Flying Saw – General Information

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1 Introduction

This Application Note contains general information on the "Flying Saw" application. Further, variants of "Flying Saws" are described in detail. For realizing these variants, corresponding Jetter system components have been made available. Please note further Application Note 31 "Flying Saw" - JX2-SV1 / CAN-DIMA", respectively no. 38 "Flying Saw" – JM-2xx. In this Application Note, cross cutter applications are not dealt with.

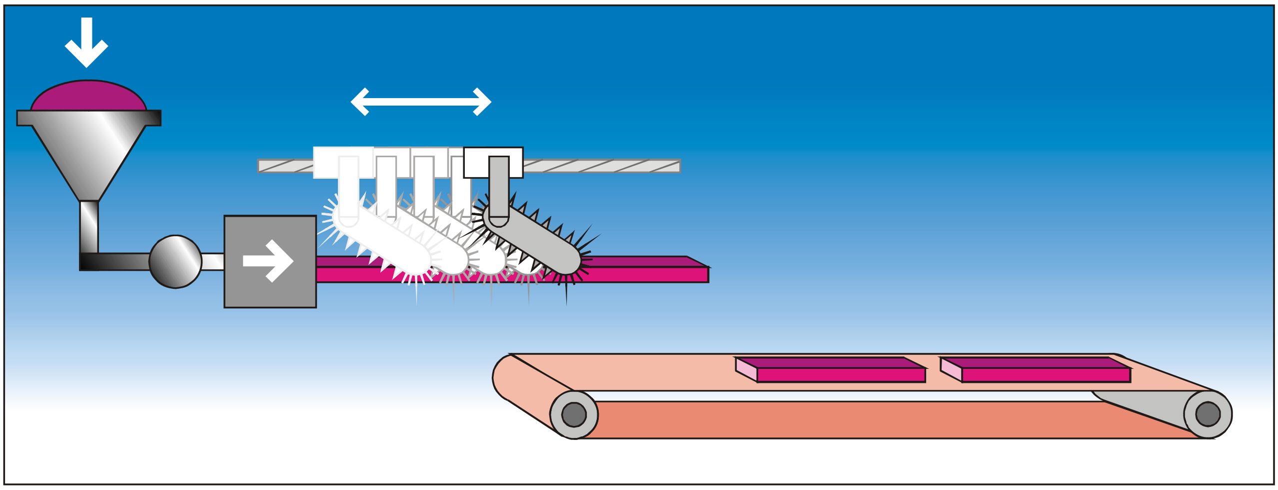


Fig. 1 Example of a Flying Saw

2 Definition

A Flying Saw is defined as follows:

This application consists of the following units:

- Master axis
- Slave axis
- Tools unit

The **master axis** moves the material that is to be processed. Normally, it keeps running in always the same direction in endless mode. There might be applications, in which the master axis first moves into one direction for some time and then returns to its home position.

The master axis transmits its actual position to the slave axis. For this reason, the master axis need not be a physical axis. It can also consist of an encoder – sensing wheel-unit, which records the motion of the material automatically. An extruder for metal profile manufacturing might serve as an example. In this case, a sensing wheel takes up the motion of the already hardened material.

The **slave axis** moves the tools unit. It keeps moving within a definite working range. After each cutting cycle, it returns to its home position. It is also possible for the axis not to go back to its home position before having completed some cutting cycles. In this case, the cutting cycles are carried out right one after the other in the same direction. This makes up the difference between a Flying Saw and a cross cutter. The slave axis of a cross cutter is always a rotatory axis endlessly moving in the same direction. Further, no additional tools unit is needed in a cross cutter, as the slave axis is already the tools axis.

The master axis transmits its position to the slave axis. At a cutting request, it accelerates to the actual speed of the master axis via an acceleration ramp and couples exactly to the cutting position. After coupling to the cutting position, cutting is carried out. After the cutting procedure, the slave axis discouples and moves back to its home position. The following demands can be set to decoupling: e.g. transporting the cut material together with the tools unit via acceleration ramp to create an obvious gap between the pieces of the cut material. This could be another requirement: After the cutting process, decelerate by the maximum deceleration ramp and return to home position.

The **tools unit** processes the material during the cutting process. The cutting action is the phase, in which the slave axis synchronises with the master axis to hit the cutting position exactly. A countless number of applications is conceivable. Below, only some are listed as an example:

- Cutting of endless materials: e.g. pipes, profiles, paper, foil, wood
- Combining various materials: e.g. glueing labels or CD envelopes on magazines
- Joining various materials: e.g. blister packaging
- Transporting various objects: e.g. shifting components from one transporting belt to another, or taking components from a belt

3 Phases of a Sawing Cycle

The sawing cycle runs in 3 phases, see fig. 2:

