# Valmet Paper Lab
# - Tensile Stiffness Orientation module

Fiber orientation refers to how the direction of firers is distributed "in-plane" of paper. The fibers in paper are directed in different directions, but not equally in all directions: there are more fibers in some directions than in some others.

When paper is made, more fibers are aligned in the machine direction than in cross direction. Fiber orientation is one factor affecting the anisotropy of paper properties, and the desired anisotropy is different for different paper grades.

## The most common parameters describing fiber orientation

Orientation angle: describes how much the average direction of fibers differs from machine direction.
Fiber orientation index: describes the relation between fibers directed at orientation angle and fibers directed vertically at orientation angle.

Figure 1 shows an example of how fibers are directed in-plane of paper. As we can see the average direction of fibers is very close to machine direction, and the orientation angle is then almost zero. We can also see that more fibers are close to the average direction of fibers than in the vertical direction. As a result the value of fiber orientation index is quite high.

Figure 2 shows the orientation angle in co-ordinates.

Tensile stiffness orientation module is able to measure the properties listed on the following page (the **bolded** ones are the most common). Properties 27, 28, 29, 30, 35-46 have to be correlated with the bench instrument to get absolute correct values from the module (correction is made in PAL software in C-level for each property).

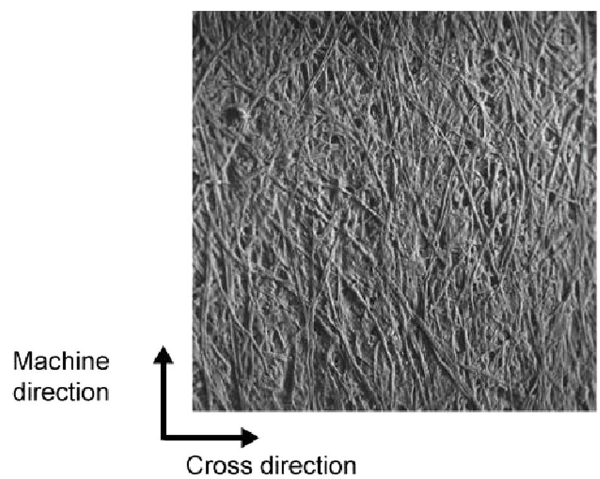



*Figure 1 – Fibers directed in paper.*

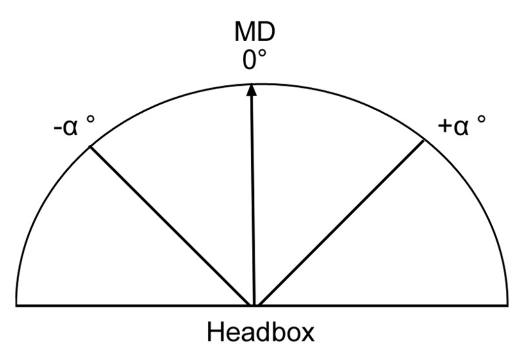



*Figure 2 – Description of orientation angle.*

Valmet

| | | | |
|---|---|---|---|
| 1) | **Orientation angle MD** = max. transmitting velocity | | |
| 2) | Orientation angle CD= min. transmitting velocity | | |
| 3) | Max/Min-ratio (speed) | | |
| 4) | MD/CD-ratio (speed 0º / speed 90º) | | |
| 5) | Maximum propagating velocity (km/s) | | |
| 6) | Minimum propagating velocity (km/s) | | |
| 7) | 0º velocity, km/s | 57) | 0º velocity, µs |
| 8) | 11.25º velocity, km/s | 58) | 11.25º velocity, µs |
| 9) | 22.5 º velocity, km/s | 59) | 22.5º velocity, µs |
| 10) | 33.75º velocity, km/s | 60) | 33.75º velocity, µs |
| 11) | 45º velocity, km/s | 61) | 45º velocity, µs |
| 12) | 56.25º velocity, km/s | 62) | 56.25º velocity, µs |
| 13) | 67.5º velocity, km/s | 63) | 67.5º velocity, µs |
| 14) | 78.75º velocity, km/s | 64) | 78.75º velocity, µs |
| 15) | 90º velocity, km/s | 65) | 90º velocity, µs |
| 16) | 101.25º velocity, km/s | 66) | 101.25º velocity, µs |
| 17) | 112.5º velocity, km/s | 67) | 112.5º velocity, µs |
| 18) | 123.75º velocity, km/s | 68) | 123.75º velocity, µs |
| 19) | 135º velocity, km/s | 69) | 135º velocity, µs |
| 20) | 146.25º velocity, km/s | 70) | 146.25º velocity, µs |
| 21) | 157.5º velocity, km/s | 71) | 157.5º velocity, µs |
| 22) | 168.75º velocity, km/s | 72) | 168.75º velocity, µs |
| 25) | TSI Max (peak value)$^2$ , (km/s)$^2$ | | |
| 26) | TSI Min (peak value)$^2$ ,(km/s)$^2$ | | |
| 27) | Bending stiffness MD, * | 28) | Bending stiffness MD ave. * |
| 29) | Bending stiffness CD, * | 30) | Bending stiffness CD ave. * |
| 31) | **TSI MD** (0º speed)$^2$ | 32) | **TSI CD** (90º speed)$^2$ |
| 33) | **TSI MD/CD** (0º speed)$^2$/(90º speed)$^2$ | 34) | EG geometrical average of Modulus Young |
| 35) | SCT MD ** | 36) | SCT CD ** |
| 37) | RCT MD ** | 38) | RCT CD ** |
| 39) | CCT MD ** | 40) | CCT CD ** |
| 41) | SCT MD (ave.) ** | 42) | SCT CD (ave.) ** |
| 43) | RCT MD (ave.) ** | 44) | RCT CD (ave.) ** |
| 45) | CCT MD (ave.) ** | 46) | CCT CD (ave.) ** |
| 47) | Tensile MD *** | 48) | Tensile CD *** |
| 49) | Tensile MD (ave.) *** | 50) | Tensile CD (ave.) *** |
| 91) | Tear MD **** | 92) | Tear CD **** |
| 93) | Tear MD (ave.)**** | 94) | Tear CD (ave.) **** |

