THE LB-550 DYNAMIC LIGHT SCATTERING TECHNIQUE

The LB-550 Dynamic Light Scattering (DLS) System measures particle size from 1 nanometer to 6 microns at concentrations up to 40% w/v. All DLS systems measure light scattering effects arising from the Brownian motion of particles in suspension. Unlike systems using correlators, the LB-550 uses a fast Fourier transform to create a power spectrum from the light scattering fluctuations. The power spectrum is then used to create the particle size distribution. This technical note explains the underlying principles used by the LB-550 nanoparticle size analyzer.

Introduction

Particle size distribution analyzers based on measuring the phenomenon of Brownian motion can be broadly classified as being based on either autocorrelators or on power spectrums. For the purpose of this document, systems using autocorrelators will be called Photon Correlation Spectroscopy (PCS) systems. Power spectrum analyzers such as the HORIBA LB-550 (see Figure 1) are designed to examine the differences in frequency of light scattered off particles.

The LB-550 technique is designed to analyze fluctuations in the intensity of any scattered light from a body in relation to the incident light. This method is also referred to as the frequency analysis method. PCS analyzers are based on the method in which the number of photons per time unit is counted, assuming that light consists of a series of photons.

As described above, the PCS instrument is designed to count moving particles in terms of the number of photons. Therefore, it must simultaneously measure particles which are moving at both fast and slow speeds. The simultaneous measurement requires that fast-moving particles be determined at high speeds, and slow-moving ones over extended periods of time. In actual practice, however, it is very difficult to create an instrument that combines the above functions with continuous data multiplication capability.

The power spectrum apparatus, on the other hand, treats light as a traveling wave, and can thus obtain the frequency spectra of scattered light by both fast- and slow-moving particles. It then temporarily introduces the obtained signals for arithmetic conversion into power spectrum data using the Fourier transformation method. This form of data contains all frequency information ranging from low frequencies, which represent slow-moving particles, to high frequencies, which represent the behavior of fast-moving particles. This permits analysis of every signal from each particle, thus ensuring that particle size distributions can be characterized with high precision.

Figure 1: LB-550 DLS system

Figure 2 below shows the basic difference between PCS and power spectrum analyzers.

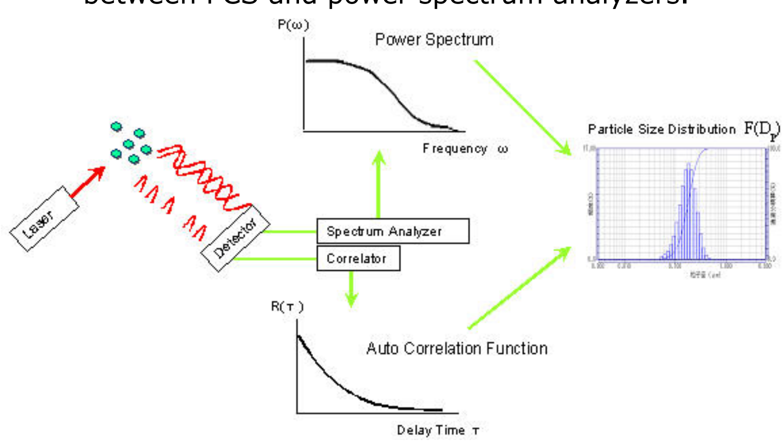

Figure 2: PCS vs. power spectrum analyzers

In both cases a laser light source interacts with the sample in a cuvette and a detector at some angle removed from the light source measures light scattered due to the Brownian motion of the particles. Either the correlation function or power spectrum is then used to calculate the particle size distribution.

The Power Spectrum and Fast Fourier Transform

For this technology the power spectrum is defined by the different frequency components in the scattered light signal and how many instances there are for each different frequency. The power spectrum graph refers to a graphical spectrum representation, in which frequency is depicted on the horizontal axis and intensity on the vertical axis. It shows the level of light intensity at each frequency. Power spectrum (frequency distribution) data is calculated using a mathematical technique called the fast Fourier transform.