1. Phase: Synchronising **(1)**
2. Phase: Sawing process **(2)**
3. Phase: Homeward voyage **(3)**

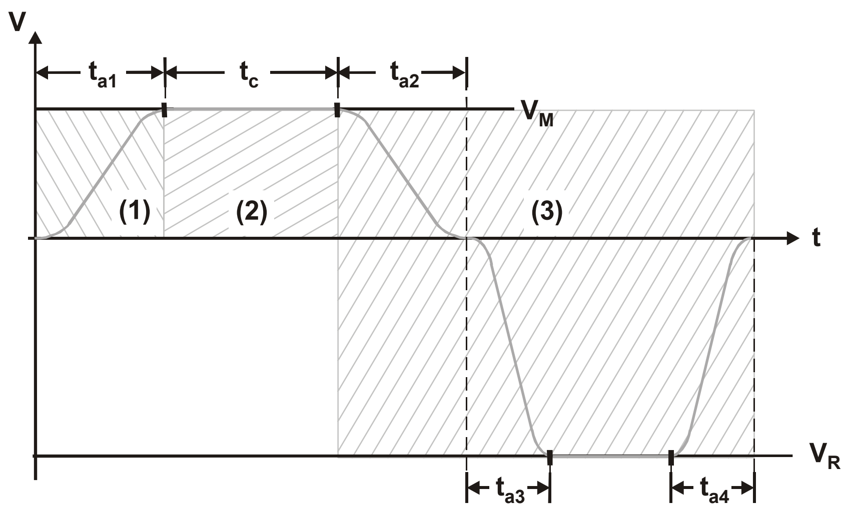


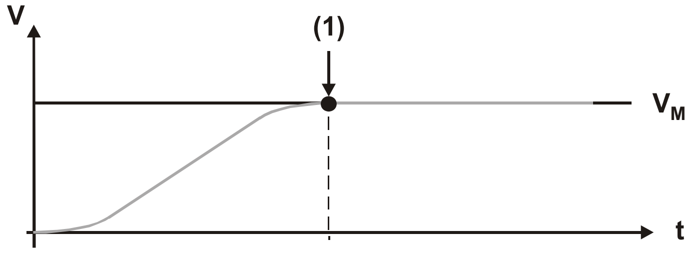
Fig. 2 Slave speed profile for a sawing cycle

The sum of the duration of all phases determines the duration of a sawing cycle.

4 Synchronising Phase

4.1 Time-Optimised Synchronising Phase

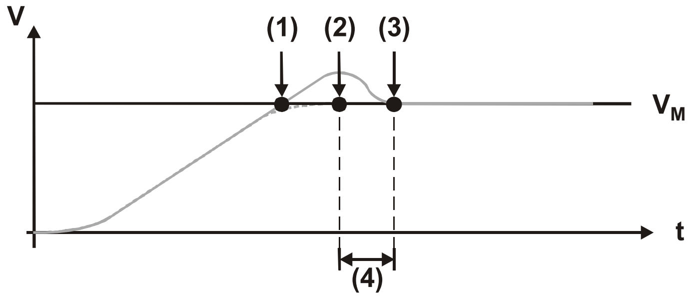
The synchronising phase, i.e. accelerating the slave to master speed, is best regarding time, if the following conditions have been met: The slave couples to cutting position exactly (e.g. the position, to which synchronisinig is made), as soon as it has reached master speed. In this case, the slave does not need to catch up after reaching the master speed; see fig. 3.



(1) Master speed and cutting position have been reached

Fig. 3 Time-optimised synchronising phase

If the slave does not exactly hit the cutting position at reaching master speed, a corrective motion must be carried out, which will take up additional time. The corrective motion can be a catch-up run as shown in fig. 4.



(1) Master speed has been reached
(2) Master speed has been reached at time-optimised synchronising, see fig. 3
(3) The cutting position has been reached
(4) Time delta for catchup run

Fig. 4 Synchronising phase, not time-optimised

It would be best timing, if the slave started accelerating, when the distance between cutting position and synchronized position is exactly the same distance covered during the slave acceleration process.

For calculating the distance to be covered by the cutting position during slave acceleration, the following derivation applies: This derivation only applies to linear and sine-square speed ramps.

$$s_{Ma} = v_M \cdot t_a \Rightarrow t_a = \frac{s_{Ma}}{v_M} \quad (1)$$

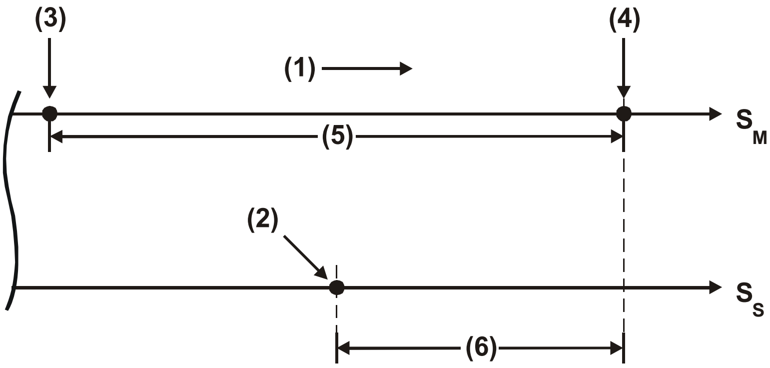
$$s_{Sa} = \frac{1}{2} v_M \cdot t_a \Rightarrow t_a = \frac{2 s_{Sa}}{v_M} \quad (2)$$

