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Relationship between distance, speed and acceleration for draw-wire sensors.

1. Allgemeines

The following description is intended to illustrate the relationship between distance, speed and acceleration in draw-wire sensors.
Oft wird eine Geschwindigkeit gefordert, mit der ein Seilzugsensor betrieben werden kann. Hierzu gibt es jedoch keine allgemein festgelegte Definition der Geschwindigkeit.

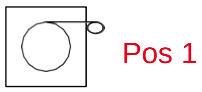
A speed is often required at which a draw-wire sensor can be operated. However, there is no generally established definition of speed.
For example, the maximum speed or an average value over the distance travelled can be specified.
The speed and acceleration curves over a period are analysed in more detail below.
The relationship between distance, speed and acceleration of a draw-wire sensor can be explained in more detail using the example of a spring-mass oscillator.
For better clarification, let us consider the SZG-95-0300 as a concrete example.

2. Boundary conditions

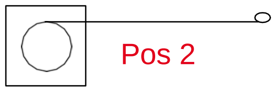
A draw-wire sensor consists of a cable drum on which a measuring cable is wound. The measuring cable is pre-tensioned with a spring. The maximum possible cable speed is highly dependent on the spring force with which the measuring cable is tensioned. The measuring cable can only be retracted and extended as fast as the spring is able to keep the measuring cable tensioned. If the measuring cable is retracted too quickly, so that the spring can no longer keep the measuring cable taut, it will fall off the drum and the sensor will be damaged.

From a mechanical point of view, the measuring cable must always have a speed of 0 m/s when retracted and when fully extended. In order to achieve the maximum speed and to be able to comply with the aforementioned boundary conditions, the measuring cable may only be accelerated up to half of the distance; the second half must be used for the braking process. The mass inertia can be neglected for small measuring ranges compared to the significantly greater spring force in the following consideration.

Dies wird nachfolgend an einem Beispiel gezeigt:



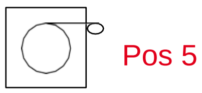
s = 0 mm; v = 0 m/s



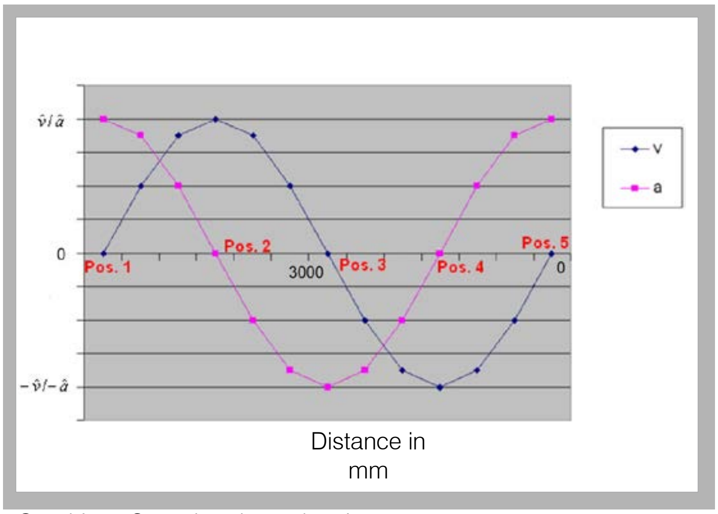
s = MB/2 = 1500 mm; v = v_{max}, a = 0 m/s²

