PENNSTATE
EO Electro-Optics Center

Penn State Electro-Optics Center
222 Northpointe Blvd.
Freeport, PA 16229
Phone: (724) 295-7000
Fax: (724) 295-7001
www.electro-optic.org

Spinning Wedge Results

Tests were performed to explore the drilling ability of the spinning wedge trepanning system. The four wedge trepanning system (Figure 21) consists of a primary pair of 12 degree wedges ($W_{1,2}$) which are at a fixed orientation to each other and are driven by one motor. The second pair of 440 arc second wedges has an independent motor drive for each wedge. This allows differential velocities and orientation angles between the wedges. The programmable variables include the speeds and direction of wedge 1 and 2 ($W_{1,2}$) combined, wedge 3 (W_3) and wedge 4 (W_4). Speeds are reported in rotations per minute (RPM) and have a positive or negative direction, to indicate if they are moving in the same direction or opposite directions. Also the offset of Wedge 4 with respect to Wedge 3 is called W_4 offset and the offset of the set of Wedges 3 and 4 as a set to wedges 1 and 2 (once W_4 offset is defined) is called $W_{3,4}$ offset. The offsets are reported in degrees from 0 to 359, as determined by the control software.

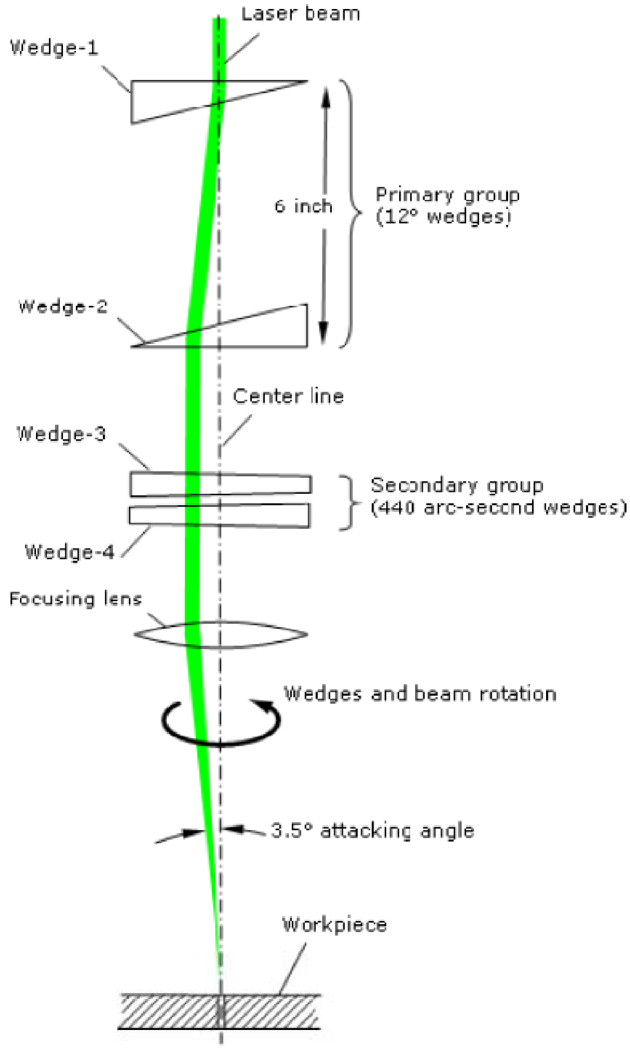


Figure 21 Schematic of 4 wedge trepanning system
picture courtesy of wedge manual from the Ex One Company

Penn State Electro-Optics Center
222 Northpointe Blvd.
Freeport, PA 16229
Phone: (724) 295-7000
Fax: (724) 295-7001
www.electro-optic.org