equate (1) and (2):

$$\frac{s_{Ma}}{v_M} = \frac{2 s_{Sa}}{v_M} \Rightarrow \boxed{s_{Ma} = 2 s_{Sa}}$$

s_{Ma} : Distance covered by the master (= distance covered by the cutting point)
s_{Sa} : during acceleration ramp of the slave
Distance of the slave covered during the
v_M : ramp
t_a : Constant speed of the master
Duration of the ramp on v_M

As is shown in the formula above, the distance covered by the cutting position during slave acceleration equals double the distance covered by the slave during acceleration. In the time-optimum case, the slave must start, when the distance of the cutting position is still as far from the starting point of the slave, which the slave needs for accelerating, see fig. 5.

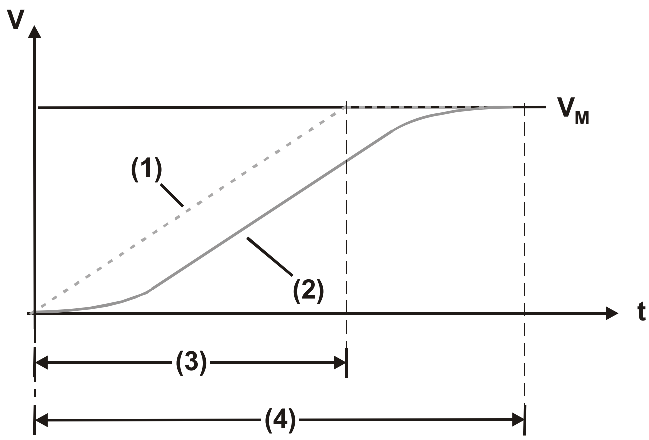


(1) Motion direction of the master
(2) Starting position of the slave
(3) Cutting position at slave start
(4) Cutting position when the axes are on the same level
(5) Distance covered by the cutting position during slave acceleration 2 * (6)
(6) Accelerating distance of the slave

Fig. 5 Distances - Overview

4.2 Ramp Types

For acceleration, various speed ramps are possible. Below, the linear ramp is compared with a sine-square ramp, see fig. 6.



(1) linear speed ramp
(2) sine-square speed ramp
(3) linear speed ramp time
(4) sine-square speed ramp time

Fig. 6 Linear and sine-square speed ramp

If both ramp types are based on the same maximum acceleration, this is kept constant throughout in case of the linear ramp, while, in case of a sine-square ramp, maximum acceleration only occurs in the middle of the ramp. For this reason, the linear speed ramp time is shorter than the sine-square speed ramp time. It takes about 1.57 times longer than the linear ramp, as is shown in figure 6.

5 Calculating the Ramp Time

linear ramp: $t_a = \frac{v_M}{a_{\max}}$

Sine-square ramp: $t_a = \frac{\pi}{2} \cdot \frac{v_M}{a_{\max}}$

t_a : Rampendauer
v_M : konstante Geschwindigkeit des Masters
a_{max} : maximale Beschleunigung der Sinus²-Rampe bzw. konstante Beschleunigung der linearen Rampe

6 The Cutting Length

The cutting length is the distance between one cutting position and the next. Please consider that the width of the cutting tool must also be counted as part of the cutting length.

6.1 Shortest Possible Cutting Length

In case of a Flying Saw application, there are restrictions concerning cutting length and master speed. This means that noch every cutting length can be set in combination with any master speed.

By means of the following formulas, the shortest possible cutting length at a set master speed can be determined. For assigning the input parameters, please consider fig. 2 and 7. For calculating the ramp times, please turn to chapter "Fig. 6 Linear and sine-square speed ramp

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s : Cutting length [mm] or [°]
s_{min} : Shortest possible cutting length [mm] or [°]
t_{a1} : Duration of ramps from v= 0 to V_M for forward motion [s]
t_{a2} : Duration of ramps from V_M to v=0 for forward motion [s]
t_c : Duration of the mere cutting procedure [s]
(Time between the signals "slave axis, synchronised" and "cutting procedure")
t_{a3} : Duration of ramps from v=0 to V_R for backward motion [s]
t_{a4} : Duration of ramps from V_R to v=0 for backward motion [s]
v_M : Constant speed of the master axis [mm/s] or [°/s]
v_{Mmax} : Maximum speed of the master axis in [mm/s] or [°/s] at a given cutting length, please refer to chapter "Maximum Master Speed"
v_R : Constant speed of the slave axis at backward motion [mm/s] or [°/s]

