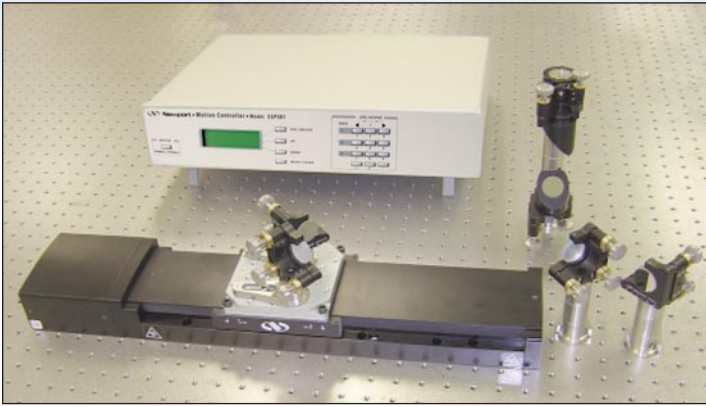


Selecting delay lines for optical time-resolved measurements



One of the most critical elements of any time-resolved spectroscopy and dynamics experiment is the optical delay line. A typical optical delay line consists of a retro-reflector or folding mirrors on a translation stage (Figure 1). See Newport's Optical Delay Line Kit for further discussion of component selection.

When selecting the translation stage, certain parameters from the stage and the driver or controller should be taken into account as they affect data analysis and interpretation. In this note, the key motion control parameters including total delay, Minimum Incremental Motion (MIM), repeatability, accuracy and mechanical errors which affect the time-resolved measurements are briefly reviewed.

The first parameter to consider for the linear stage is the total delay required for the application. The total delay (T), which is the time takes for the light to travel to the retro-reflecting optics and make a return path, is directly related to the travel range of the linear stage (L) that is $T=2*L/c$ where c is the speed of light in vacuum. The next most important parameter is the delay resolution ($\Delta\tau$) which is related to the minimum incremental motion (MIM) of the translation stage and is calculated as $\Delta\tau=2*MIM/c$. It is important to distinguish between the MIM and the resolution of the motion system as

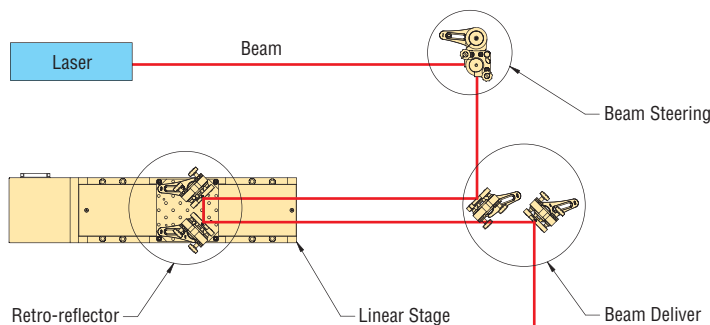


Figure 1. General schematic of the optical delay line.

they represent two different concepts. MIM is the minimum incremental motion that a device is capable of consistently and reliably delivering and it is therefore a system capability whereas the resolution (display or encoder resolution) is the smallest controller display value or smallest encoder increment and refers to a design feature.

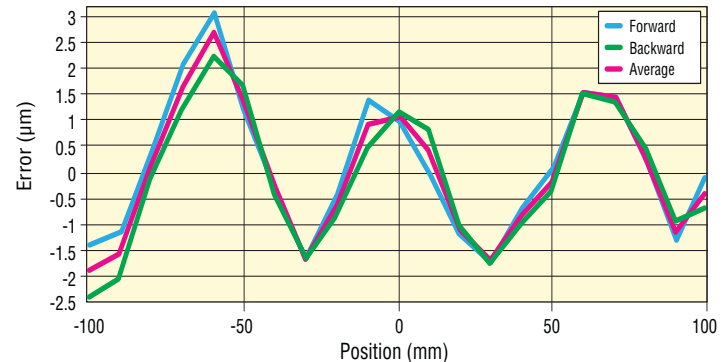


Figure 2. Repeatability of a typical linear stage.

