LASER DOPPLER VELOCIMETER

Ing. Karel ČERMÁK, Doctoral Degree Programme (2)
Dept. of Radio Electronics, FEEC, BUT
E-mail: cermakk@feec.vutbr.cz

Supervised by: Dr. Aleš Prokeš

ABSTRACT

There are several methods for surface velocity measurement. This article tries to familiarise the reader with the principle of Laser Doppler Anemometer (LDA).

1 PRINCIPLE OF LASER DOPPLER ANEMOMETR

The Laser Doppler Anemometer creates a fringe pattern on the measured object (interference figure) using two coherent laser beams as shown in picture 1.

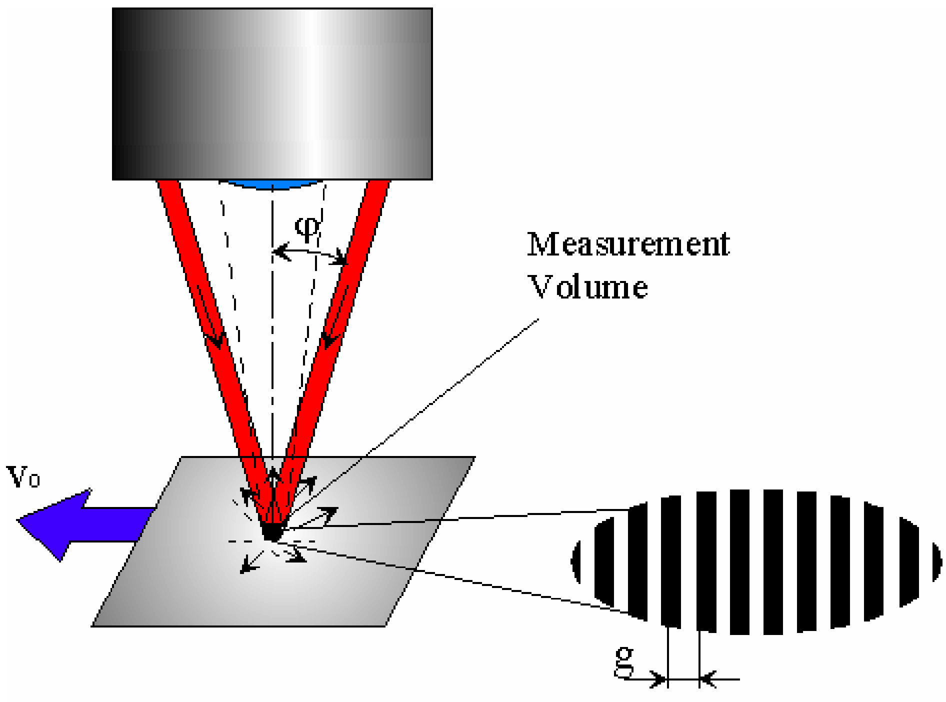

Fig. 1: *Producing of fringe pattern*

The fringe spacing g is given by

$$g = \frac{\lambda}{2\sin\varphi}, \tag{1}$$

where λ is the wavelength of the laser. By the movement of the object with the velocity v_o a frequency shift f_D is produced. This change is described by the Doppler formula

$$f_D = \frac{v_o}{g}. \tag{2}$$

The change of the velocity v_o is also proportional to the generated Doppler frequency f_D. However, in laser anemometer the Doppler shift is a very small fraction of the frequency. Light has a frequency of about $5 \cdot 10^{14}$ Hz (λ = 600nm) but the Doppler shift is generally of the order $10^5 - 10^6$ Hz. No spectrometer has such high resolution and thus another means of analysis must be employed. The generally adopted method is to interfere the signal beam and the reference beam so that the two produce the differential frequency. This is known as a heterodyne technique.

It is often desirable to know not only the object velocity but also its direction and absolute zero-speed. The device shown on the picture 2 makes this possible.

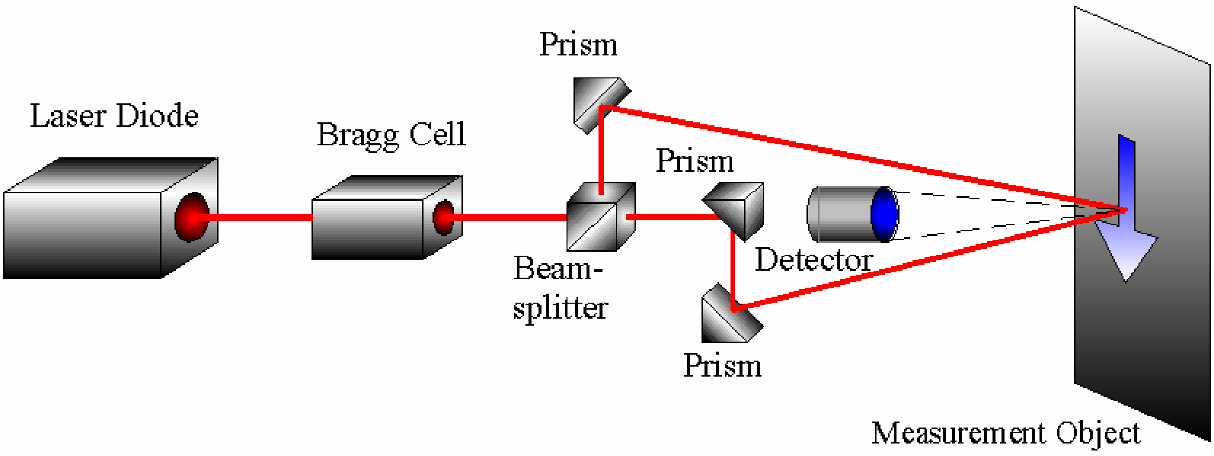

Fig. 2: *The LDA measurement setup with Bragg Cell*

In this device laser diode is mostly used as the source of coherent light with punctually stabilized wavelength. The Brag Cell splits light from a laser diode into two beams and introduces a frequency shift f_S (typically 40MHz) to one of the beams. Both beams are then focused into one point on moving surface where they form a pattern of equally spaced bright and dark fringes.