When inserting the wedges into the systems, wedges 3 and 4 must be nulled-out, setting the offset to zero when they are 180 degrees out of phase from each other so they have no effect on the beam angle, but induce a slight offset (if they were in contact they would have no effect). A simple way to null wedges 3 and 4 was discovered when looking at the laser light in the far field. The beam was directed through the spinning wedges and the leakage of laser light through the third turning mirror was observed on the far wall approximately 25' away (Figure 22). Initially all wedges were homed (the offsets in the parameter file are also set to zero) and the laser shutter opened with minimal power out of the laser. Wedges 1 and 2 were rotated at a rate of 1000rpm using the free run command in the Aerotech software. This resulted in a circle being projected onto the far wall. Next wedges 3 and 4 are rotated in the same direction as wedges 1 and 2 at a rate of 1500rpm using the wedge lens panel program. This will produce a pulsating donut on the far wall if the wedges 3 and 4 are not null. Wedge 4 is then adjusted in the wedge lens panel until the donut stops pulsating. The number of degrees offset on Wedge 4 should be entered into the parameter file as the null offset. The nulling of wedges 3 and 4 is then complete.

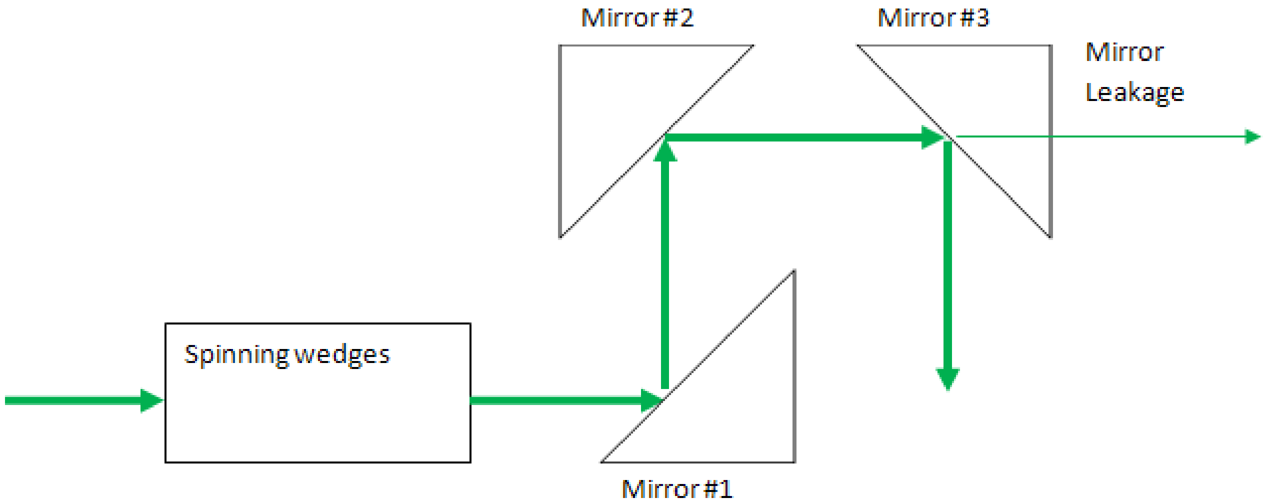


Figure 22 Beam path through SuperPulse workstation, showing laser leakage used for nulling wedges 3 and 4

It should also be noted while refining this procedure, if wedges 3 and 4 were rotated as a set with opposite direction from the set of wedges 1 and 2, numerous shapes are made such as a circle, straight line, asterisk, flower, and star as seen in Table 2. All of the shapes contained one or more axes of symmetry. After some experimentation, a simple relationship was defined to calculate the number of points, arms or petals at a given offset, dependent only on the rotational speeds for a particular wedge offset. Given the angular rotation speeds of the two sets of wedges (ω_1 , ω_2 respectively, with the W_4 offset programmed and wedges 3 and 4 locked as a set) and n being an odd positive integer:

$$n = \frac{|\omega_1| + |\omega_2|}{|\omega_1| - |\omega_2|}$$

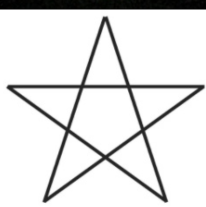
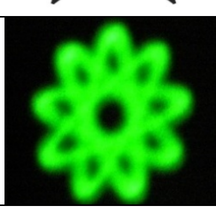
Penn State Electro-Optics Center
222 Northpointe Blvd.
Freeport, PA 16229
Phone: (724) 295-7000
Fax: (724) 295-7001
www.electro-optic.org

