Polytec

Basic Principles *of Velocimetry*

FOR BEGINNERS AND EXPERIENCED USERS

Laser Doppler Velocimeters are non-contact measurement systems used to make velocity and length measurements on moving surfaces, such as steel sheeting, films, paper, textiles and other strip goods. The non-contact optical measurement process allows very high accuracy. It can be applied in complex measurement tasks, where touch sensors can not make a measurement or only with great difficulty, such as making measurements on red-hot objects.

Thus in continuous casting systems, Laser Doppler Velocimeters replace the measurement rollers traditionally used for measuring casting lengths and velocities. Thanks to the non-contact measurement process, slippage, scaling deposits or damage to bearings no longer affect the results of the measurement as they did when using measuring wheels.

Laser Surface Velocimeters work on the Laser Doppler Principle and evaluate the laser light scattered back from a moving object. Polytec's LSVs are based on the sophisticated heterodyne detection method. Unlike conventional non-contact methods which measure only the absolute value of the velocity, Polytec's velocimeters are able to detect changes in direction and even standstill conditions. The measurement precision is fine enough that minute motions can be accurately measured.

Polytec GmbH
Polytec-Platz 1-7
D-76337 Waldbronn
Tel. +49 (0) 72 43 6 04-0
Fax +49 (0) 72 43 6 99 44
Lm@polytec.de

Both in general and for any velocities, the Doppler problem was solved by Einstein's relativity theory. In summary, the result of his shrewd analysis, that both a stationary and also a moving observer (receiver) measures the same value for the speed of light, but that the respective coordinates which the two observers use to describe processes subtly depend on their relative movement.

The Doppler Effect

How does the laser light scattered back provide any information on the movement status of the scattering object? In the following we demonstrate the effect a relative movement between the source and the receiver has on the wavelength measured, or respectively, on the frequency of the wave.

A stationary light source emits a continuous light wave with the frequency f and the wavelength λ. A wave train with the length λ passes a stationary observer in the time $T = 1/f$. If in contrast the observer moves away from the light source at the speed v, then the wave train needs a slightly longer time T', to pass the observer. What distance c T' does the wave travel in the time T'? The total distance includes the distance λ of the observed wave train and also the distance v T' traveled by the moved observer in the time T'

$$c\,T' = \lambda + v\,T' \quad (c - v)T' = \lambda$$

For the moving observer, the wave vibration has the cycle duration T' and because $f' = 1/T'$ and $\lambda = c/f$ this then results in:

$$(c - v)/f' = c/f$$

and thus the frequency f' to

$$f' = f(c - v)/c = f(1 - v/c)$$

Therefore, if the observer moves away from the light source ($v > 0$), then the light frequency is shifted to smaller values (red shift), if he moves towards the light source ($v < 0$), then an increased frequency is measured (blue shift).

The above analysis is an approximation for small velocities in comparison to the speed of light which is fulfilled very well for practically all technically relevant velocities.

The Differential Doppler Process

To make a measurement on moving objects, which can in principle be of any length, requires a measurement design with an observation axis for the sensor which is at a right angle to the direction of movement of the object under investigation.

Polytec Velocimeters work according to the so-called Difference Doppler Technique. Here, 2 laser beams which are each incident to the optical axis at an angle φ, are superimposed on the surface of the object. For a point P, which moves at velocity **v** through the intersection point of the two laser beams, the frequencies of the two laser beams are Doppler shifted in accordance with the above formula. At the point P of the object which is moving at the velocity **v**, the following frequencies therefore occur:

$$f_{P1,2} = f_{1,2}\,(1 - \mathbf{v}\cdot\mathbf{e}_{1,2}/c)$$

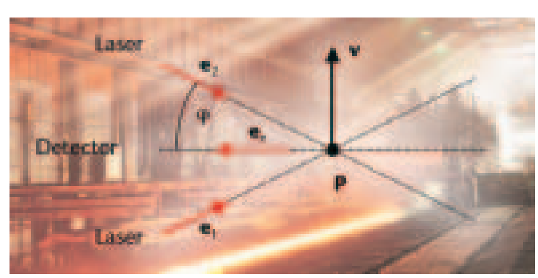
$\mathbf{e}_{1,2,e}$ = Unit vectors of laser beams 1 and 2 and in direction detector