Another stage parameter as important as MIM is the stage repeatability which refers to the ability of a system to achieve a commanded position over many attempts (Figure 2). In a typical time-resolved measurement, the linear stage is scanned over a certain distance (which corresponds to specific time delay) and some signal from the target sample is recorded as a function of time delay. Depending on the signal strength from the sample and the expected signal-to-noise ratio, the average of many scans is a method that has been routinely employed in time-resolved measurements. With this procedure, it is critical that the linear stage has high enough repeatability to resolve the signal. Depending on the scan type (forward scan or cycle scan), uni-directional (repeatability in one direction) or bi-directional (repeatability in both forward and backward directions) becomes an important factor.

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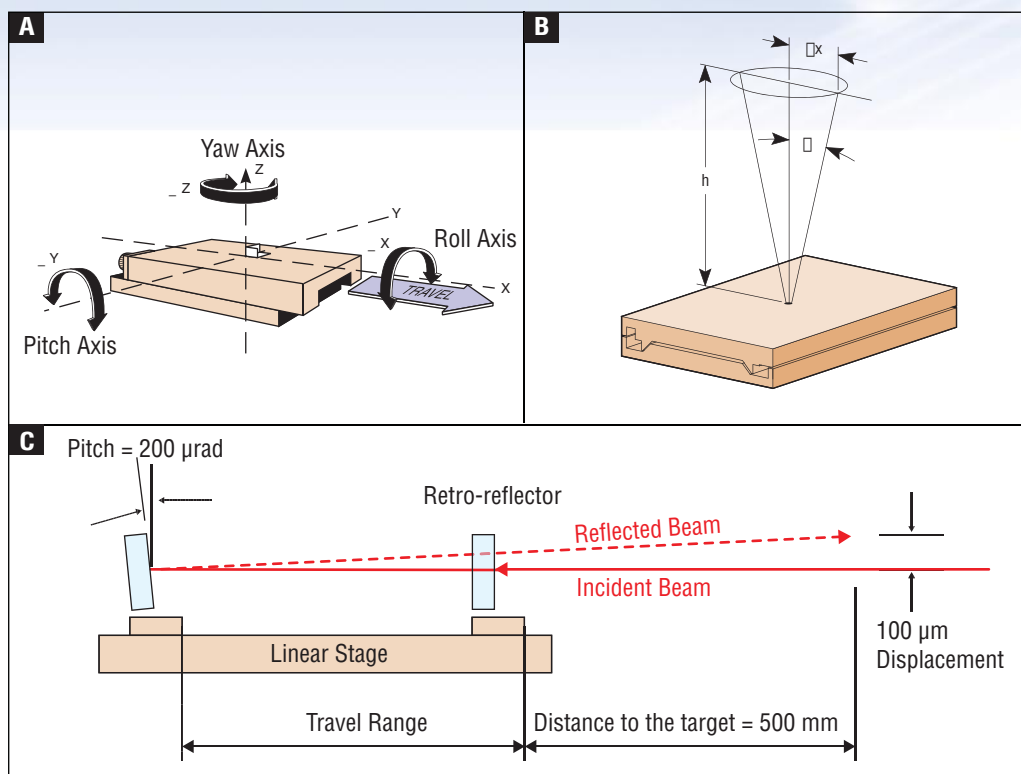


Figure 3. Illustration of pitch, yaw and roll (A), Abbe error (B) and the effect of linear stage pitch on the overlap of two beams in pump-probe experiment (C).

Runout of linear stage (both linear and angular runout) which affects the position accuracy is another important factor for selecting the right motion system for delay line applications. Flatness and straightness (linear runout) represent the deviation from the ideal straight line motion and these are perpendicular to the direction of the travel in horizontal and vertical planes respectively. Pitch and yaw are rotations around the axis perpendicular to linear motion (perpendicular to the direction of travel) in the horizontal and vertical planes respectively (Figure 3). Roll is the rotation around an axis in the direction of travel. In the simplest variant of time-resolved measurements (pump-probe scheme) the pump and probe beams are spatially overlapped at the target sample and the temporal overlap is altered by scanning the linear stage. Runout of the stage (especially angular runout) is an important factor as it is an indication of how the spatial overlap is preserved during the scan of temporal overlap. The pitch and yaw become even more critical in configurations where the target sample at which the beam should be overlapped spatially, is far from the delay stage (Figure 3).