* = requires Basis Weight & Caliper modules
** = requires Basis weight module
*** = requires other side of tensile module
**** = requires other side of tear module

## Properties strongly dependent on fiber orientation

The relationship between fiber orientation and other paper properties can be explained by the fact that

- fiber strength is better in the longitudinal direction than in the cross direction of fiber,
- moisture distension is stronger in cross direction of fiber than in the longitudinal direction.

For example tensile strength, bending stiffness and compression strength reach their maximum value in the direction in which the majority of fibers are directed. Some other properties, for example tear strength and moisture distension, reach their highest values vertically to that direction.

At the same time we must remember that fiber orientation is not the only decisive factor for the paper properties mentioned above: pulp type, the amount and type of filler, and the tension of the  paper web during drying also affect these properties. Some paper properties correlate relatively well with the orientation angle or fiber orientation index and they can be calculated from orientation results. When paper properties are calculated from fiber orientation results, the reliability of the results must always be verified by comparing the calculated results to the measured results.

## Factors affecting fiber orientation

The common idea is that fiber orientation is mainly formed in the wet end of the paper machine, or in the headbox and former. The press and drying section also influences fiber orientation, although the effect is considerably smaller than that of the  headbox and former.

In the headbox and former, fiber orientation in the machine direction is caused by

- the accelerating flow in the headbox,
- jet/wire speed ratio differing from value 1,
- obliquely occurring dewatering during drainage.

In the press section the water content in the web decreases before the web enters the drying section. Pressing also affects the properties of the end product, because at this stage the fibers are placed closer to each other while the conditions for bonding improve. The press section does not significantly affect fiber orientation, except by compressing together the different plies of the web.

Web transformations occuring in the drying section increase the anisotropy of the web; this effect can be seen especially in multi-layer papers. In the drying stage the edges of the paper web shrink, which partly affects the cross profile of orientation.

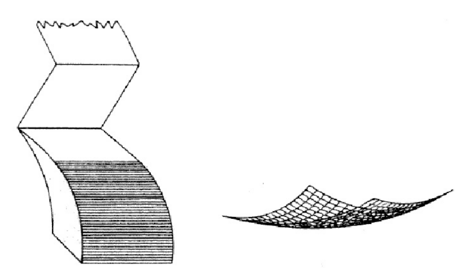
## Significance of fiber orientation for different paper grades

Changes in the orientation angle profile cause problems for paper makers as well as for the end users of paper. Different paper grades are suitable for different uses and are usually processed in some way before being used by the end customer. The properties required from papers depend greatly on the process and requirements of the end customer.

For the paper maker, the problems caused by poor fiber orientation include:

- runnability problems in the slitter, calender and coater,
- cuts on the paper machine,
- difficulties in threading/web feeding.

For **office papers** the orientation angle should be close to zero, and the orientation index should be very low. Especially copying and laser printer papers are very sensitive to orientation faults. In the copying machine or laser printer the toner is transferred to the paper surface at a high temperature and at the same time the paper dries slightly. If the orientation profile is uneven, this drying causes changes in the dimensional stability of paper. Orientation angle deviations from the machine direction causes paper jams in copying machines and printers, and another significant problem are slanting paper stacks after printing or copying. Orientation angle deviation of 1° from machine direction may look insignificant, but at the other end of a 100 m long continuous stretch of stationery paper it means a deviation of about 1.7 meters.



