HOLLOW-CORE FIBERS (HCFs), Formalization of the stretching process for implementation in spectral broadening

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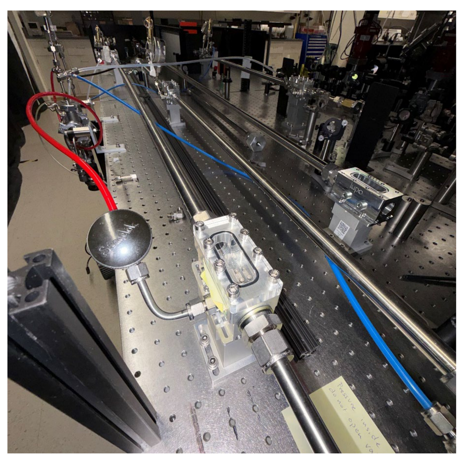
BACKGROUND

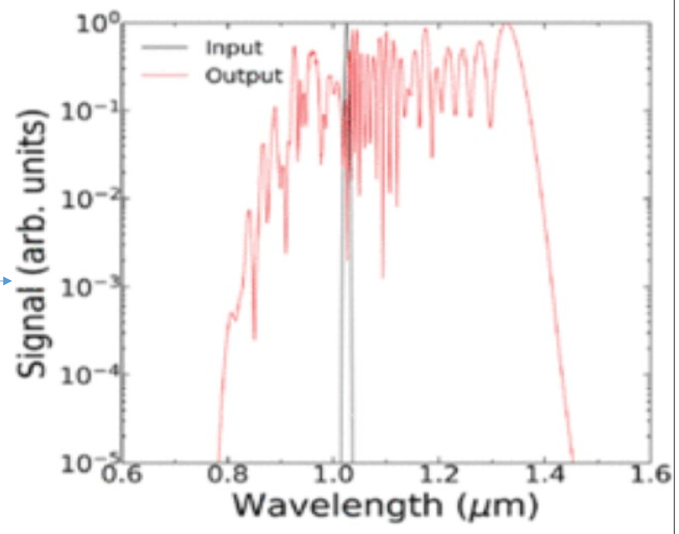
Ultrafast Science

- Observation of atoms and molecules at femtosecond ($10^{-15}\ s$) timescales or faster. [1]
- Ex: Short pulses of radiation capture interatomic/intermolecular processes in a method called "pump-probe" experimentation. [1]

Hollow-Core Fibers (HCFs): Achieving Attosecond Pulses

1. A laser is pulsed coaxially through an HCF. A non-linear optical effect called Self-Phase Modulation cause HCFs to produce spectral broadening of the pulse. [2]





2. The spectrally broadened pulse exits the HCF with chirp. Superimposing wavelengths using chirp mirrors causes wave interference and creates a pulse. [2]

INTRODUCTION

HCF Stretching Process

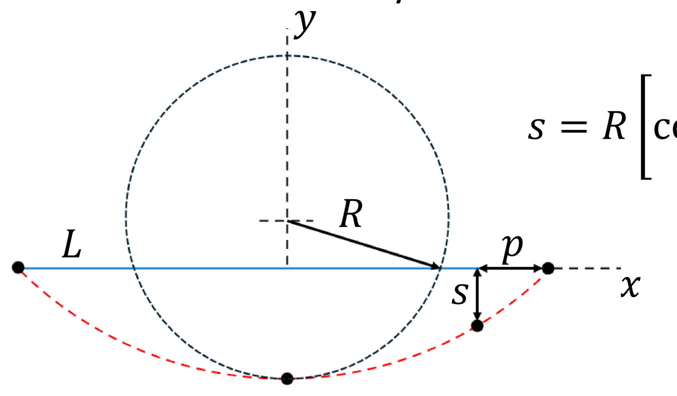
- Laser attenuation occurs when the HCF is not coaxial with the incident beam.
- A perfectly straight HCF (infinite radius of curvature) maximizes beam transmission. [4] [5]
- **The current system for stretching HCFs at SLAC is difficult to perform and lacks repeatability. This project aims to repeatably and easily control the straightness of the installed HCF.**

THE MODEL

- The catenary is a function that describes the curvature of the HCF as it is stretched between two points. [3] [4]
- A relationship between radius of curvature R and tension F for a catenary:

$$F = \vec{g} \cdot \rho_{fiber} \cdot R \cdot \frac{\pi\left(D_o^2 - D_i^2\right)}{4}$$

