WIRE SHAKE WITHOUT REACTION FORCES

Uwe Knotzer, M.sc. Phd.
Helmut Widauer, M.sc.
VOITH Paper Austria GmbH & Co KG
Linzer Str. 55
3100 St. Poelten, Austria

ABSTRACT
Formation and sheet properties can be positively influenced by oscillations of the forming wire. High speeds on state-of-the-art paper machines require modern wire shaking. Standard shaking units show little to no effect at higher machine speeds. Only the functional principle of the Voith DuoShake™ allows for effective adaptation to higher machine speeds, which has been proven by the investigations described in this article and numerous installations all over the world for different paper grades.

INTRODUCTION
The positive influence of shaking movements on (homogeneous) sheet formation and fiber orientation has been known since the early days of handsheet paper making. Even the very first paper machine, invented back in 1799 by Louis Robert, provided automatic oscillation of the forming wire. From the beginning of the 19th up to the end of the 20th century, few had changed in the basic principle of shaking devices. At high machine speeds, conventional shaking units hardly show any effect, and high vibrations in the area of the wire section occur.

In a conventional shaking unit with an eccentric, the force exerted on the breast roll via the shaking rod also induces reaction forces in the framing and foundation of the shaking device, leading to heavy vibrations in the wire section.

In the DuoShake™, the oscillating carriage can move freely in the sliding bearings, without any frictional connection to framing or foundations. Therefore, no reaction forces have to be absorbed by these parts. The DuoShake™ gearbox is easy to maintain.

Shaking number
To be able to evaluate the effectiveness of a set of operation parameters, the shaking number has been defined as

$$ SKZ := \frac{f^2 \cdot S}{v_{Wire}} $$

with a higher shaking number indicating a greater impact on paper properties. Since the frequency $f$ [rpm] is squared in the equation, an increase in shaking frequency drastically increases the shaking number. The stroke $s$ [mm] or the amplitude of the oscillation is of linear influence, while an increase in machine speed $v_{Wire}$ [m/min] results in a lower shaking number.

THE DUO SHAKE™ PRINCIPLE
The shake unit and the breast roll represent a system of coupled masses. The composite barycenter of such a system will not change its position unless external forces are applied to the system (principle of linear momentum, Newton’s First Law of Motion). Since there is no frictional connection between the oscillating system and any other parts, no such forces are effective in the axial direction of the breast roll, and the common center of gravity of the whole system will remain fixed. For this to be true, the individual masses the system consists of are subject to

$$ \sum m_i \cdot s_i = 0 $$

where $m_i$ are the individual masses, and $s_i$ are the virtual dislocations of the respective barycenters. Fig. 3 shows a system of two coupled masses. In this case, the equation yields $m_1 s_1 = -m_2 s_2$, with the negative signum indicating that the masses move in opposite directions.
The centripetal force resulting from the rotation of a single eccentrically rotating mass can be calculated from mass, angular speed (or frequency) and the distance between the center of rotation and the barycenter of the component:

\[ F_c = m \cdot \omega^2 \cdot r \]

\[ r \approx \frac{4R}{3\pi} \]

assuming the shape of the component resembles a half cylinder. When this force is split up into a vertical and a horizontal portion at any time of the rotation, these forces are described by

\[ F_x = F_c \cdot \cos \omega t \]
\[ F_y = F_c \cdot \sin \omega t \]

The maximum force in either direction is the aforesaid centripetal force. Fig. 5A shows one rotating weight. The vertical force does not contribute to the shaking movement and is undesirable, since it unnecessarily strains the framing and foundation of the shaking device.

By simply adding another rotating weight with identical mass, geometry and angular speed but with reverse sense of rotation, the unwanted vertical forces compensate each other, while the resulting horizontal force is increased by the additional rotating mass (Fig. 5B). In the DuoShake™, synchronous rotation of the pair of rotating masses is guaranteed by coupling them via gears.

While the half cylinders are in rotation, their individual barycenters will change their relative positions within the system, which would also alter the position of the composite barycenter. Instead, the system starts oscillating, thus leaving the absolute position of the composite center of gravity unchanged. The amplitude of the resulting oscillation therefore equals the distance between the two extremal relative positions of the composite barycenter within the system.

The amplitude or stroke of such a device with two rotating masses can only be altered by changing mass or geometry of the components.

To be able to change the stroke of the oscillation, it is sufficient to add yet another pair of rotating half cylinders.

By changing the phase difference between the two pairs of unbalanced masses, the stroke of the oscillating movement of the carriage can be altered.
Fig. 6 shows three different examples of phase differences of the unbalanced mass pairs. Maximum stroke can be reached with a phase difference of 180° between the two pairs through an addition of the horizontal forces.

The stroke will be reduced constantly through a reduction of the phase difference. At a phase difference of 0° the horizontal forces, as well as the vertical forces, are compensated, leading to no stroke at all.