Note that the equation does not apply to the offsets that produce the circle or line. A more practical form of the equation would be to solve for a rotational frequency given one rotational frequency and the desired number of points. By letting ω_1 be the maximum rotational speed, ω_2 will always be a smaller value using this equation:

$$\omega_2 = -\left(\frac{n-1}{n+1}\right)\omega_1$$

A slight shift in one of the rotational speeds would cause the shape to process slowly, and the procession would increase in speed as the n value moved farther from an integer value, until it settles into a stable equilibrium at the next odd integer value. It should be noted that these shapes are possible using only the Aerotech control. Unfortunately the degree of offset for wedges 3 and 4 is not easily controlled in the Aerotech software. The wedge lens panel is only programmed to rotate all 4 wedges in the same direction and will fault out otherwise.

Table 2 Examples of shapes projected by the wedge system and the parameters that produced each object

Representative Image	Shape	Wedge 1,2 Speed (RPM)	Wedge 3,4 Speed (RPM)	W4 offset (degrees)
	Circle	2000	-1500	30
	Line	2000	-2000	88
	7-armed asterisk	2000	-1500	90
	5-pointed star *picture not available	1800	-1200	130
	9-petal flower	2000	-1600	0

After discovering the various shapes that the 4 wedge system could produce, it was learned that the company Laser Mechanisms Inc. (a.k.a. Laser Mech) recently introduced a rotary Wedge Scanner system (Figure 23) with the flexibility to easily input these types of parameters to create and control these shapes for laser patterning. Their system uses only 2 wedges which are independently controlled. The system at the EOC differs by having two sets of wedges which allows more complexity for the shapes it produces. The EOC system could run in a configuration identical to the Laser Mech System by removing the first set of fixed wedges, and in theory produce the same shapes.