In the time-domain version of multidimensional spectroscopy, i.e., 2D spectroscopy, where time-domain signals are Fourier Transformed to get the frequency domain axes, more than one translation stage is required to get the frequency in two axes. In either electronic or vibrational 2D spectroscopy, the pulse sequence consists of three pulses and a so called local

oscillator to recover the phase of the emitted signal in the phase-matched direction. The time accuracy of the pulse sequences is of paramount importance as it results in a decrease of the detected signal strength and a distortion of the line shape (producing a ghost shape). The important stage parameter for this type of application is the accuracy of the stage. Accuracy of the translation stage is the degree to which the commanded position matches the real position.

The accuracy of the stage, to a large part, depends on the drive mechanism (lead screw, ball screw, belt drive or linear motor) and the feedback. Lead screw and ball screw based drives provide moderately good MIM but suffer from low accuracy as they are mainly used in open-loop configuration where there is no position feedback. In cases where there is position feedback, a rotary encoder at the end of the motor is typically used. Additionally, thermal expansion errors due to either ambient temperature changes or the heat induced from the nut friction reduce the accuracy of the stage. A linear motor based system, in contrast to a screw driven system, does not introduce any backlash because the linear bearing is the only friction point. In addition these systems use linear encoders (as opposed to rotary encoders with screw driven stages) which minimize thermal expansion errors as well as cumulative and periodic errors inherent in lead and ball screws.

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Apart from the drive mechanism, the location of the feedback device relative to the motor, directly affects the accuracy of the motion system. The closer the feedback device is to the object being controlled, the more effective it will be in achieving the desired position. A rotary encoder is typically directly attached to the lead screw or ball screw which eliminates errors due to belt, gear or coupling wind-up or backlash, but the final position output still depends on the accuracy of the lead screw or ball screw. The linear encoder scale, on the other hand, is directly attached to the translation stage carriage and the position of the carriage and mirror is read directly. The effects of mechanical limitations on the stage performance could be further minimized with different types of error compensation methods available from Newport Engineers.

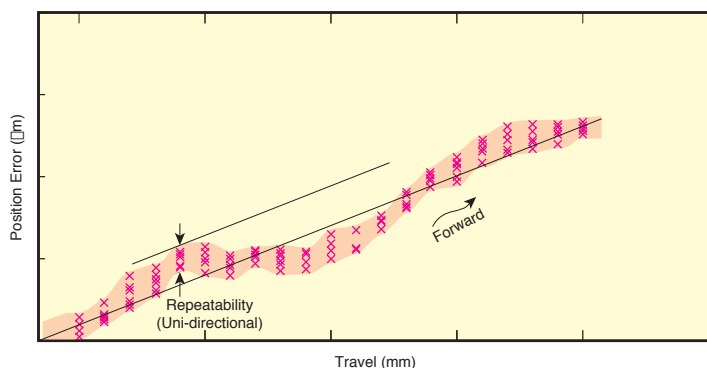


Figure 4. Estimation of on-axis accuracy after linear error compensation.

The linear or monotonically increasing errors include cosine error, inaccuracy of the lead screw pitch, angular deviation at the measuring point (Abbe error), and thermal expansion

effects can be compensated by linear error compensation. Graphically, these errors can be approximated by the slope of a best fit, straight line on a plot of position versus deviation (Figure 4). Knowing the slope of this line (error/travel), one can estimate the accuracy after linear compensation error as: $\text{Accuracy}_{(\text{After linear compensation})} = \text{Accuracy}_{(\text{Before linear compensation})} - (\text{Slope} \times \text{Travel})$ where slope is the slope of best fit to the aforementioned graph and Travel is the travel range of the translation stage.

Non-linear errors are compensated by error mapping using a laser interferometer. A typical laser interferometer is based on a Michelson interferometer consisting of a stable light source, polarization beam splitting optics, retroreflector on a translation stage and a detection system. After reading the position (by the interferometer) at each increment, a text file representing the position and the associated error at that position is created. Depending on the level of position accuracy needed, different numbers of points are selected. The controller then uses the text file to compute and execute the command position correcting for positioning error. The final accuracy after error mapping can be as low as few hundred nanometers for stages with linear encoders.

In conclusion, for obtaining an accurate means of creating reliable delays in any time-resolved spectroscopy or dynamic experiment, several factors about the delay line stage must be considered to reduce or eliminate errors associated with linear stages. Be wary of specifications, like resolution, and choose the stage that meets the MIM value that is required to finely resolve the phenomena under study. For any questions or assistance in selecting a linear stage for optical delay line applications, feel free to contact Newport.



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