s = MB = 3000 mm; v = 0 m/s; a = a_{max}

s = MB/2 = 1500 mm; v = v_{max}



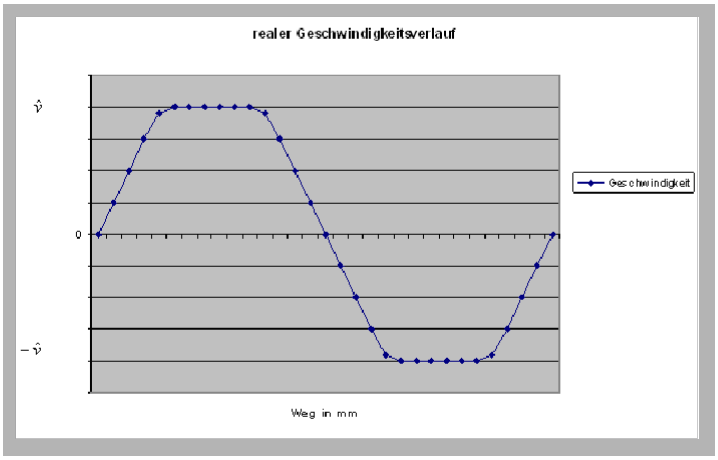
s = 0 mm; v = 0 m/s



Graphic 1: Speed and acceleration

The maximum speed occurs at two points during the entire movement. This maximum speed can only be achieved if the measuring cable is operated at maximum acceleration.

The previous illustration applies in the event that the maximum speed is reached. A real speed curve can be represented as follows.



Graphic 2: real speed curve

These schematically considered movement sequences can be formulated as follows.

3. Formal correlations

The cable must be accelerated and decelerated again over the entire measuring path. This means that only half of the measuring path can be used for acceleration.
We can consider the draw-wire sensor as a spring-mass oscillator that oscillates around MB/2.
The moment of inertia can be disregarded for short measuring lengths. The movement is considered ideal.

The following formal relationships of the spring-mass oscillator therefore apply.

$$s(t) = -\hat{s} \cdot \cos(\omega \cdot t)$$
$$v(t) = \dot{s}(t) = -\hat{s} \cdot \omega(-\sin(\omega \cdot t)) \longrightarrow \hat{v} = \hat{s} \cdot \omega = \hat{s} \cdot 2 \cdot \pi \cdot f$$
$$a(t) = \ddot{s}(t) = \hat{s} \cdot \omega^2 \cdot \cos(\omega \cdot t) \longrightarrow \hat{a} = \hat{s} \cdot \omega^2 = \hat{s} \cdot 4 \cdot \pi^2 \cdot f^2$$

$$\omega = 2 \cdot \pi \cdot f = \frac{2 \cdot \pi}{T} \longrightarrow f = \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{\hat{a}}{\hat{s}}}$$

If we look at this for our specific example of the SZG95-0300, the results are as follows:

Measuring range SMR = 3000 mm

Maximum rope acceleration â = 15 g

The movement of the measuring cable must be accelerated and decelerated within the 3000 mm measuring path. This means that 1500 mm, i.e. half of the measuring path, is available for acceleration.

$s_{MR} = 2 * \hat{s} = 3000$ mm $\longrightarrow$ $\hat{s} = 1500$ mm

$\hat{a} = 15g = 15 * 9{,}81 \frac{m}{s} = 147{,}15 \frac{m}{s^2}$

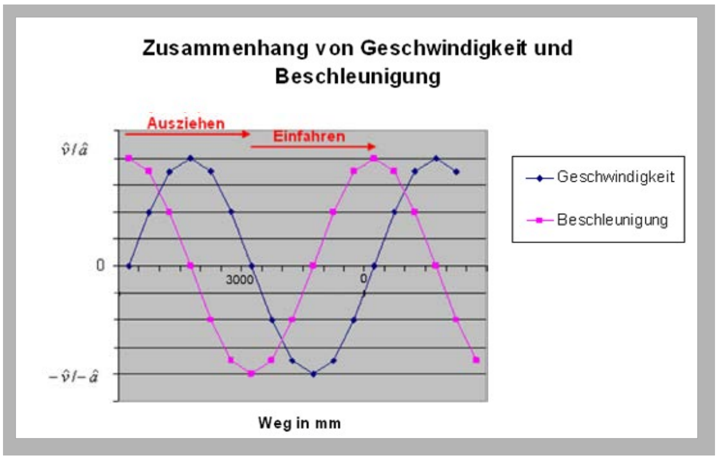
With this information and the following formal relationship, the following results for the frequency

$$f = \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{\hat{a}}{\hat{s}}} = \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{147{,}15 \ \frac{m}{s^2}}{1{,}5 \ m}} = 1{,}58 \text{ Hz}$$

The maximum rope speed can be calculated using the determined frequency

$$\hat{v} = \hat{s} \cdot 2 \cdot \pi \cdot f = 1{,}5 \text{ m} \cdot 2 \cdot \pi \cdot 1{,}12 \text{ Hz} = 10{,}56 \ \frac{m}{s}$$

The calculated speed ˆv corresponds to the maximum speed. This speed only occurs at two short points in the course of the movement. This is illustrated in the following diagram.



