A Simple Robust Method for Creating a Non-Contact High Rate Optical Extensometer

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This project demonstrates the theory of a potential, non-contact, optical extensometer used to accurately measure the relative motion of two points on a stretching object or material specimen. A small He-Ne laser spot is shined on the pattern of light and dark lines attached to or painted on the object. After measuring the intensity of reflected light, the relative motion of the stretching object could be recorded for further analysis. This measurement is fundamental in the study of the mechanical behavior of materials.

1. Introductions

An extensometer is a device with a very simple purpose. It accurately measures the relative motion of two points on a stretching object or material specimen. Mechanical extensometers have several drawbacks. The knife edges can score (cut) brittle or delicate specimens causing premature failure of a stretched specimen. In addition, the mass of an extensometer reduces the accuracy of the strain measurement in a dynamic test. Also, due to the violent nature of dynamic tests, mechanical extensometers are easily damaged by all but the slowest mechanical tests.

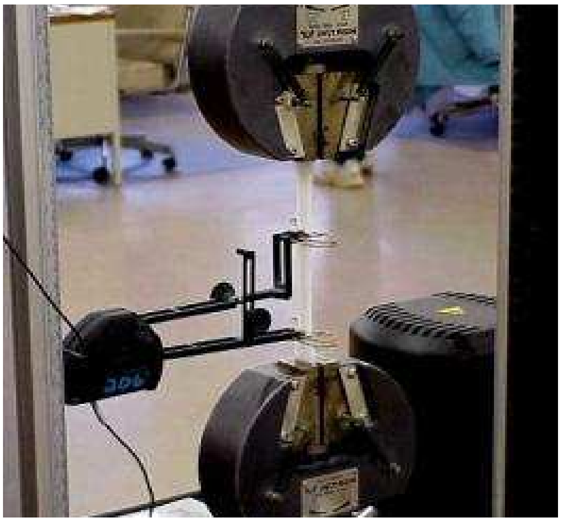

Fig.1 A mechanical extensometer clamped on a stretched material specimen.

A non-contact, optical extensometer potentially overcomes all of these disadvantages. As the specimen is not physically touched, there is no risk of cutting the delicate specimen. This method would also avoid any bonding or gluing that would be required with most contact type measurement methods. Bonding or gluing of a measurement device to the specimen has the potential to skew data measurements by either enhancing or degrading the integrity of the physical properties of the specimen. Currently, optical extensometers exist, but they rely on methods which are either limited in rate (i.e. rotating mirror) or they are expensive and unreliable. Such an optical extensometer that exists uses speckle interferometry and tracking of a contrast line using a photomultiplier tube.

This report outlines a method of position measurement similar to an optical encoder. A pattern of light and dark lines of known width are attached to or painted on the object to be measured. The lines are then illuminated by a He-Ne laser (λ = 632 nm) with a spot size equal to or smaller than the line width and/or spacing of the pattern. As the pattern of lines move (or stretch), the laser beam is then reflected and its optical power is measured by a photodetector. The light and dark lines will change the intensity of the reflected light with a period equal to the spacing of the lines. The number of peaks or valleys may be multiplied by the line spacing to obtain a displacement. Post-processing may be able to increase the resolution beyond the line spacing by measuring the relative changes in light intensity.

2. Proof of concept

The initial proof of concept experiment was conducted as follows: A pattern of black and white lines (referred to as "Ronchi Rulings") with spacing measured at approximately 0.5mm was fixed to a linear stage. A calibrated Linear Variable Differential Transformer (LVDT) was attached to the stage to measure the displacement. Traces of the LVDT output and the measure light intensity (optical power) were captured using an Oscilloscope (Data Acquisition System, 300 kS/s).

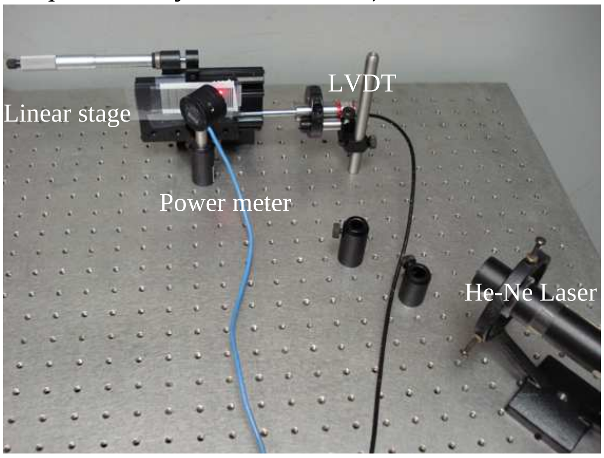

Fig.2 Initial proof of concept experiment.