Fig. 7 Variables for calculation

A distinction between two cases must be made:

a) If the total distance of forward motion > Distance of the two ramps at backward motion, expressed in the following formulas: $\left(\frac{1}{2}t_{a1} + t_c + \frac{1}{2}t_{a2}\right) \cdot v_M > \left(\frac{1}{2}t_{a3} + \frac{1}{2}t_{a4}\right) \cdot v_R$ the shortest possible cutting length is

$$s_{\min} = v_M \cdot \left(t_{a1} \cdot \left(1 + \frac{v_M}{2 \cdot v_R}\right) + t_c \cdot \left(1 + \frac{v_M}{v_R}\right) + t_{a2} \cdot \left(1 + \frac{v_M}{2 \cdot v_R}\right) + \frac{1}{2}t_{a3} + \frac{1}{2}t_{a4} \right)$$

b) If the total distance of forward motion ≤ Distance of the two ramps at backward motion, expressed in the following formulas: $\left(\frac{1}{2}t_{a1} + t_c + \frac{1}{2}t_{a2}\right)\cdot v_M \le \left(\frac{1}{2}t_{a3} + \frac{1}{2}t_{a4}\right)\cdot v_R$ the shortest possible cutting length is

$$s_{\min} = v_M \cdot \left(t_{a1} + t_c + t_{a2} + t_{a3} + t_{a4}\right)$$

Situation a) is the standard situation. Situation b) implies the condition that the entire distance of forward motion is smaller than the added up distance of the two ramps at backward motion. In practice, the distance covered at homeward voyage should not be longer than the distance covered at forward motion, otherwise the home position of the slave would not remain constant. This condition is to comply with triangle homeward voyage.

In triangle motion, speed V_R is not met, as the way is too short. Instead, an immediate changeover is made from acceleration to deceleration ramp. Actually, the values of the two ramp times R_3 and R_4 are smaller than the values calculated for reaching V_R.
The precise ramp times cannot be determined exactly, as the final speed, to which the system is accelerated in triangular motion is not known usually. For this reason, only an approximate value of the shortest step width is determined by specifying R_3 and R_4 in case b). The actual cutting length is shorter than the calculated one. The actually shortest step width can be determined by means of the case b) formula, though, if R_3 and R_4 contain the actual time values.

If shorter lengths than the determined ones are to be cut, either the master speed or time T must be reduced.

7 Maximum Master Speed

The maximum master speed can be calculated by means of the following formulas at a given cutting length. For this, please consider fig. 2 and 7.

A distinction between two cases must be made:

a) If the cutting length > optimum distance of the sawing cycle, expressed in formulas:

$s > v_R \cdot \frac{\left(\frac{1}{2}t_{a3} + \frac{1}{2}t_{a4}\right)}{\left(\frac{1}{2}t_{a1} + t_c + \frac{1}{2}t_{a2}\right)} \cdot \left(t_{a1} + t_c + t_{a2} + t_{a3} + t_{a4}\right)$ the master speed must not become greater than

$$v_{M\max} = v_R \cdot \left(\frac{-t_{a1} - t_{a2} - t_c - \frac{1}{2}t_{a3} - \frac{1}{2}t_{a4} + \sqrt{\left(t_{a1} + t_{a2} + t_c + \frac{1}{2}t_{a3} + \frac{1}{2}t_{a4}\right)^2 + \frac{4\cdot s}{v_R}\cdot\left(\frac{1}{2}t_{a1} + \frac{1}{2}t_{a2} + t_c\right)}}{\left(t_{a1} + t_{a2} + 2\cdot t_c\right)} \right)$$

b) If the cutting length ≤ optimum distance of the sawing cycle , expressed in formulas:

$s \le v_R \cdot \frac{\left(\frac{1}{2}t_{a3} + \frac{1}{2}t_{a4}\right)}{\left(\frac{1}{2}t_{a1} + t_c + \frac{1}{2}t_{a2}\right)} \cdot \left(t_{a1} + t_c + t_{a2} + t_{a3} + t_{a4}\right)$ the master speed must not become greater than

$$v_{M\max} = \frac{s}{\left(t_{a1} + t_c + t_{a2} + t_{a3} + t_{a4}\right)}$$

The optimum distance of the sawing cycle results from the total distance of the forward motion plus the distance covered by both ramps during backward motion, while the distance for each of the two motions must be the same.
Situation a) is the standard situation. Situation b) is based on the assumption, that the cutting length is smaller than the optimum travel of the cutting cycle. Yet, this kind of cutting length cannot be physically established. This assumption is to meet the requirements of triangular peaked ramp shape at backward motion; please also consider the calculation of the minimum cutting length shown in the previous chapter.

Only an approximate value of the maximum master speed is determined by specifying R_3 and R_4 in case b) for the triangular peaked ramp. The actual maximum master speed is shorter than the calculated one.
The actually maximum master speed can be determined by means of the case b) formula, though, if R_3 and R_4 contain the actual time values.

If the master axis is to travel at a higher speed than at the determined one, either the cutting length or time T must be reduced.

