High Power NanoScan®

Addendum to NanoScan Installation and Operation Manual

Model # ________________________
Serial # ________________________
Date ________________________

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A High Power NanoScan Addendum

A.1. “High Power” Defined

Photon’s High Power NanoScan is designed to measure “high power” laser beams that were previously impossible to measure with standard BeamScan or NanoScan products. High power is a fairly indistinct term that means different things in different contexts. For our purposes, “high power” is defined as between 100W and 5000W, however the High Power NanoScan will not be able to measure this power range for all wavelengths. High power laser beams are handled by using reflective materials, and the level of reflectivity, and thus its inverse, absorption, are dependent on the wavelength of the laser light.

In general the long infrared wavelengths, such as that of the carbon dioxide laser at 10.6microns, are highly reflective. These allow for the highest power measurements up to the maximum levels of several kilowatts. When measuring these lasers and power levels the principle concern is the heat buildup in the scan head. The surfaces of the measurement drum and slits are better than 98% reflective to this wavelength, and thus only 2% of the incident power will be absorbed by the scanhead and heat it up. Nonetheless, at 5000W this represents a heat load of 100W that will raise the temperature of the internal components, which may cause damage to the detector and encoder electronics. The High Power NanoScan is designed to be used for short-term measurements at these power levels. The beam should only be incident on the scan head for a few seconds. The software is equipped with a record mode that makes it easy to make a short measurement and then review the data while the scanhead is allowed to cool down.

The reflectivity of the system is around 98% for wavelengths from around 3microns and above. Below this, between around 700nm and 3 microns the reflectivity is around 96%. Although this is still pretty good, it means that the absorbance has doubled, and thus the power levels that can be handled are cut in half. From 700nm to the ultraviolet wavelengths the reflectivity drops dramatically, to below 35% at 200nm. “High power” in the UV is measured in watts not kilowatts. Consult the wavelength-corrected operating space charts to understand the how the High Power NanoScan should be used with your specific laser. These will give safe power levels that can be measured continuously and give recommended exposure times for powers above the safe levels in the different wavelength regimes.

A.2. Power Levels Measurable with Standard NanoScan Scanheads

The High Power NanoScan is based on the same operating principles of the standard NanoScan and its predecessor, the BeamScan. All of these systems use the moving slit measurement system, one of the strengths of which is the natural attenuation of the technique. It is only when the slit traverses the beam that light hits the detector. The standard NanoScan scanhead, designed to measure beams up to a few watts, has blackened slits to prevent reflection back into the laser cavity. These systems use silicon or germanium detectors, which are sensitive enough to detect and accurately measure lasers with microwatt outputs in the UV, visible and near IR wavelengths. As the powers increase, it is possible to use a pyroelectric detector, which has the benefit of responding across the entire electromagnetic spectrum from UV to far IR. For beams up to 100W (IR) the standard pyroelectric detector equipped standard NanoScan is a good choice. The pyro-NanoScan uses standard alloy slits, but without blackening to increase the power handling capability. This can be extended a bit by the inclusion of the optional copper slits. Copper is very reflective from 700nm to 3microns, and even better above 3 microns. In addition its heat transmission makes it ideal for high power applications.

The power that can be handled by the NanoScan is dependent on the wavelength of the light to be measured. The wavelength of light determines both its reflectivity from the slit surfaces and the energetic nature of the interactions with materials. As a rule of thumb, there are three basic wavelength regimes that govern how much power the scanhead can handle:

- 3µm to FIR (>20µm) –100W maximum pyroelectric detector
- 700nm to 3µm—25W maximum pyroelectric detector;
  1W germanium detector
- 190nm to 700nm—3W maximum pyroelectric detector;
  1W silicon detector

Power levels above these for any of these wavelength regimes can be considered “High Power.”