In the case of **printing papers**, the orientation angle should be near zero but the orientation index should be as high as possible. Printing paper (newsprint, magazine papers) are usually sold in reels from the paper mill, and the reels are cut to sheets only after printing.

Newsprint is required to endure the high-speed printing process without cuts or wrinkles, and to keep its dimensions during printing. This calls for high strength in the machine direction, and an even strength profile both in the machine direction and cross direction is also important.

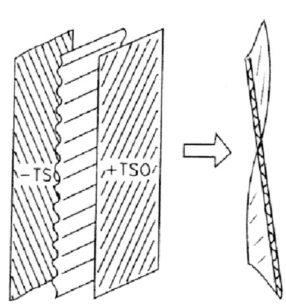
Permanence is even more important for magazine papers, and thus good strength properties in both directions are very important. Magazine papers have a higher basis weight than newsprint, and this is a way to increase strength: by using fillers we can decrease the tensile index below that of newsprint and yet keep the orientation index high.

**Multi-layer boards** require that the orientation angle in every layer should be near zero (= no great variation between layers), and the orientation index should be low. Multi-layer boards are usually used in packaging. Folding boxboard is used for example for cigarette and confectionery boxes. Paperboard boxes are made by attaching liner board (a surface layer of corrugated board) on both sides of corrugation board (fluting).

The strength properties of the different layers of liner board must be close to each other in both machine and cross direction, and therefore the orientation index must be low. In this way we get good burst strength.

Orientation angle in every layer should be close to zero. The strength of liner board is dependent on the average strength properties and average orientation angles of all layers. If the average orientation angle varies a lot, the boxes may twist when piled on top of each other.

Variations in orientation angle between the different layers of liner board cause oblique curling. When the layers are attached together and the liner board is dried, each layer will shrink in a different direction. This causes tensions between the layers and results in oblique curling and dimensional instability. Curling is common for multi-layer paper grades but it can also occur in single-layer paper grades.




The importance of fiber orientation for **other grades** varies considerably. Fiber orientation is an insignificant factor for soft tissue papers and construction papers. For sack papers, high tear and burst strength are the most important strength properties; thus the orientation angle is not very critical, provided that the orientation index and formation remain good.

## Understanding the results from Valmet Paper Lab TSO module

The Tensile Stiffness Orientation module measures the propagation velocity of ultrasound in-plane of paper. The velocity of ultrasound is higher in solid material than in the air, and the velocity depends on the elastic properties of paper: ultrasound moves faster in stiffer papers.

The module is able to report many properties, but the most commonly used are the following:

**Orientation angle MD, TSO MD (°)**
**TSO MD** is the orientation of the maximum TSI as an angle deviating from the MD. Maximum TSI describes the direction in which the elasticity is the greatest. This gives the paper machine operator information about how well balanced the headbox is. TSO can also give an indication about the curling or twisting tendency of the paper sheet. Curl itself is mainly induced by the two-sideness of paper, while the twist component is related to the elastic orientation.

The average **orientation angle MD** profile should be near zero, ± 0.5 is still acceptable. When reviewing the orientation angle md profile, it should be noticed that all individual values between ± 5° are acceptable and anything outside that range may cause problems for example in printing (runnability problems, twisting, curling).

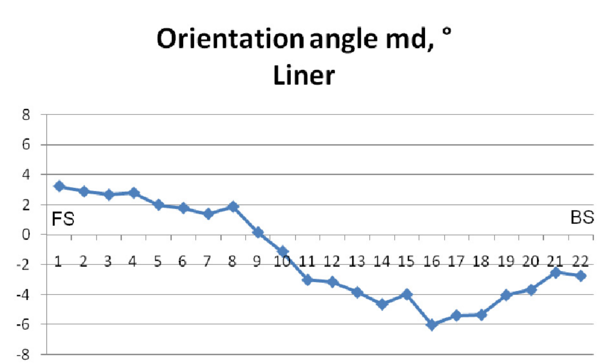
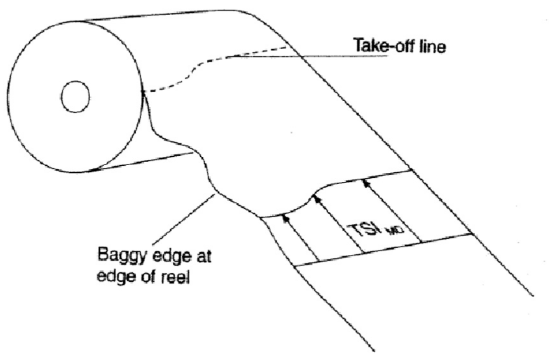



*Figure 3 – Example of orientation angle MD profile.*

**TSI MD (kNm/g)**
**TSI MD** describes elasticity in the machine direction and gives information about how well the press section is adjusted or how even the CD moisture profile was in the wet end. This property is directly related to many runnability problems that occur on a paper machine or in the subsequent converting proces.