The power spectrum (frequency/intensity distribution) provides information regarding the intensity of light as a function of its frequency. However, any such power spectrum cannot be obtained without transformation of all input signals to the detector. A mixture of light waves at 1 Hz, 2 Hz and so on are incident upon the detector. These incident signals are commingled (Figure 3) to an extent that does not provide any helpful information concerning frequency/intensity distribution. The Fourier transform technique is therefore applied to elicit pertinent information regarding the intensity of light at a frequency of, say, 1Hz, from these unavoidably messy signals.

Fourier transform methods are available in a variety of calculation techniques, some characterized by high precision and others by short computation time. Included among these is a technique called the fast Fourier transform. This method innovatively performs high-speed computation with regards to the sample whose size is a power of two. The LB -550 adopts this mathematical process.

Figure 3 shows the conversion from the light fluctuation signal into the power spectrum.

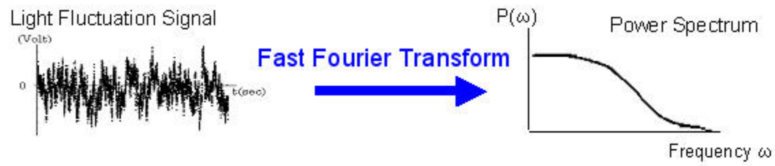

Figure 3: Light scattering to the power spectrum

Calculating Particle Size from the Power Spectrum

The algorithm for calculation is based on the principle in which f(a) is determined from any measured frequency/intensity distribution S(ω) by solving the following general Fredholm's integration of the first kind:

$$S(\omega) = \int K(\omega, a)\, f(a)\, da \qquad \text{Eq. 1}$$

where *ω* is the angular frequency and *a* is the particle size. This solution (elucidation) must solve very difficult non-linear problems called inverse operations. In order to accomplish this, the LB-550 employs a uniquely optimized iterative method for particle sizing. K (ω, a) is an intermediate function referred to as a response function, which is calculated as follows:

> *Let* k *be the Boltzmann constant,* T *the absolute temperature,* η *the viscosity coefficient of a solvent,* a *the particle size, and* D *the diffusion coefficient. Then the diffusion coefficient* D *can be expressed from the Stokes-Einstein equation:*

$$D = kT / (3\pi\eta a) \qquad \text{Eq. 2}$$

In addition, suppose that *λ* is the wavelength of a laser beam in the full vacuum, *n* is the refractive index of a solvent and *α* is the angle through which the laser beam is scattered. Then, the scatter vector *K* can be described as

$$K = 4\pi(n/\lambda) \cdot \sin(\alpha/2) \qquad \text{Eq. 3}$$

Since it has been proven that for any spherical particle, its frequency/intensity distribution is in agreement with any distribution obtained using the Lorentzian function, the calculated frequency/intensity distribution $S_0(\omega)$ for each particle size is given by

$$S_0(\omega) = 2\,DK^2 / \{ (2\,DK^2)^2 + \omega^2 \} \qquad \text{Eq. 4}$$

A group of the calculated frequency/intensity distributions $S_0(\omega)$ for all particle sizes involved are employed to calculate the response function $K(\omega, a)$, which is required to characterize the particle size distribution $f(a)$ by the repetition operation. Suppose that the particle size distribution $f_0(a)$ is an initial hypothetical distribution. For example, consider a particle size distribution which occurs for all particle sizes with the same frequency. Then, the difference between this and the observed frequency/intensity distributions is determined, the hypothetical frequency/intensity distribution is modified so as to decrease the difference, and the modified distribution is re-defined as $f_0(a)$. This loop is operated repeatedly. When Eq. 1 is established, that is, the measured frequency/intensity distribution coincides with any distribution determined from the hypothetical particle size distribution $f_0(a)$ using the response function, the particle size distribution operation is completed by regarding this $f_0(a)$ as the true particle size distribution.

Summary

The HORIBA LB-550 nanoparticle size analyzer uses the dynamic light scattering method to measure the size distribution of particles undergoing Brownian motion. The power spectrum approach is employed to convert light scattering fluctuations into the particle size distribution utilizing a fast Fourier transform and the approach described in this technical note. The advantages of the LB-550 include the ability to better measure broad particle size distributions and the ability to measure at high concentrations while maintaining a wide size measurement range.

For further information on this document or our products, please contact:
HORIBA Instruments, Inc.
17671 Armstrong Ave.
Irvine, CA 92614 USA
1-800-4-HORIBA
www.horibalab.com
labinfo@horiba.com