8 Distance to be Travelled

The travel can be calculated by the following formula. For this, please consider fig. 2 and 7.

$$d = v_{M\max} \cdot (t_{a1} + t_c + t_{a2})$$

9 Thoughts on Cut Accuracy

The cut accuracy is mainly determined by the following factors:

- Mechanic stiffness of the power-transmitting mechanic parts, e.g. backlash, belt tension, etc.
- Factors influencing gear ratio: inappropriate values, such as periodic factors being effective over longer runtimes
- Material: Changes in length during processing, e.g. shrinking due to cooling down or to deformation
- Encoder information by both master axis and slave axis: no accurate and reliable signals, e.g. slip at the measuring wheel
- Resolution of the encoder information: The number of incremental encoder pulses is too low, resolver resolution (HIPERFACE instead of resolver)
- Settings of the control loop in the combination of motor and amplifier referring to tracking error and output value overshoot
- Adjustment of the slave to the master axis: e.g. unprecise positioning of the head cut

The actual tracking error value of the slave axis indicates to what extend the servo amplifier contributes to the cut accuracy.

If the cuts are remarkably more inprecise than allowed by the maximum tracking error value, the cause must be found outside the amplifier. In this case, the following features must be checked:

- Slip of the mechanics
- The measuring wheel is not in vertical position to the web, or it is running untrue
- Allowable limits of the measuring wheel circumference, respectively of other length and circumference values
- Unprecise particulars concerning the gear ratio
- Changes of material length between measuring and cutting
- Synchronization of the mechanical units
- The encoder resolution is too low

10 Flying Saw Function Types

In this chapter, two basic types of the Flying Saw with various variants are described.

- Classical Flying Saw (without hardware signal)

- Flying Saw with hardware signal

10.1 Classical Flying Saw

In this case, the cutting position is known from the beginning. The next step follows the preceding one in relation to the cutting length. The classical type of the Flying Saw is used for processing endless materials, such as tubes, profiles, etc. There are two ways of doing this:

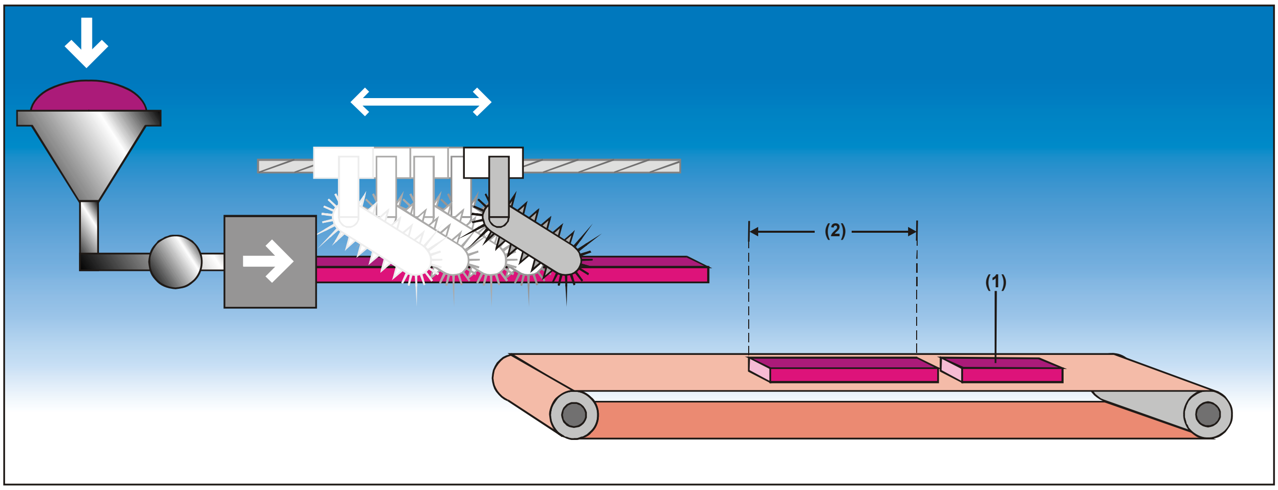
- Variant 1: Head cut as starting position ("head cut")
- Variant 2: Starting by synchronizing material and tools unit

Variant 1: Head cut as starting position ("head cut")

The head cut sets the starting position. This cut is carried out without adjusting the tools unit to the material web, which means the material is cut at any position. Thus, the first piece that has been cut off ("head cut") cannot be used. The following cuts are set in relation to this head cut and thus adjusted to the tools unit.