Light scattered from a material moving through this fringe pattern experiences an intensity modulation with Doppler frequency f_D proportional to the speed v_o of the material. Part of the scattered light is collected by the receiver lens, then converted by a photo detector to an electrical signal. The frequency offset f_S is particularly important because it acts as an FM (frequency modulation) carrier for the scattered light. The measured frequency f_m is then

$$f_m = f_s \pm f_D . \tag{3}$$

The velocity of the object v_C is then defined

$$v_C = f_D \cdot g . \tag{4}$$

The integration of the computed velocity v_C over time t provides the length L.

$$L = \int_t v_C dt \tag{5}$$

2 SIGNAL PROCESSING

The purpose of the signal processing in a laser anemometer is to convert the frequency f_D in the output of the photo detector into velocity v_C. This has two purposes:

- To optimize signal/noise ratio,
- To optimize the velocity resolution.

There are five systems, which achieve this to a greater or lesser degree. They are:

- Spectrum analyzer
- Tracking filter
- Discriminator
- Correlator
- FFT computing

Nowadays the tracking filter and FFT computing methods are most used. The description and principle of each method can be found in [1] and [2].

3 THE SHAPE OF DETECTED SIGNAL

The output of the photo detector in a laser anemometer is not a simple sine wave, but a more complex signal as shown in Figs. 3 and 4. First there is always the system noise present as a background. As a single particle enters the system it scatters some light, as well as producing an oscillatory signal that is not symmetrical (Fig.3). There is a background low frequency signal from the scattered light and a high frequency signal caused by the Doppler signal. In any laser anemometer system, it is advisable to place a high pass filter as near as possible to the photo detector to cut out this scattering signal. When many particles are present (Fig.4), the scattering signal and Doppler signal always occur. There is also a continual change in amplitude and phase of the signals as different groups of particles enter the measuring region.

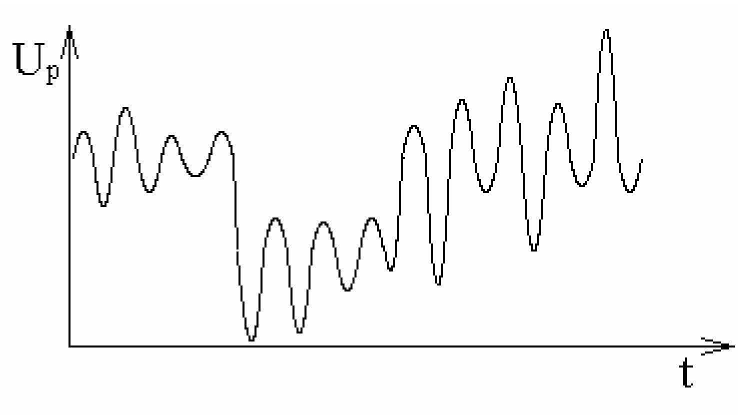

Fig. 3: *The output signal of the photo detector*

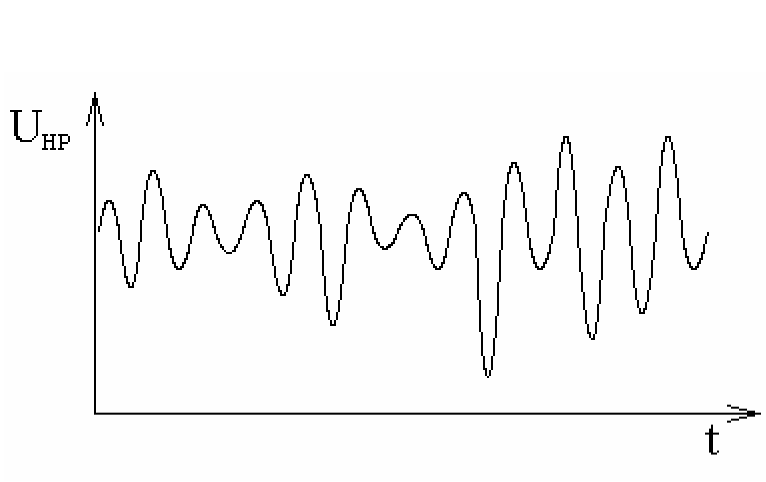

Fig. 4: *The signal after passing high pass filter*

4 CONCLUSION

The first Laser Doppler Anemometer has been built in 1964. More ways of signal processing have been discovered since than. However, these days the most frequent one is the real time FFT computing or using a tracking filter. LDA is still under development and it has already found a wide spectrum of application not only in research field but also in industry. The Laser Doppler Anemometer makes it possible to measure with high accuracy (typical ± 0.05% - ± 1%) the velocity v_o up to 120 $m \cdot s^{-1}$ [1].

REFERENCES

[1] www.polytec.de

[2] RUDD, M.J.: The laser anemometr – a review. Optics and Laser Technology, 1971, p. 200-207.

[3] POKLEKOWSKI, G. und SCHULZ, W.: Geschwindigkeitsmessung an Schnelllaufenden Walzstraßen mit Hilfe der Lasertechnik. Stahl und Eisen 90, Nr. 17, 1970, p. 897-903.