$f_{1,2}$ = Frequencies of the laser beams 1 and 2

$f_{P1,P2}$ = Doppler shifted frequencies of laser beams 1 and 2 in point P

The point P now emits scatter waves in the direction of the detector. As P is moving with the object, the scattered radiation in the direction $\mathbf{e}_e$ of the detector is also Doppler shifted. Thus for the frequency of the scatter waves in the direction of the detector, it can be said:

$$f_{e1,e2} = f_{P1,P2}\,(1 - \mathbf{v}\cdot\mathbf{e}_e/c)$$
$$= f_{1,2}\,(1 - \mathbf{v}\cdot\mathbf{e}_{1,2}/c)\,(1 - \mathbf{v}\cdot\mathbf{e}_e/c)$$



The scatter waves are superimposed on the detector. Due to the interference of the scatter waves from the two laser beams, there are different frequency components in the superimposition. The low-frequency beat frequency of the superimposed scatter radiation which corresponds to the Doppler frequency f_D is analyzed metrologically. When both incidental laser beams are at the same frequency (same wavelength), this is seen as a difference of f_{e2} and f_{e1} to:

$$f_D = f_{e2} - f_{e1}$$
$$= f\,(\mathbf{v} \cdot (\mathbf{e}_1 - \mathbf{e}_2)/c)\,(1 - \mathbf{v} \cdot \mathbf{e}_e/c)$$

If point P moves vertically with reference to the optical axis and at the same angle of incidence φ, it can be said that:

$$\mathbf{v} \cdot (\mathbf{e}_1 - \mathbf{e}_2) = 2\mathrm{v}\,\sin\varphi \text{ and } \mathbf{v} \cdot \mathbf{e}_e = 0$$

This means the final result is:

$$f_D = \frac{2\mathrm{v}}{\lambda}\sin\varphi$$

The Doppler shift is thus directly proportional to the velocity. A graphic explanation which leads to the same result follows:

Graphic Representation of the Difference Doppler Technique

Both the laser beams are superimposed in the measurement volume and in this spatial area, generate an interference pattern of bright and dark fringes.

The fringe spacing Δs is a system constant which depends on the laser wavelength λ and the angle between the laser beams 2φ:

$$\Delta s = \lambda/(2\,\sin\varphi)$$

If a particle moves through the fringe pattern, then the intensity of the light it scatters back is modulated.

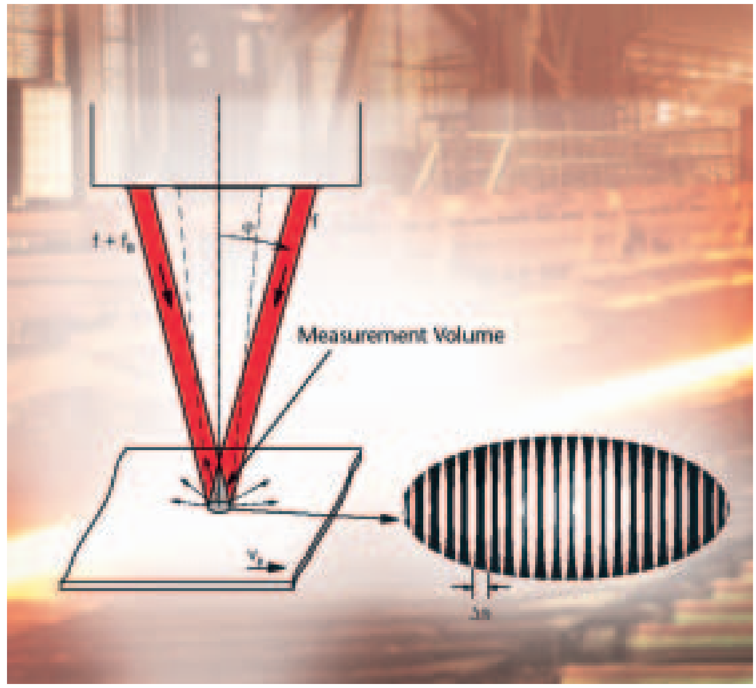
As a result of this, a photo receiver in the sensor head generates an AC signal, the frequency f_D of which is directly proportional to the velocity component of the surface in measurement direction v_p and it can be said that:

$$f_D = v_p/\Delta s = \frac{2\mathrm{v}}{\lambda}\sin\varphi$$

f_D = Doppler frequency

v_p = Velocity component in the direction of measurement

Δs = Fringe spacing in the measurement volume



The value $\lambda/\sin\varphi$ makes up the material measure for the velocity and length measurement.
It is measured precisely for every sensor head and is printed on the identification label. When configuring the LSV controller, the fringe spacing is written in the flash memory as a calibration factor. There it forms the basis for calculating the measurement values. If the sensor head is exchanged, the new fringe spacing has to be entered using the LSV software.