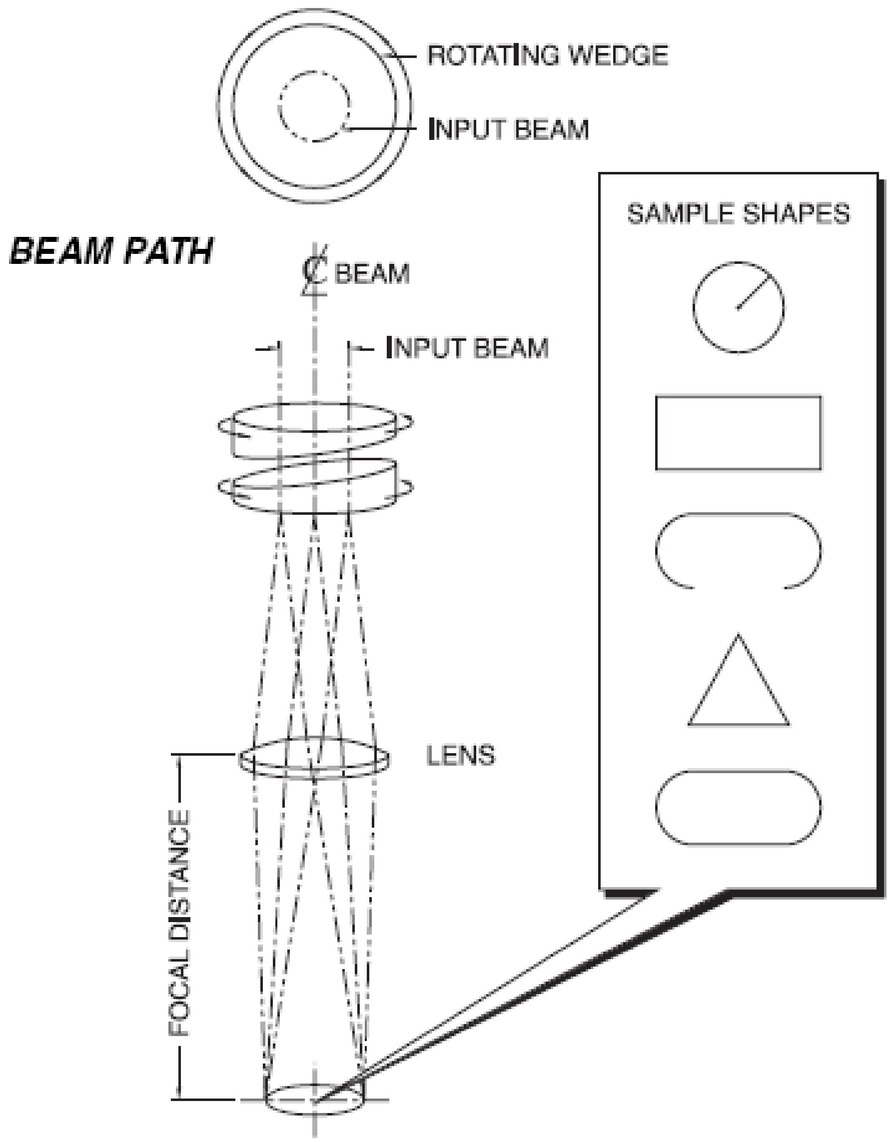


Figure 23 Rotary Wedge Scanner schematic produced by Laser Mechanism Inc. http://www.lasermech.com/graphics/pubs/Rotary%20Wedge%20Scanner.pdf

Penn State Electro-Optics Center
222 Northpointe Blvd.
Freeport, PA 16229
Phone: (724) 295-7000
Fax: (724) 295-7001
www.electro-optic.org

In an attempt to control the amount of taper in a laser drilled hole, the spinning wedge systems parameter space was mapped for various relative speeds and positions of the wedges. Tests were done in thin stainless (0.5mm) steel and titanium, which nearly resulted in a straight hole (only a few degrees of taper). A test in thicker material showed that only positive taper (entrance larger than exit hole) could be obtained. It is believed that poor alignment through the wedges prevents negative taper (exit larger than entrance hole) features.

It was demonstrated in thin stainless steel that the hole diameter can be changed by adjusting the last wedge in the system relative to its paired wedge. Figure 24 shows hole size as a function of wedge offset in degrees. The holes ranged in diameter from 0.2mm to 1.2 mm. Once an initial hole size is set using this guide, then the relative offset between the first pair and second pair of wedges can be adjusted to produce taper as seen in Figure 25 and Figure 26. Changing taper produces changes in hole size, so the W_4 offset must be adjusted iteratively with the $W_{3,4}$ offset to get an accurate hole size and taper.