Graphic 3: Speed and acceleration curve

Graph 3 shows the speed curve and the acceleration curve over the distance. In each case, the maximum speed occurs when the measuring cable is extended by 1500 mm. This corresponds to the calculated value of 10.56 m/s.

The effective speed at which the sensor can be operated over the entire measuring distance is significantly lower than the calculated maximum speed. The effective speed at which the sensor is operated can be calculated as follows:

$$v_{eff} = \frac{1}{\sqrt{2}} \cdot \hat{v}$$

For the specific example, this results in:

$$v_{eff} = \frac{1}{\sqrt{2}} \cdot 10{,}56 \frac{m}{s} = 7{,}47 \frac{m}{s}$$

This effective speed can only occur if the sensor is operated at maximum acceleration. This is very difficult to achieve under real conditions. Specifying a speed at which a draw-wire sensor can be operated is therefore very complicated.

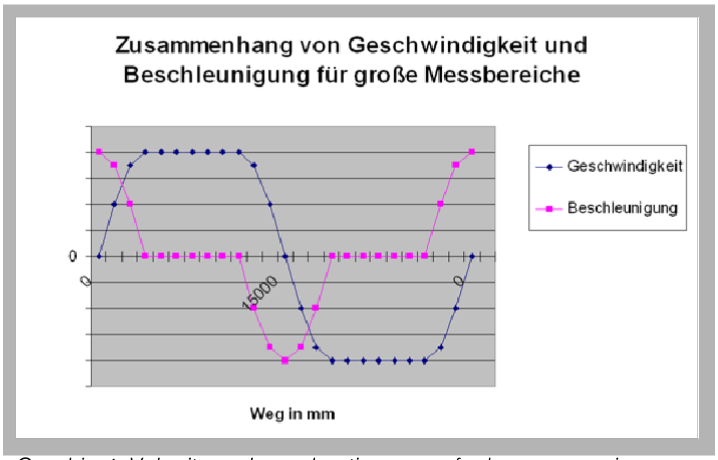
To prevent damage to the sensor, the cable speed at which the sensor is operated must be below the maximum speed. High cable speeds lead to increased wear on the cable pull mechanism. In order to ensure a long service life for the sensor, conservatively estimated speed values are specified for the maximum cable speed.

4. Movement cycle for longer measuring lengths

For sensors with larger measuring ranges (e.g. SZG165), the mass inertia can no longer be neglected, as was assumed under point 2. Therefore, the sensor may only be accelerated for a shorter distance. After this acceleration, the measuring cable continues to move at a constant speed. Before the cable movement is decelerated again.

This process is repeated when the measuring cable is retracted. If the sensor were to be accelerated for longer, as with the shorter measuring cables, the sensor could not be braked in time. And the measuring cable would break. A limit speed therefore occurs with sensors with large measuring ranges.

The speed and acceleration curve for long measuring lengths is shown in the following example.



Graphic 4: Velocity and acceleration curve for long measuring lengths

5. Recommended guide values

The table below shows the recommended guide values for the maximum rope speed.
This table should help you to make a speed statement for the various sensor types.

Sensortyp	Recommended max. speed
SZG60	10 m/s
SZG95	8 m/s
SZG140	8 m/s
SZG165-0800	8 m/s
SZG165-1000	6 m/s
SZG165-2000	5 m/s*
SZG165-4000	5 m/s*
SZG107	1 m/s
SZG50	1 m/s
SZG78	2 m/s

* Please note the considerations under point 4