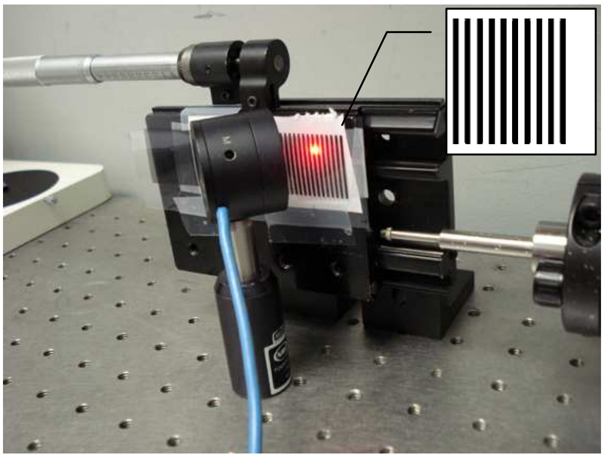

Fig.3 Ronchi Rulings on a linear stage, LVDT was attached to the right edge to measure the displacement.

The reflected intensity was changing while we measured the relative movement of the stage by using LVDT. With a fine lens, we could also focus the laser spot so that smaller spacing of Ronchi Rulings could be used to make a measurement.

3. Test Procedures & Results

An additional experiment was carried out to repeat prior measurements at high rate. An air actuated (pneumatic) linear stage was used in replacement of the manual linear stage used in the first experiment.

Fig.4 The manual linear stage is replaced with an air actuated linear stage to carry out the high pressure test.

Compressed air was used to actuate the linear stage at a much faster rate than the manual stage that was used in the first experiment.

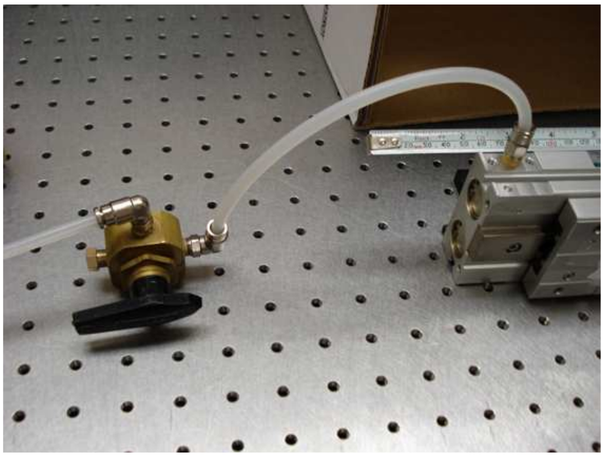

Fig.5 The pipe used to actuate the linear stage with high compressed air. On the left is a switch used to deflate the stage and move it back to original position.

At a rate of over 83 inches per second, the photodetector can still clearly distinguish between the light and dark contract lines.

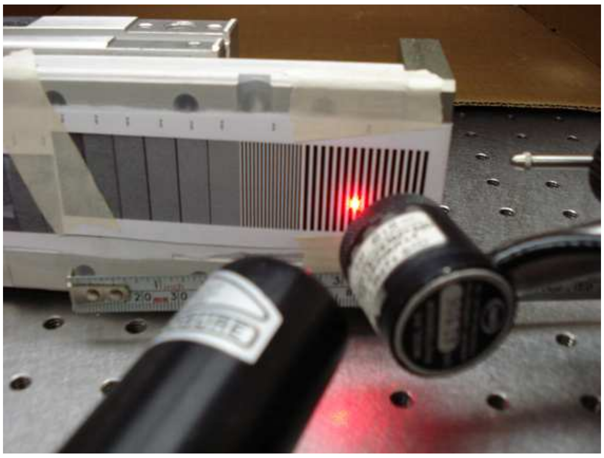

Fig.6 Measurement with light on.

Fig.7 Measurement with light off.

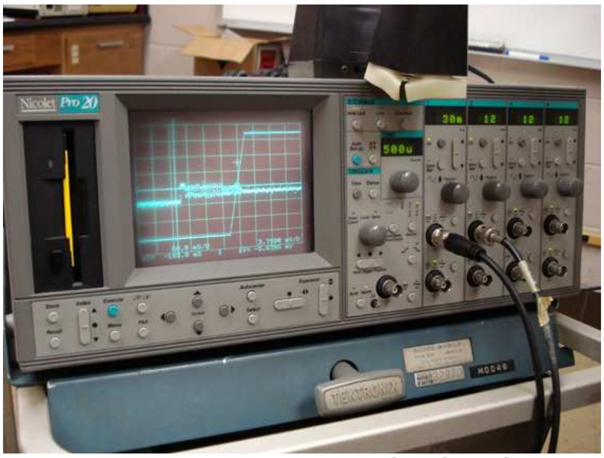

Fig.8 Data acquisition system with 2 channels on. Channel one is for LVDT. Channel two is for photo detector.

From Fig. 9 we could see that line 1 goes up at spot A and stay at the same level at spot B. Line 1 represent the movement of LVDT.

Spot A is the moment when the edge of the stage hits the LVDT and spot B is the moment that the LVDT stops. Sinusoidal-like curves in the middle of the screen are records of the reflected intensity. Spot C is the moment that the laser starts to shine on the paper.