These values are total power capability of the scanhead. The actual measurement capability is dependent on the power density of the beam to be measured in W/cm^2. The smaller the beam, the more concentrated the power density, and therefore the lower the power that can be safely measured. Consult the operating space charts for information about specific beam diameters and measurable power levels.

A.3. High Power NanoScan

The High Power NanoScan uses these features of copper to increase the measuring range to the high power levels discussed above. The High Power NanoScan also uses a larger mass to help dissipate the energy load. The drum is copper clad; the slits are a heavier gauge copper, and the scanhead is fan-cooled to aid in the dissipation of the heat from the absorbed laser energy. It is important that nothing occlude the airflow from the fan. This is an important consideration when designing any beam reflection control fixtures. They must allow for the air circulation around the aperture of the scanhead and not create an “oven” that traps the heat.

The High Power NanoScan’s record mode has the added advantage of allowing the operator to make measurements remotely. The NanoScan can be set up, the laser turned on for a brief exposure, then turned off, shuttered, or directed into a safe beam dump while the operator evaluates the measurement data.

A.3.1. Pulsed Mode Operation

Although the NanoScan was designed originally to measure continuous wave (CW) laser beams, many lasers are operated in the pulsed mode. Although low frequency pulsed lasers operating in the 1Hz to 1000Hz range have no real alternative to the array profiler, the NanoScan can measure kHz frequency lasers. The NanoScan profiler incorporates the “peak connect” algorithm and software-controlled variable scan speed on all scanheads to enable the measurement of pulsed lasers. The NanoScan is ideal for measuring Q-switched lasers and lasers operating with pulse width modulation (PWM) power control.

A.3.1.1. PWM Lasers

Many lasers, especially CO_2 lasers, use pulse width modulation (PWM) to control the power level of the laser. This is not true pulsed operation, but rather a reduction of the duty cycle to lower the average power. The beam operates as if it was CW, and many operators do not even realize that the laser is pulsing. However, when attempting to measure a PWM laser with a scanning slit profiler, it must be treated as a pulsed laser source. To use the pulsed mode of the NanoScan the laser’s pulse frequency must be at least several kHz, and the combination of the frequency and beam size must provide a sufficient number of pulses across the beam to generate a meaningful profile. Eight to ten pulses are a reasonable minimum. PWM lasers usually operate around 10kHz. The relationship of the beam size and frequency is a fairly simple mathematical model. The NanoScan drum speed is software controlled from 1.25Hz to 20Hz. The high Power NanoScan uses a drum with 84mm diameter. At the 1.25Hz rotation rate the slits travel at around 300mm per second or 300µm per millisecond. At a 10kHz laser repetition rate, a 200µm beam would have 9-10 pulses during the time that the slit was traversing it. This would provide just enough data to generate a meaningful profile. A smaller beam would require a faster pulse rate, a larger one could perhaps run at a lower repetition rate. For example, a 1.0mm beam could be measured with a pulse rate as low as 2kHz and still provide a profile.

The table on the next page shows minimum beam sizes and pulse frequencies scan speeds printed. It is recommended that the 1.25Hz scan speed be used for pulsed beams, however, if the beam sizes are large enough, the measurement can be sped up by increasing the scan speed.