- A useful equation can be employed to determine R from the sag s between the catenary and the nominal fiber axis.



$$s = R\left[\cosh\left(\frac{L}{2R}\right) - \cosh\left(\frac{L-2p}{2R}\right)\right]$$

- A target R can be found from HCF and beam characteristics. [5]

$$R = \sqrt{\frac{2\pi^2 D_i^3 f_{nm}}{3u_{nm}^2\lambda^2}\left(1 - \frac{n(n-2)}{u_{nm}^2} + \frac{3\delta_n(v^2-1)\cos 2\theta_0}{4(v^2+1)}\right)} \cdot \sqrt{\left(\frac{-\ln T}{L} - \frac{2u_{nm}^2\lambda^2 f_{nm}}{\pi^2 D_i^3}\right)^{-1}}$$

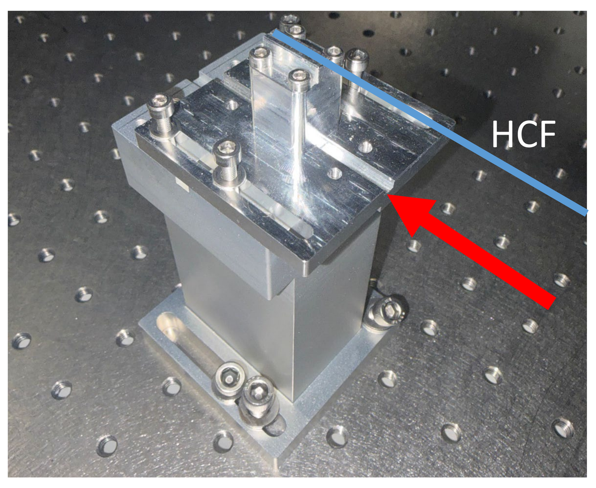
- Young's Modulus (E) of the HCF relates the tensile force experienced in the HCF with displacement ΔL.

$$F = \frac{\pi E}{4L_0}\left(D_o^2 - D_i^2\right)\Delta L$$

STRETCHING SYSTEM

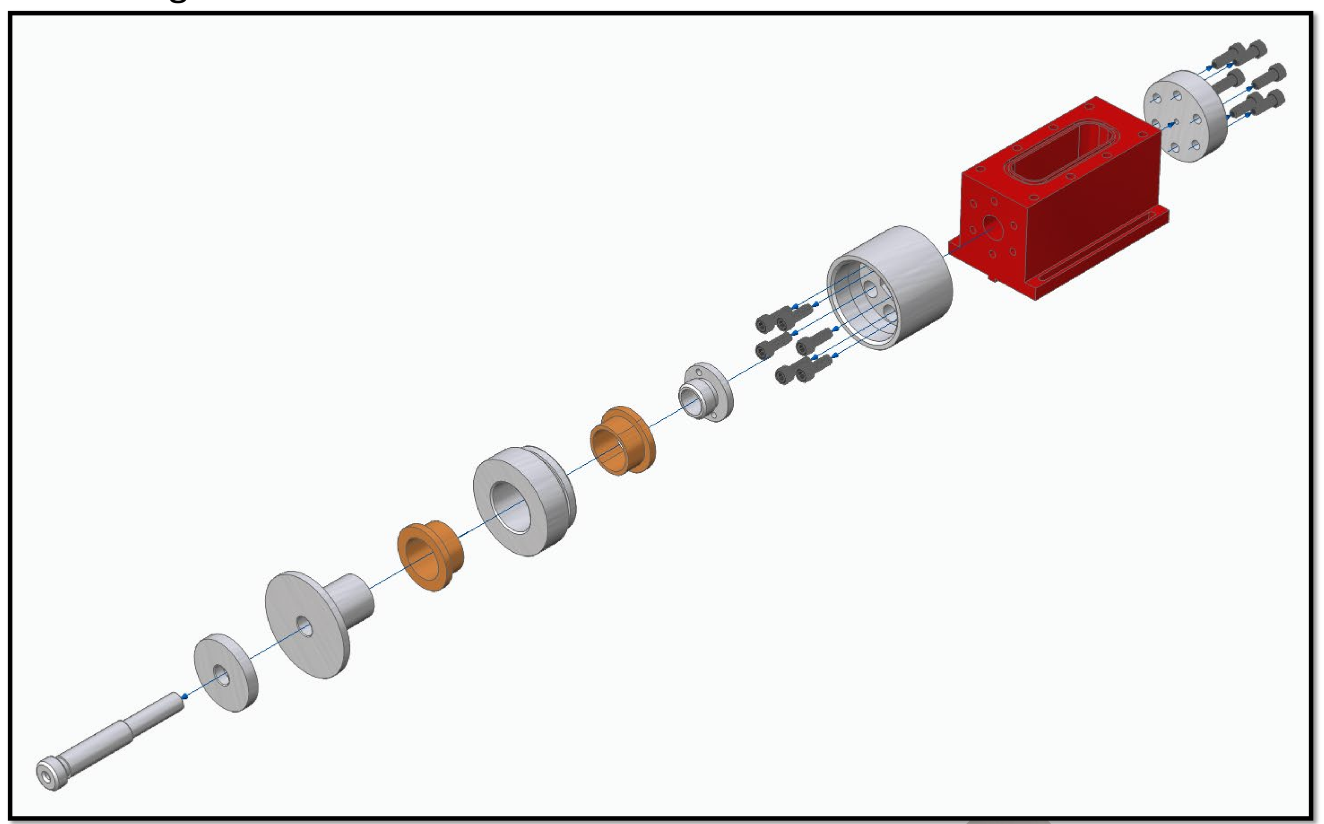
- The current stretching system at SLAC is unrepeatable and of great difficulty to those installing the HCFs.
- The current failure rate of the stretching process is ~75%.