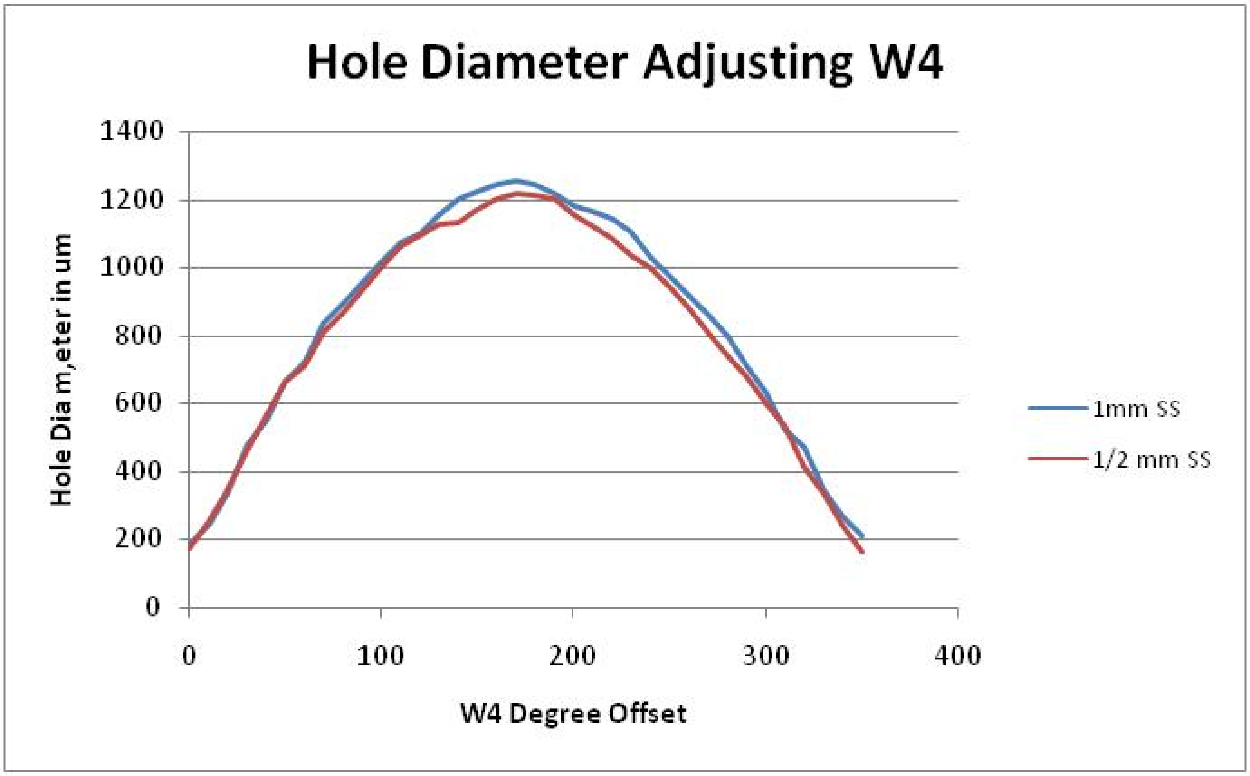


Figure 24 Study the effect on hole diameter by varying the W4 offset

Penn State Electro-Optics Center
222 Northpointe Blvd.
Freeport, PA 16229
Phone: (724) 295-7000
Fax: (724) 295-7001
www.electro-optic.org

