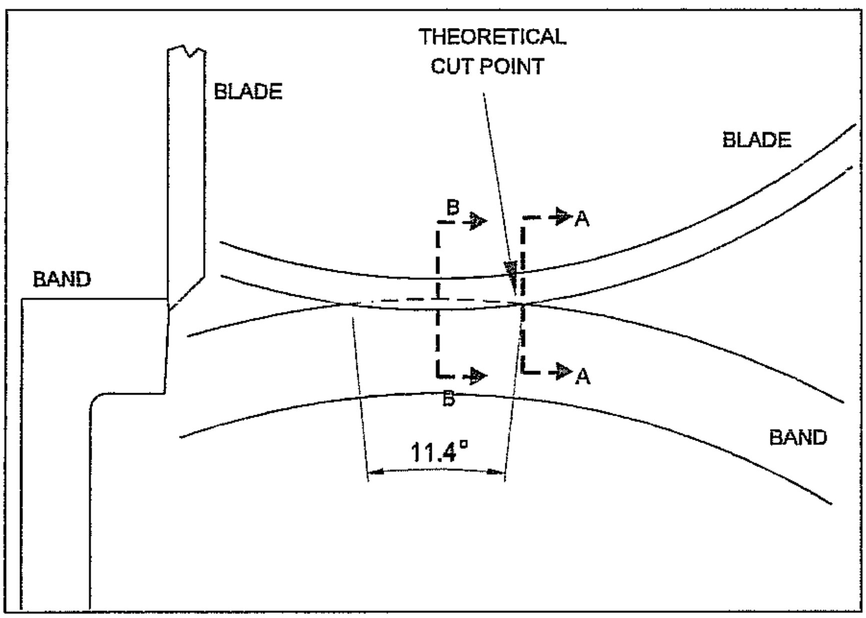

Fig. 10. Shear cut or blade-band type slitter, with penetration (overlap) of 0.67% of the distance between blade and band centers. Some wear has occurred to move the place of contact to B-B instead of A-A. See Fig.11.

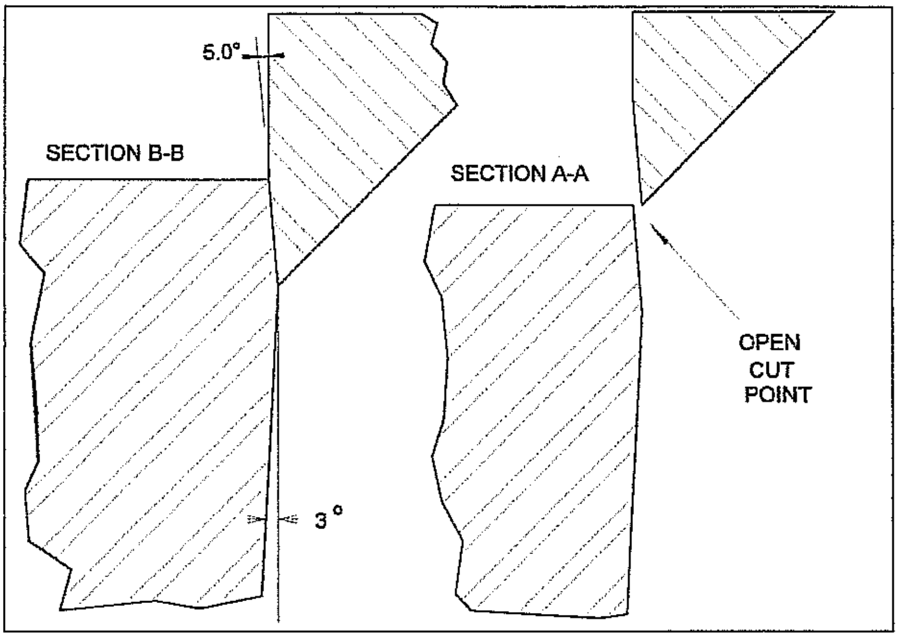

Fig. 11. Magnified sectional views along lines B-B and A-A of Fig. 10. Wear has occurred at a 5 degree angle. The band was initially ground with a 3 degree relief. The blade has a sharp edge, but it is not touching the band at A-A. Paper fibers will be torn instead of cut.