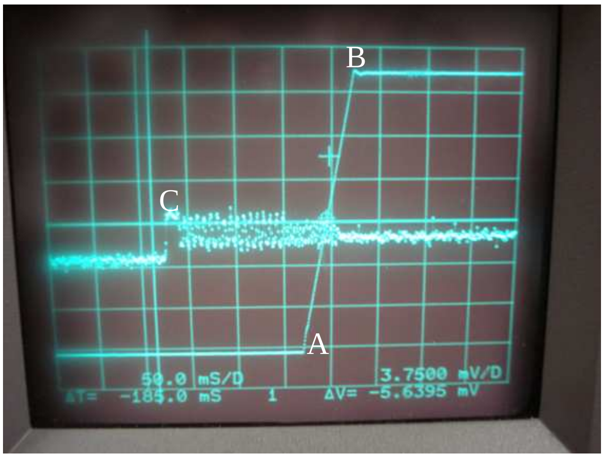

Fig.9 Analysis of different data.

We could see some large sinusoidal curves at first followed by some smaller sinusoidal curves which are the intensity of smaller spacing Ronchi Rulings. After moment B, the variation of intensity measurement are mainly caused by background light fluctuation.

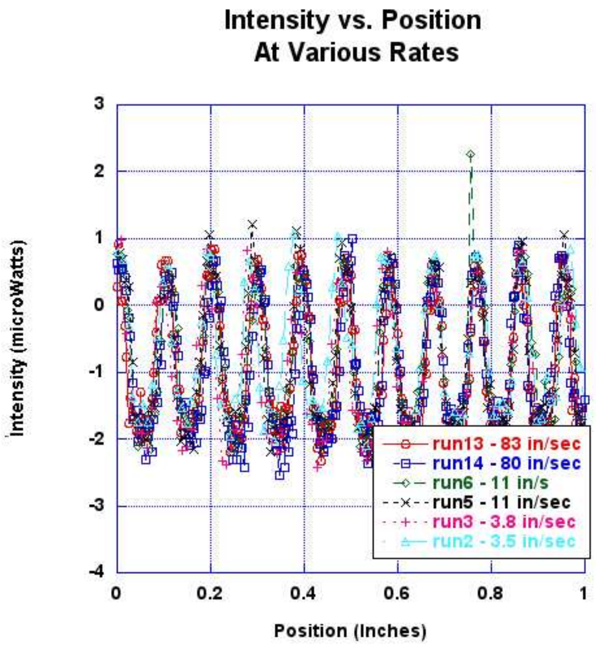

Fig.10 Intensity vs. Position at various rates.

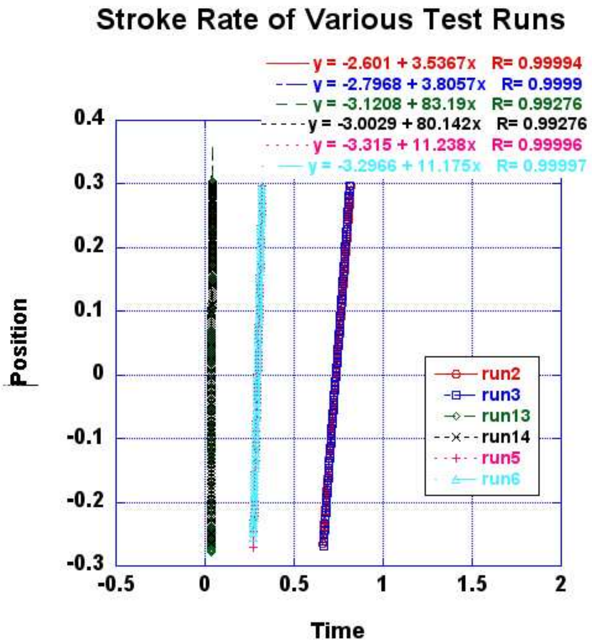

Fig.11 Stroke Rate of various test runs.

From Fig. 10 and Fig. 11, we could clearly see the relative movement of different points on the object.

4. Error Analyses

4.1 Ambient light fluctuation brings the noise to our intensity measurement. With smaller spacing Ronchi Rulings, the Signal to Noise Ratio would decrease. The smallest spacing that we could tell the signal from the noise is 1/120 inch.

4.2 Circuit noise should be concerned. As we tuned the data acquisition system, the noise gets smaller.

4.3 The thickness of the ink on the Ronchi Rulings paper may cause fluctuation on the intensity.

5. Conclusions

This method uses common technology (COTS) to solve a difficult problem. There is currently no inexpensive reliable non-contact method for measuring strain at high rates. The method and theory of operation described in this report offers the potential to do so.

6. Way Forward/Future Improvements

Future improvements include:

- ✓ Measurement of a more tightly focused beam and more closely separated lines.
- ✓ The use of fiber optic cabling to couple the light to and from the light source and photodetector, thereby improving the portability and packaging of the system.
- ✓ The use of two detectors to act as an extensometer.
- ✓ The use of four detectors to, two per end, approximately 90° out of phase. This has the potential to greatly improve the measurement accuracy and resolution (reference for quadrature) and allow the direction of motion to be accurately determined.
- ✓ The measurement of a stretching pattern of lines to test the ability to resolve a pattern printed or fastened onto a specimen

7. Acknowledgement and Thanks

We want to acknowledge Dr. Andrew Sarangan for the fruitful discussions.