Examples of use:

- Cutting of endless materials: e.g. pipes, extruding profiles, paper, foil



(1) Head cut
(2) Fixed cutting length

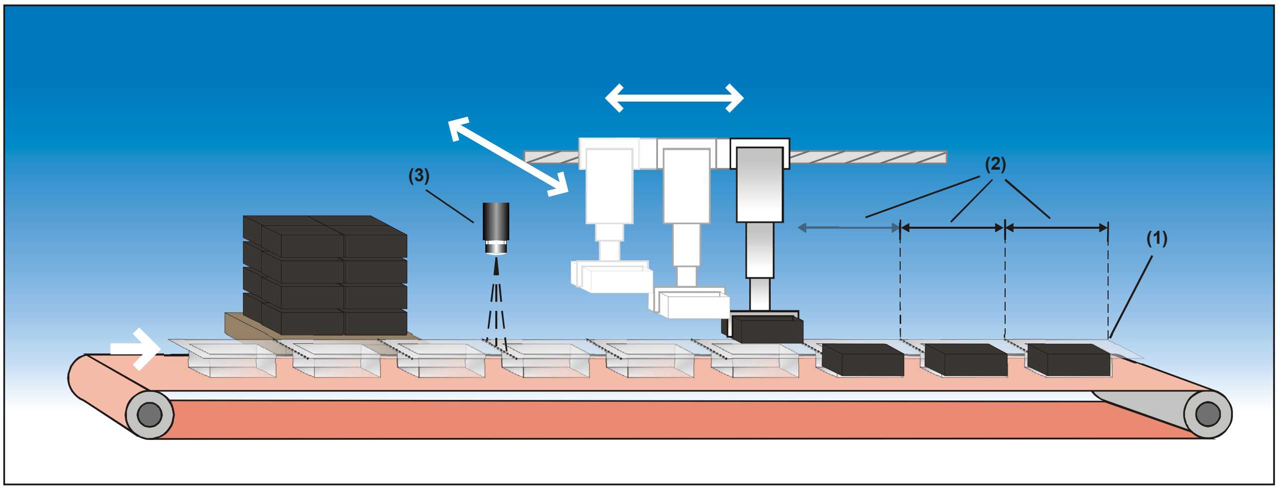
Fig. 8 Classical flying saw with head cut

Variant 2: Starting by synchronizing material and tools unit

Before the head cut, material and tools unit are synchronized with each other; this way, the cutting position on the material is exactly set from the very head cut. As, in this variant, every cut follows in relation to the preceding ones, the cutting position must be made sure not to be displaced after a certain runtime. The cutting position can be displaced, for example, due to inaccuricies of the mechanic specifications. Synchronizing the material and tools unit is carried out manually or automatically before the head cut. At automatic synchronizing, a material sensor displaying the starting edge of the material, see figure 9.

Examples of use:

- Combining various materials: e.g. glueing labels or CD envelopes on magazines
- Joining various materials: e.g. blister packaging



(1) Position of material and tools unit synchronization
(2) Fixed cutting length
(3) Material sensor for automatic synchronizing

Fig. 9 Classical flying saw without head cut

10.2 Flying Saw with Hardware Signal

This application is made use of, if the cutting lengths (distances) between the individual items cannot be defined precisely in advance. By means of a hardware signal, the material position before each cut is acquired. This way, the material keeps being synchronized with the tools unit. This application is mainly used for processing single-piece products or for materials the length of which changes in the process, e.g. due to temperature, mechanical tension respectively compression of the material.

The hardware signal is evaluated as follows:

1. **Capture**: The signal always captures the present master position. By means of setting off the the newly stored master position against the former one, the next cutting length is calculated. The next step follows the preceding one in relation to the cutting length. The master position is allowed to overflow only once between one capture and the next.

or

2. **Referencing**: The signal sets the master position to a defined value, e.g. to 0. The cutting position can be determined by the cutting length.

or

3. **Instant Start:** The signal instantly starts a sawing cycle.

By means of the hardware signal, the material is synchronized with the tools unit at each cut. Accumulating, respectively accruing of minimum length differences per cut, e.g. due to specifying an unprecise cutting length or an unapt gear ratio, cannot occur.

There are two variants for the Flying Saw with hardware signal. It is a decisive factor for the variants, at which position the hardware signal synchronizes with the material, and which are the distances between the respective products.

- Variant 1: Direct starting of the sawing cycle after the hardware signal
- Variant 2: Accumulating of several hardware signals until the corresponding sawing cycle is started

Variant 1: Direct starting of the sawing cycle after the hardware signal

The sawing cycle is started directly after the corresponding hardware signal. The hardware signal synchronizes with the material in such a way, that between the hardware signal and the start of the corresponding sawing cycle, no further hardware signals are generated that might be able to start another sawing cycle.