FORMATION IMPROVEMENT
As the vertical movement has been eliminated, the DuoShake™ is a perfect tool to shake fourdrinier wires at higher speeds. Typical applications are the production of kraft sack paper, cigarette paper, newsprint, speciality paper and the middle layer of board. The horizontal forces which are brought into the wire section will lead to an homogenizing process during formation. With the help of shaking pulses, formation can be improved by destroying flocks. Fig. 7 shows the results of wire shaking with a DuoShake™ unit in 50 g/m² newsprint. The formation could be improved significantly.

The results of similar trials on a filler ply of whitelined chipboard with a ply weight of 186 g/m² at 220 m/min are shown in Figure 8. The left image shows the formation without breast roll shaking (Ambertec formation value of 0.86 sqrt(g/m²)) whereas the image on the right shows the middle ply produced with a DuoShake™ (Ambertec formation value of 0.75 sqrt(g/m²)) at a shaking number of 5700.

Many other similar trials on paper, board and trial machines show similar results.

PAPER PROPERTY IMPROVEMENT
Breast roll shaking not only influences formation values, it also improves some paper properties, because the sheet structure is influenced by the vibrations brought into the fiber water suspension. One way to measure sheet properties that gives an average value across the total paper thickness is measuring physical properties. (e.g. SCT, Burst). Another way is visualization of z-directional properties.

How To Measure Sheet Structure
An appropriate method to characterize the sheet structure is to determine the orientation of the individual fibers. Since the paper web is of a pronouncedly layered structure, fiber orientation has to be measured on multi-ply split samples, as shown in Fig.9.

The orientation of all detectable fiber segments of each layer is determined and the resulting distribution of angles illustrated in polar coordinates, with the length \( r(\alpha) \) of the pointer in direction \( \alpha \) indicating how many of the sampled fiber segments show this angle of orientation. This results in the typical elliptic graph displayed in Fig. 10 A.
To describe the fiber orientation of a sample, two characteristic numbers are necessary: the anisotropy (i.e. intensity of orientation) and the cardinal angle of the fiber orientation distribution. The level of anisotropy is calculated from the lengths of the semiminor and semimajor axes ($a$ and $b$ in Fig. 10 B) as per

$$A := 1 - \frac{b}{a}.$$

The dominant angle of the distribution (i.e. the angle of the major axis) is called the fiber orientation angle $\varphi$, with $\varphi=0$ representing orientation in machine direction.

The more distinctly oriented a sample is, the more the length of the semiminor axis is exceeded by that of the semimajor axis, which makes $A$ approach 1 as its maximum. The other extreme will be a sample without a dominant angle. This will result in equal lengths for all angles (thus $a=b$), which gives a circular graph, representing an anisotropy of $A = 1 - 1 = 0$.

Anisotropy measured in z-direction can be visualized with the help of a colour map (Fig. 11). 11 layers of the sample were measured. Blue colours symbolize lower anisotropy levels, whereas red colours stand for higher MD/CD ratios. Average values per layer are shown in the small figures to the right. Fig.11A shows varying anisotropy across the cross section of the sample. Fig. 11B has been produced with a DuoShake™.

Two important results can be seen:

First, the anisotropy is much more even across the cross section, which will significantly reduce the risk of diagonal curl. Diagonal curl can be seen especially in coated paper and board grades and can be influenced through the drying process. However, if the paper structure tends to curl diagonally already in the wire section, it is hard and sometimes impossible to correct this error through the drying process.

Second, the average level of the MD/CD ratio decreased, which is important for different paper grades like sack paper, folding box board or copy paper.

When producing kraft paper, the consistency of the suspension in the headbox is very low ($k\approx0.1\%$) because of the very long fibers. This dilution leads to a very thick layer of suspension on the wire (6-8cm). Internal friction of the suspension leads to a rapid decrease of the impact of breast roll shaking. So far, the idea was that shaking effects go less than one fourth into the layered structure of paper.

Fig. 12 and Fig. 13 show a comparison of fiber orientation angles of two kraft papers - one produced with breast roll shaking through a DuoShake™ and another one without breast roll shaking. Due to the fact that the production was run with jet-to-wire ratios close to 1, the fiber orientation angle varies a lot.

The bold lines symbolize the average fiber orientation angle through all layers of the specimens. The thin, dashed lines stand for single results of the splitting process. As one can see, the bold lines do not differ much, the thin lines, however, do. Especially in the first two-thirds of the paper sheet, there is a significant difference. While there is little fluctuation in the paper with breast roll shaking, there is a much bigger one in the sample without shaking. Thus, the influence of breast roll shaking in this trial goes two-thirds into the paper and improves paper structure. The layers close to the top side are no longer affected by the shaking process.
CONCLUSIONS

The functional principle of the Voith DuoShake™ allows for effective adaptation to highest machine speeds on fourdrinier, which has been proven by numerous investigations on trial facilities and more than 80 paper and board machines worldwide at different paper grades. Better formation and improved paper structure lead to optimized paper and board quality.