The profile itself should be as flat as possible, since it gives an even elasticity across the paper machine. Variations are allowed from 5–10 % depending on paper grade.

TSI MD can indicate the tendency of both baggy edges and wrinkles. Highly oriented paper, such as newsprint, should have very low variation in order to avoid "baggy edges", web breaks on the paper machine or press room breaks, wrinkles/roping etc.



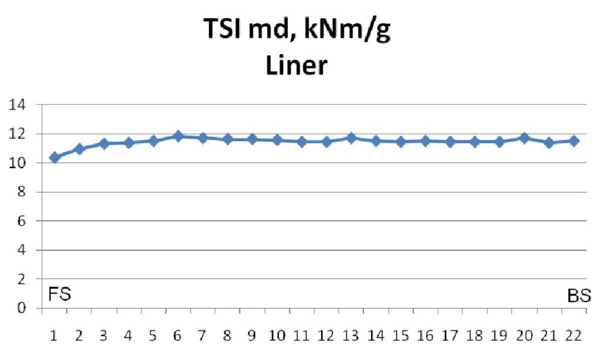




*Figure 4 – An example of TSI MD profile.*

**TSI CD (kNm/g)**

**TSI CD**, which describes the elasticity in the cross machine direction, is directly related to the strength and shrinkage/expansion across the web. TSI CD relates to the CD shrinkage profile, and it gives information about how well the dryer section is adjusted and also how intense the refining is.

Variation of the TSI CD profile should be within 10–20 % depending on grade, assuming that the caliper, basis weight and moisture profiles are kept within ± 2% variation. Newsprint is an exception, normally giving higher variation than 20 % for TSI CD, even up to 30 %.

The speed differential between the Jet and Wire speed controls the level and shape of both TSI CD and TSI MD profiles. Furnish refining influences the "banana" shape of the profile. Shrinkage in the cross direction can be controlled by adjusting the Rush/Drag ratio, refining and the cross machine restrained drying in the dryer section. The shrinkage profile affects the shape of the TSI CD profile.

Factors with a direct effect on TSI CD profile:

- Dryer section
- Refining
- MD draw
- CD draw
- Rush/Drag ratio

Poor TSI CD profile can cause runnability problems on the machine or at the end users, or misregister problems in multi-color printing.

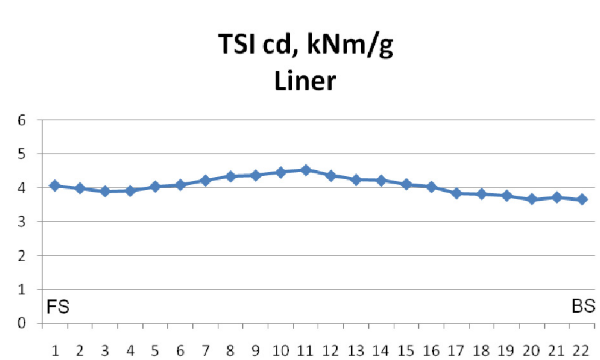



*Figure 5 – An example of TSI CD profile.*

**TSI MD/CD ratio – Anisotropy**

TSI MD/CD describes the relationship between the elasticity in the machine direction and in the cross machine direction. It gives information on the strength relationship of the sheet – the squareness of the sheet. The ratio or the anisotropy can be compared with the ratio between the classic strength properties like tensile strength, bending stiffness, compression strength etc. Target values for TSI md/cd for following paper grades are:

- Copy and laser paper 1.8–2.3
- Roll to roll printing paper 2.3–2.7
- Newsprint 3.2–5.0
- Liner board optm. for max RCT, SCT 2.0 or less (1.5–2.5)
- Liner board optm. for burst 2.5–3.5
- Board 2.0–2.5
- Sack Kraft 1.0–1.3

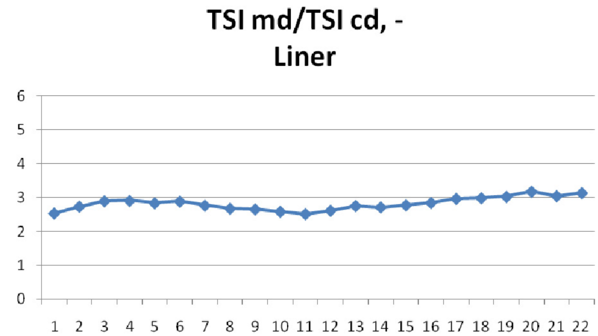



*Figure 6 – An example of TSI MD/TSI CD profile.*