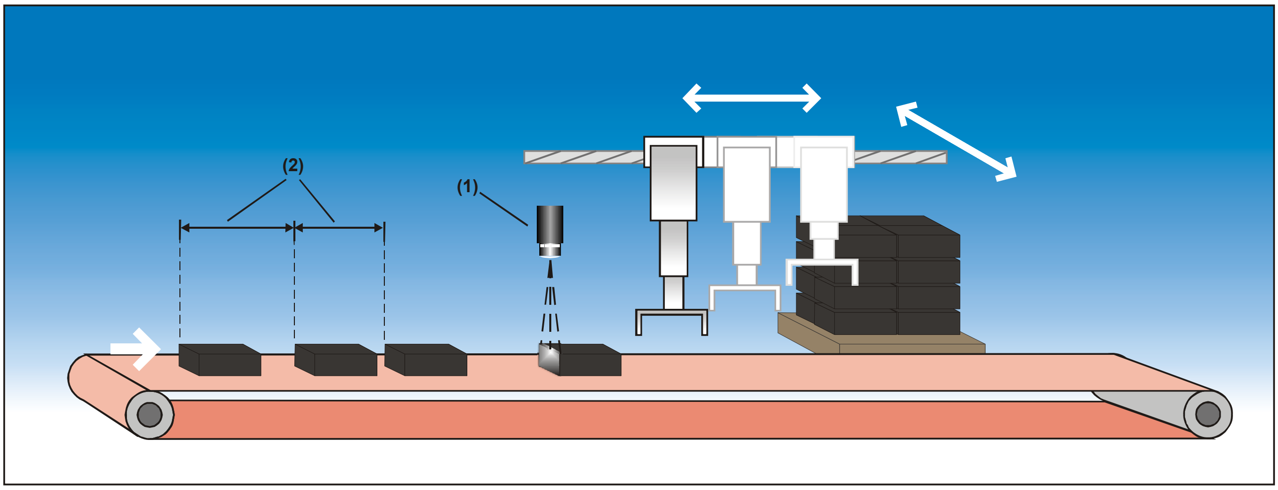
Two cases can be thought of:

- Case 1: The sawing cycle is started at each hardware signal
- Case 2: The sawing cycle is not started before a certain amount of hardware signals have been generated.

In case 1, all evaluations of hardware signal, Capture, referencing and instant start can be made immediately, see above.

Examples of use:

- Transport, packaging of items arriving in undefined intervals



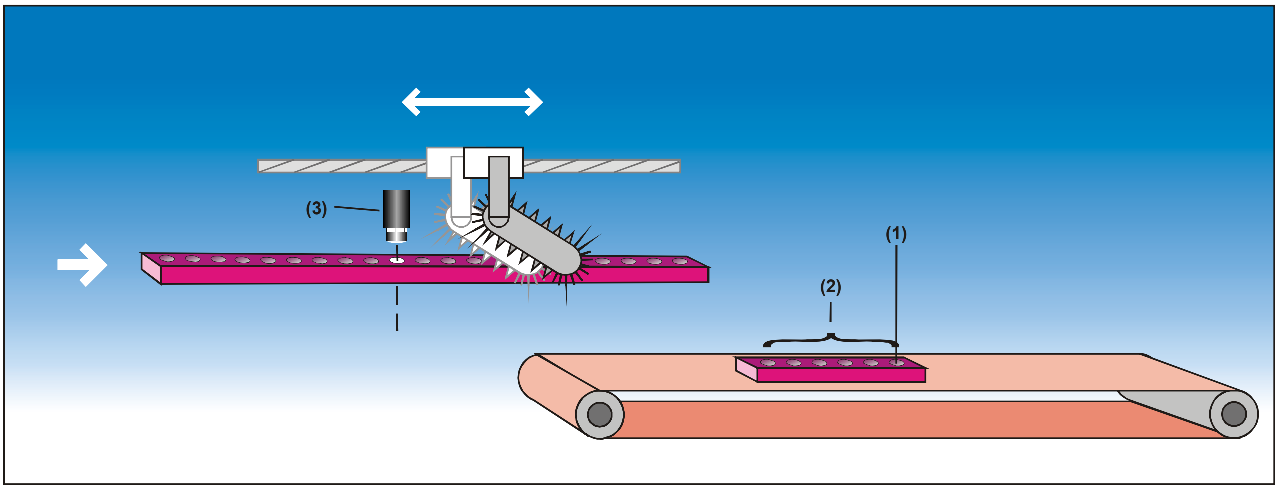
(1) The sensor acquires the edge of the products
(2) Different and not precicely predictable product spacings

Fig. 10 Flying saw with hardware signal, direct start, case 1

In case 2, the hardware signal is counted additionally; not before a certain number of signals have been given, the sawing cycle is started. In this case, all evaluations of hardware signal, Capture, referencing and instant start can also be made immediately. Yet, via the control program, the count of the hardware signal must be checked and the respective function, capture, etc. must be activated when the required number of signals has been completed. The control program must carry out this process at least within the same time that has expired between the second but last and the last counted hardware signal.