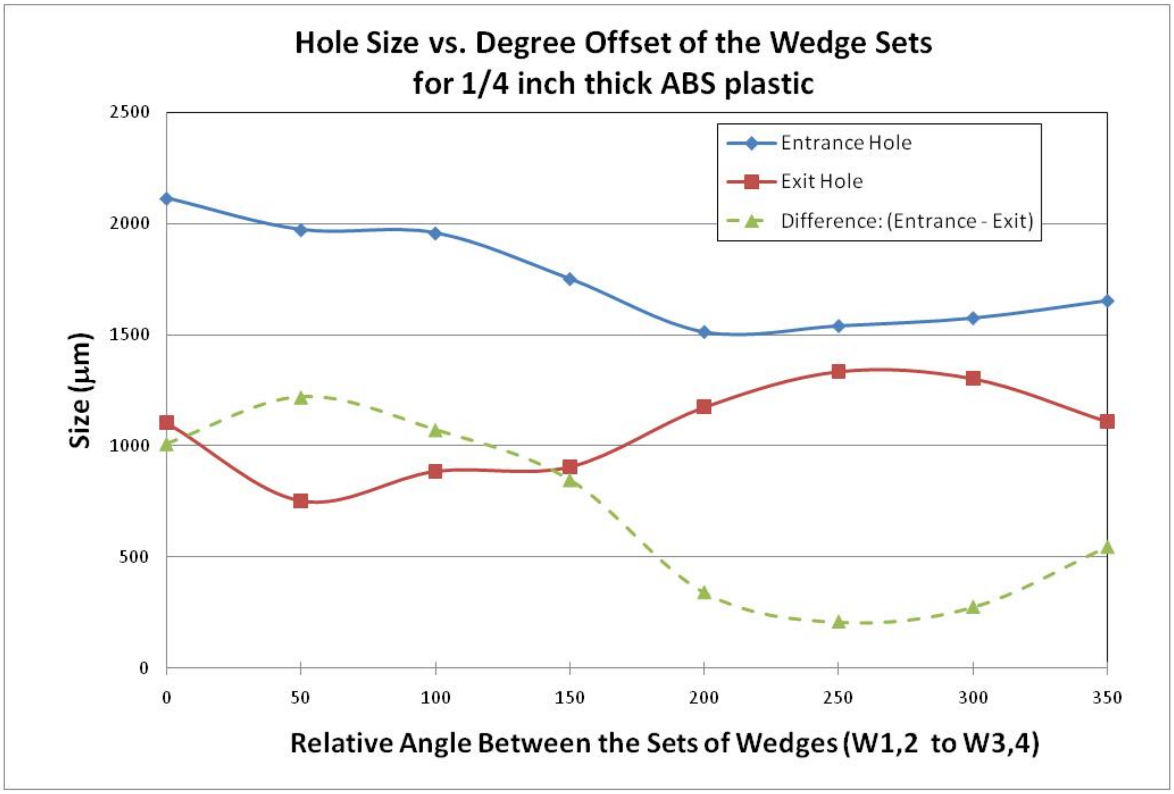


Figure 25 Measurements of tapered entrance and exit holes made in plastic as a function of wedge offset angle

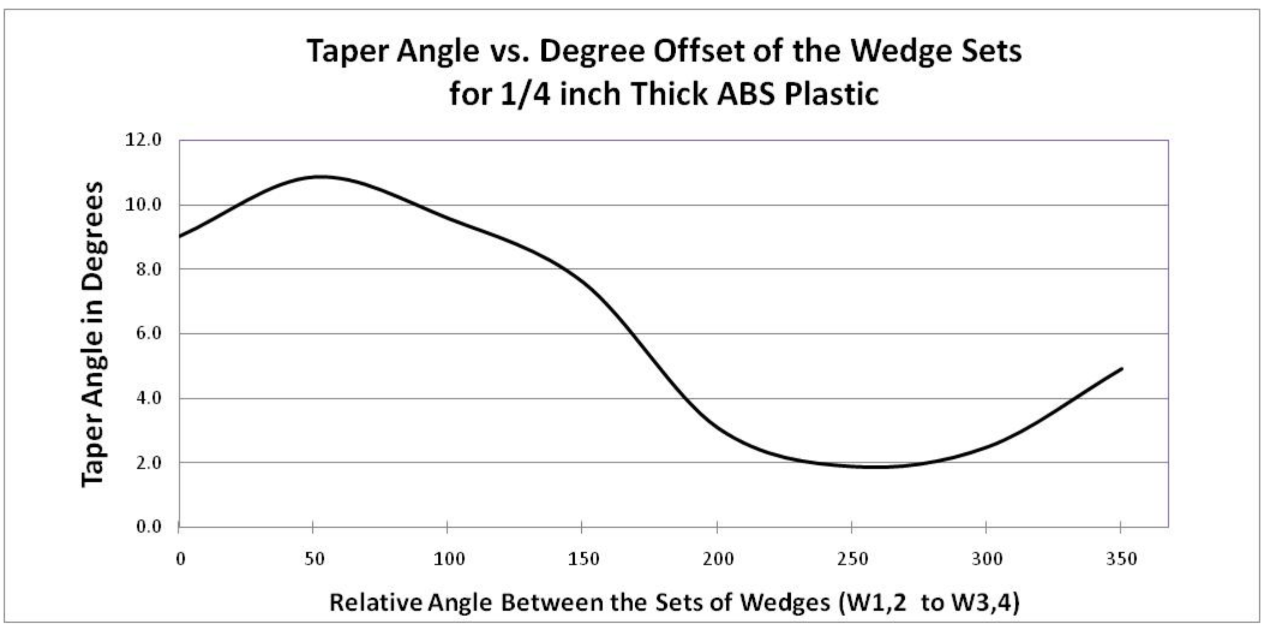


Figure 26 The calculated taper angle of holes made in plastic as a function of wedge offset angle