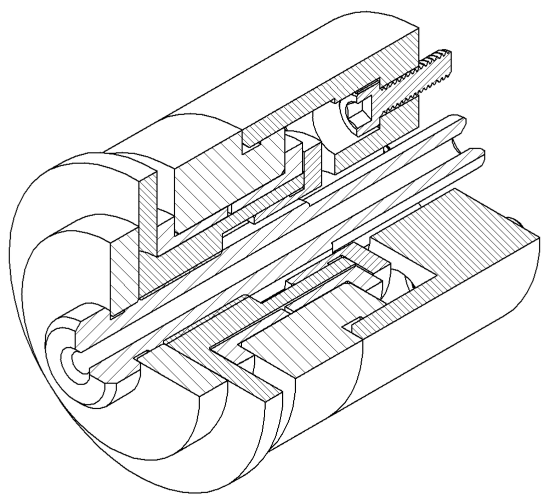
Current HCF stretching process

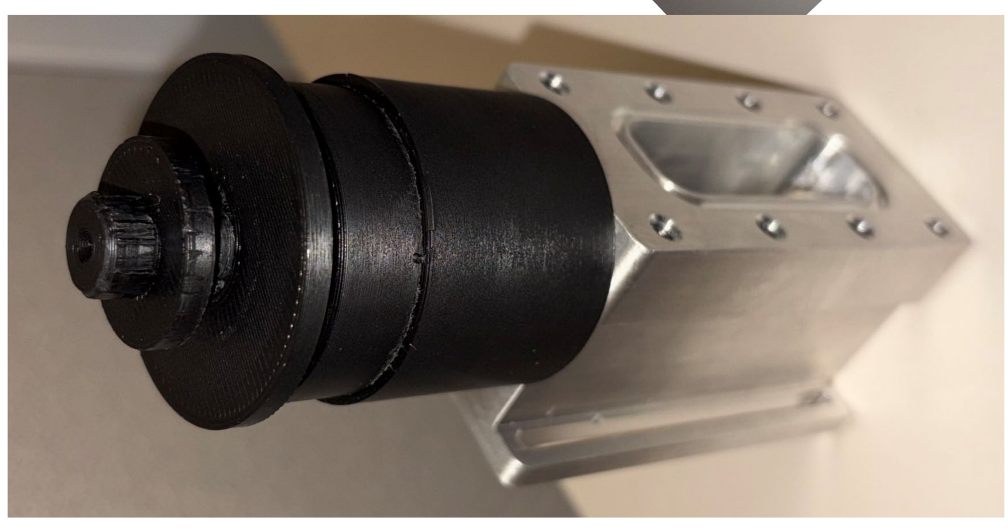


- *Few-Cycle Inc.* sells HCF stretching solutions, but these devices cannot be seamlessly implemented into existing SLAC infrastructure.