Examples of use:

- Cutting of endless materials which are only to be cut at a certain position, e.g. within a hole matrix as shown in fig. 11



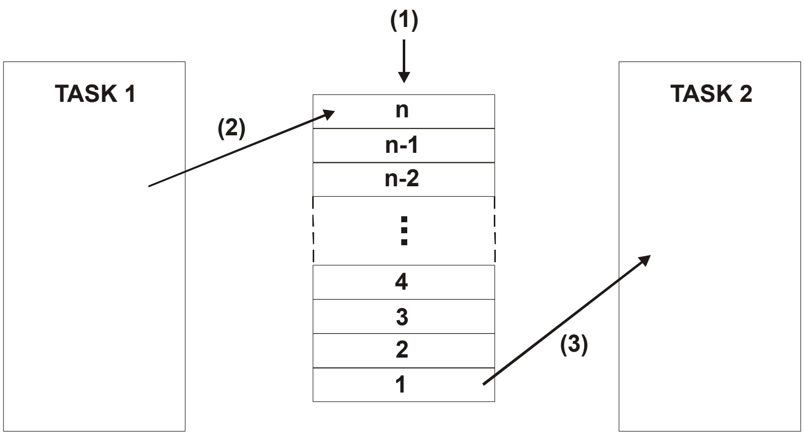
(1) Orientation position of material and tools unit via sensor, and through the hole matrix
(2) Number of holes for the cut
(3) The sensor acquires the position of the material at the hole matrix

Fig. 11 Flying saw with hardware signal, direct start, case 2

Variant 2: Accumulating of several hardware signals until the corresponding sawing cycle is started

Before the sawing cycle corresponding to a certain hardware signal is started, a certain number of further hardware signals accumulate which start a sawing cycle as well. In some applications, it is not possible to locate the hardware signal close enough to the tools unit to start the respective sawing cycle immediately after acquiring the material position.

In this application, capture evaluation of the hardware signal is applied as has been shown above in this chapter. The cutting lengths determined this way are entered in a FIFO memory. Then, the FIFO memory is read out in cyclic mode and, if there are any entries, a sawing cycle of the read out cutting length is started. Capture evaluation and writing the values to the FIFO memory is processed simultaneously to reading out the FIFO memory and to starting the sawing cycle, see fig. 12.



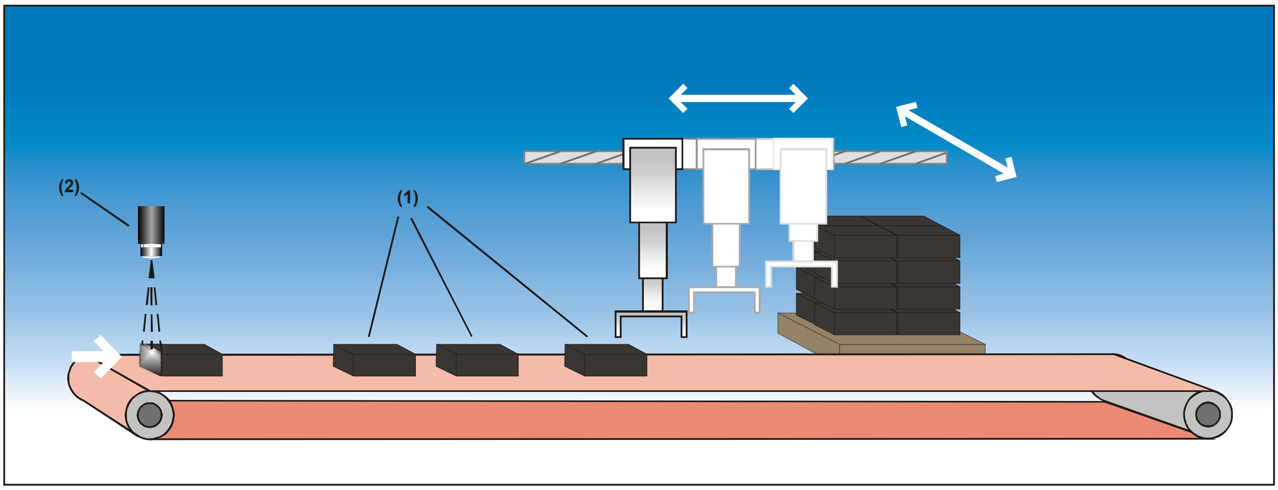
TASK1: Process of capture evaluation and writing to the FIFO memory
TASK2: Process of reading out the FIFO memory and carrying out the sawing cycle
(1) FIFO memory
(2) Entering a new cutting length
(3) Reading out the oldest cutting length

Fig. 12 Flying saw with hardware signal, FIFO processing

The cuts follow each other in relation to the distances between the respective cutting lengths. As, at a hardware signal, an individual cutting length is determined for each cut, though, accumulating of minimum length differences cannot happen.

Examples of use:

- An application of veneering individual strips of wood together and after this singling them again with a Flying Saw unit. With this application, no edges of the battens can be seen any more. For this reason, the sensor for recognizing the batten edges must be located correctly before the actual veneering process. Then, the distance between the sensor and the Flying Saw unit is great enough to make several battens fit in between the sensor and the sawing unit. No illustration available.



(1) Products that are still in the "waiting queue"
(2) The sensor acquires the edge of the products

Fig. 13 Flying saw with accumulating hardware signals