The Heterodyne Technique

Polytec Laser Surface Velocimeters work in the so-called heterodyne mode, i.e. the frequency of one of the laser beams is shifted by an offset of 40 MHz. This makes the fringes in the measurement volume travel with a velocity corresponding to the offset frequency f_B. This then makes it possible to identify the direction of movement of the object and to measure at the velocity zero. The resulting modulation frequency f_{mod} at the photo receiver in heterodyne mode is:

$$f_{mod} = f_b + v_p/\Delta s = f_b + \frac{2\mathrm{v}}{\lambda}\sin\varphi$$

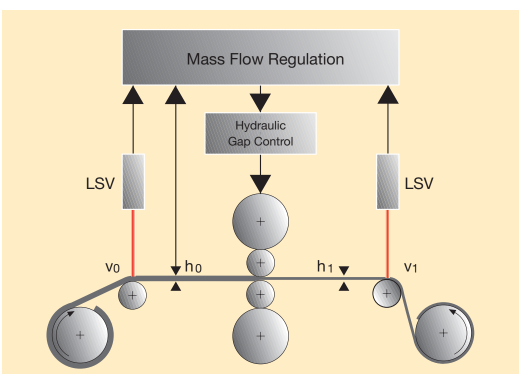
The modulation frequency is determined in the controller using Fourier transformation and converted into the measurement value for the velocity v_p. The length measurement is made by integrating the velocity signal.

Applications for Polytec Velocimeters

A complete LSV series 6000 measurement system consists of an LSV-6200 signal processor and as an option, either the extremely compact optical sensor head LSV-065, or the liquid cooled sensor head LSV-026 for applications in a harsh industrial environment.

Mass Flow Regulation

The processing industry, in particular the automobile industry, sets ever tighter tolerances regarding the quality of the steel and aluminum products used. Making velocity measurements using the LSV, which are not affected by slippage or wear and tear, make it possible to considerably reduce the thickness tolerances of cold pressed steel.
If two Laser Surface Velocimeters make measurements before and after the roll stand respectively, then with the help of the mass flow ratio, the strip thickness can be determined in the roll gap. The shorter response time in comparison to a slave system significantly reduces the strip thickness tolerances using the thickness measurement before and after the roll stand.



Length Measurements on Piece Goods

Polytec's LSV series 6000 is ideally suited for length measurement for controlling cutting materials into lengths, for controlling the length of work pieces already cut into lengths or for positioning the work piece in a saw mill.

The measurement system works reliably on all surfaces, no matter whether it is a pipe, beam, profile or rail. Even making measurements on hot surfaces with temperatures up to 1200 °C are possible. Here some sample applications of how the LSV is used in a pipe rolling mill

- Pipes with a length of between 6 and 20 m move at a virtually constant velocity between 2 and 20 m/s along the roller table.
  The LSV measures the overall length.

- Once the overall length is known, a second LSV measures the same pipe again at a low speed to cut the pipe into customer-specific section lengths in the saw mill.

There are two ways of triggering the length measurement on piece goods:

1. Self-trigger: The object recognition in the LSV series 6000 reliably starts or stops the length measurement within 100 μs as soon as the object appears or disappears in the AOI.
2. External trigger: The greatest measurement accuracy can be attained for a length measurement if the LSV is combined with external light barriers via existing trigger inputs.

Due to the great depth of field of 200 mm, the LSV can make measurements on different pipe diameters without the distance between the LSV-065 or LSV-026 sensor heads and the roller table having to be readjusted. It is thus not necessary to have a complex traversing system which keeps the distance from the sensor head to the pipe surface constant despite a different pipe diameter.

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