- *Solution:* Compact stretching device compatible with existing SLAC HCF housings.

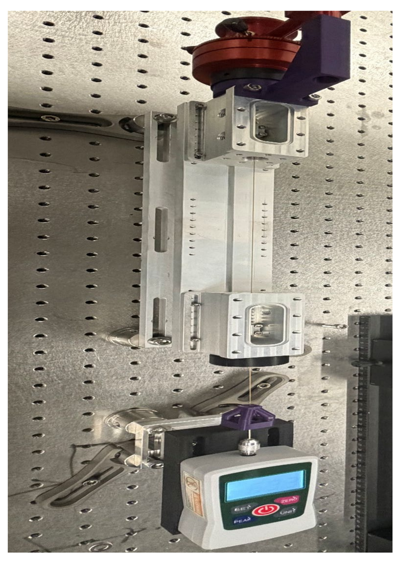


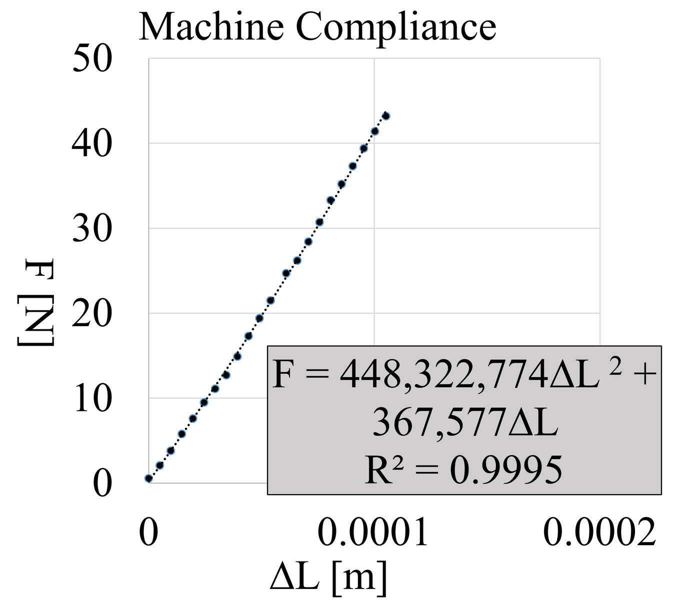


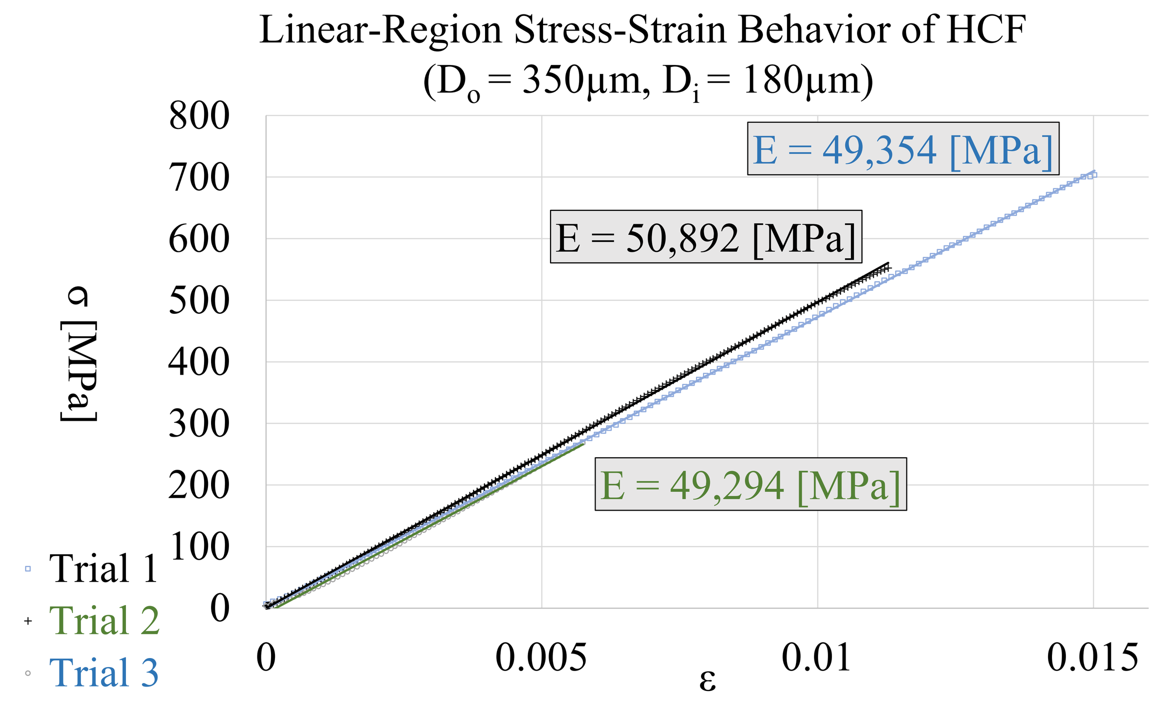


TESTING

- Mechanical testing was conducted for two sizes of Molex *"Polymicro"* glass capillary tubing with polyimide coating.

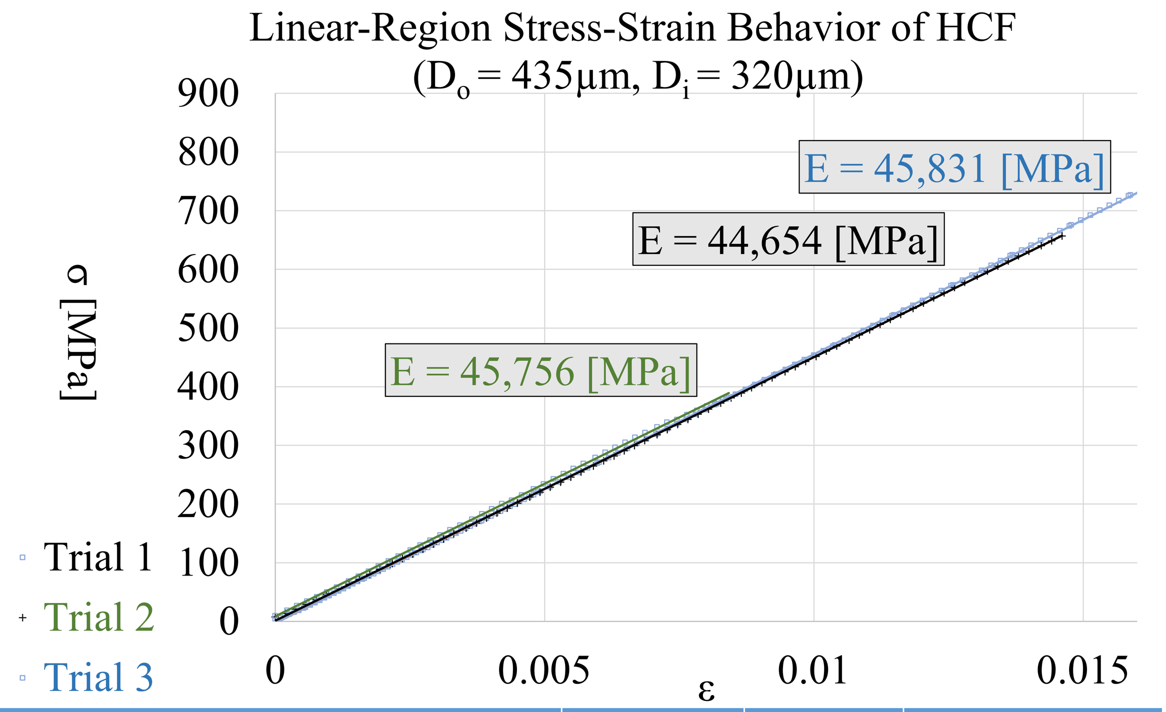






Mechanical Property	Units	Sourced	Experimental
Linear Density (w)	m/g	0.153	N/A
Modulus of Elasticity (E)	GPa	*52.5	49.8
100% Proof Tensile Strength	MPa	689	N/A

*Theoretical value ($E_{effective}$)



Mechanical Property	Units	Sourced	Experimental
Linear Density (w)	m/g	0.132	N/A
Modulus of Elasticity (E)	GPa	*46.3	45.4
100% Proof Tensile Strength	MPa	689	N/A

*Theoretical value ($E_{effective}$)

CONCLUSION

- The stretching system creates an easy, reliable, and repeatable method for stretching an HCF.
- A desired tension force can be applied to the HCF from a finite movement of the stretcher.
- Allows for the study of beam transmission vs. HCF radius of curvature.

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