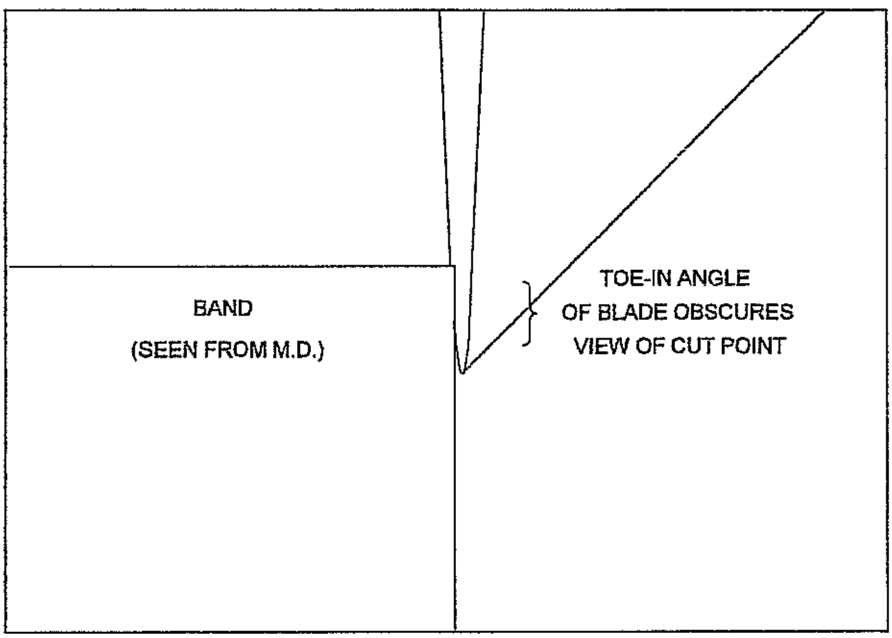

Fig. 12. Magnified straight-on or MD view of the contact between blade and band. The sharp edge of the blade appears as the tip of an ellipse, partly hidden behind the shadow of the band.

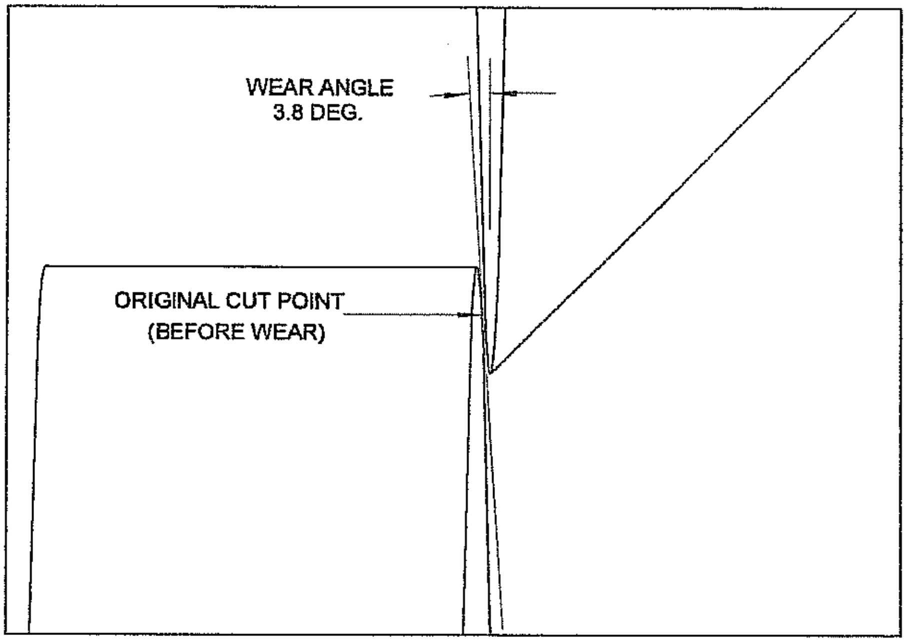

Fig. 13. When the band and blade are viewed along a sight line which is at half of the toe-in angle, both band and blade edges appear as ellipses. The common tangent line defines the wear angle.

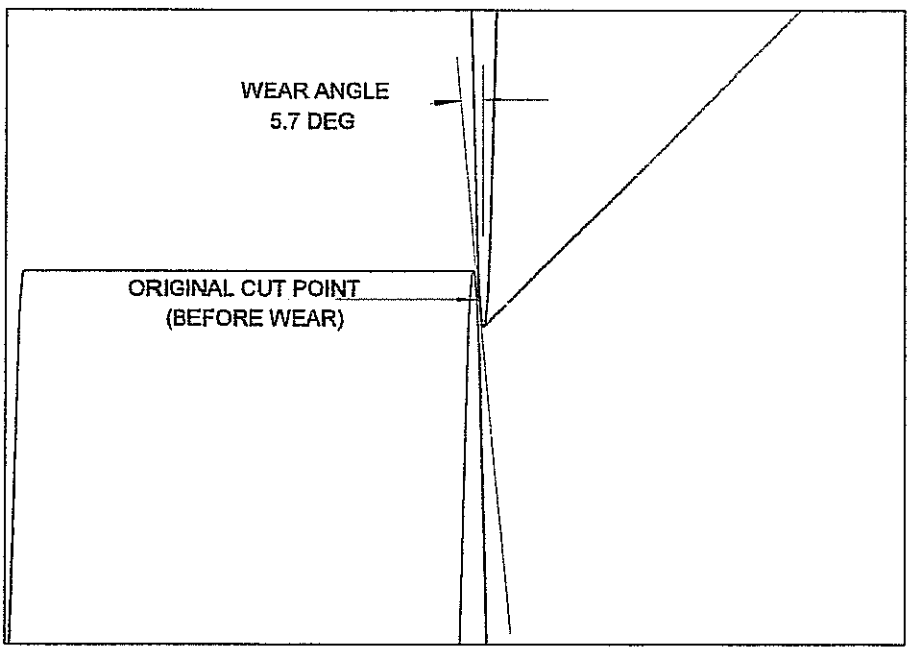

Fig. 14. Decreasing the penetration increases the wear angle.

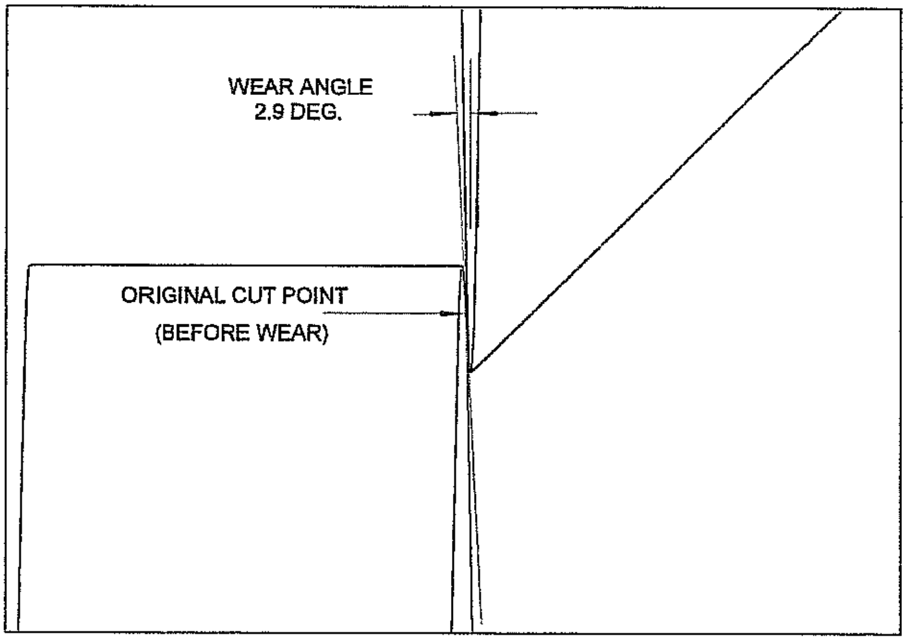

Fig. 15. Increasing the penetration decreases the wear angle.

Question –For the shear cutting pictures shown, what is effect of speed in relationship to cutter speed versus web speed?

Answer - Always it was common practice in the paper industry to always drive your center sections about 200 ft faster than the web. So that they would always be coming together before the web went into them. Now, if you are slower than the web speed, its like dragging a stationary pair of scissors through a sheet and pushing the sheer, and thats not so good, but matched speed works quite well, so if you have a close speed match between the circumferential speed of the slitting elements and the web speed that is fine.

Question - Just a Comment relative to the laser slitting. It might be said that number 1; it has been demonstrated that you can do laser slitting at high speeds so it is not limited to the degree that you mentioned. But your comment was correct. It is a power situation and then it gets to the point where for the sake of having a high tech solution to the problem it becomes exceedingly uneconomical and difficult to justify just for the sake of having a high tech solution. Relative to the water jet slitting, we've been able to demonstrate that whenever we've been working on either tissue, or more conventional grades, all the way to 300 PSI on up to 55,000 PSI water pressure, we get best results on the heavier weight grades, the liner board grades, as opposed to newsprint. We end up with a pretty ratty fuzzy edge that is somewhat suspect with the newsprint. The heavier grades that have some mass to the paper that ends up with a respectable cut. There are people in paper industry using water jet slitters on production winders and there are many people using these trim slitters prior to the reel.

Question - During slitting and after slitting I think there is a change in the strain and stress. Do you have some experience about that fact?

Answer - There are some "Do's" , and "Don't s" in notes that I wasn't able to include due to time limitations. There are some very 'Must do Rules' to follow. Such as tensioning every section of the web equally including trim as it existed before you slit it otherwise you'll have sections of the web moving ahead of the other, sheer forces at the slitting point and a really bad situation. So for the best slitting performance you must tension sections of the web equally, make sure they have a place to go once they are slit so they won't lose their tension and that will help them guide straight and be properly spread. There are also some tips about before slitter speeders and after slitter spreaders and what to do about them.