Table — Minimum Beam Size Per Pulse Frequency
NanoScan

NanoScan	Normal Drum					Large Drum (HP)			
Rotation Rate (Hz)	1.25	2.50	5.00	10.00	20	1.25	2.50	5.00	10.00
slit speed (um/msec)	116.63	233.25	466.50	933.01	1866.01	233.25	466.50	933.01	1866.01
Data Points per Profile	15	15	15	15	15	15	15	15	15
Pulse Frequency (kHz)	Minimum Beam diameter in µm					Minimum beam diameter in µm			
1	1749	3499	6998	13995	27990	3499	6998	13995	27990
2	875	1749	3499	6998	13995	1749	3499	6998	13995
3	583	1166	2333	4665	9330	1166	2333	4665	9330
4	437	875	1749	3499	6998	875	1749	3499	6998
5	350	700	1400	2799	5598	700	1400	2799	5598
6	292	583	1166	2333	4665	583	1166	2333	4665
7	250	500	1000	1999	3999	500	1000	1999	3999
8	219	437	875	1749	3499	437	875	1749	3499
9	194	389	778	1555	3110	389	778	1555	3110
10	175	350	700	1400	2799	350	700	1400	2799
11	159	318	636	1272	2545	318	636	1272	2545
12	146	292	583	1166	2333	292	583	1166	2333
13	135	269	538	1077	2153	269	538	1077	2153
14	125	250	500	1000	1999	250	500	1000	1999
15	117	233	467	933	1866	233	467	933	1866
16	109	219	437	875	1749	219	437	875	1749
17	103	206	412	823	1646	206	412	823	1646
18	97	194	389	778	1555	194	389	778	1555
19	92	184	368	737	1473	184	368	737	1473
20	87	175	350	700	1400	175	350	700	1400
21	83	167	333	666	1333	167	333	666	1333
22	80	159	318	636	1272	159	318	636	1272
23	76	152	304	608	1217	152	304	608	1217
24	73	146	292	583	1166	146	292	583	1166
25	70	140	280	560	1120	140	280	560	1120
50	35	70	140	280	560	70	140	280	560
100	17	35	70	140	280	35	70	140	280
150	12	23	47	93	187	23	47	93	187

A.3.1.2. Q-Switched Lasers

Another type of pulsed laser, operating in the kHz pulse rate regime is the Q-Switched laser. These lasers use the pulsing to increase, rather than decrease, their effective power. By concentrating the laser power into a short pulse, the peak power of each pulse increases while maintaining a low average power. In order to measure these lasers the same mathematical relationship of pulse rate to beam diameter applies, but there is an additional complication; the peak power of the pulses may exceed the damage thresholds of the NanoScan even though the average power remains within the operating space. CW beams are measured as *power (P)* in Watts; pulsed beams as *energy (E)* in Joules. Therefore it is necessary to understand the beam's energy (E_{pulse}) to determine whether the unattenuated beam can be directly measured with the NanoScan.

$$E_{pulse} = \frac{P_{avg}}{f_{laser}}$$

Therefore a beam with an average power of 300 Watts with a pulse frequency of 8kHz will have energy as follows:

$$E_{pulse} = \frac{P_{avg}}{f_{laser}} = \frac{300W}{8 \times 10^3 Hz} = 37.5mJ$$

The power density per pulse is also a function of the pulse duration τ. This is also important in understanding the potential damage to the profiler. Taking the above example, if the pulse duration is 100ms, then:

$$P_{pulse} = \frac{E_{pulse}}{\tau} \equiv \frac{37.5mJ}{100 \times 10^{-3} s} = 37.5W$$

If, on the other hand, the pulse duration were 100fsec, the power per pulse would increase to a whopping 3.75GW.

The power density of the beam is the W/cm^2. This is calculated by dividing the power per pulse by the beam area. For a 200μm diameter beam the 37.5W translates to ~120kW/cm^2. The damage threshold for the slits on the High Power NanoScan is 160kW to 5MW per square centimeter depending on the wavelength of the laser. Therefore the 300W of peak power would be within the operating range of the NanoScan.

A.3.1.3. Calculating the Minimum Beam Diameter per Pulse Frequency

Table 4.2 gives a list of calculated minimum beam diameters at a given pulse frequency for each of the drum sizes and for a desired number of pulses per profile. The more pulses per profile the more accurate the measurement is likely to be. The formula is fairly simple. Due to the 45° angle of the slits to the direction of rotation, the actual speed of the slits is the drum speed divided by the square root of two.

$$\left(\frac{\frac{v}{\sqrt{2}}}{f} \right) N = D_{\min}$$

where:

v= drum velocity in µm per msec

f = pulse frequency in kHz

N = pulses per profile

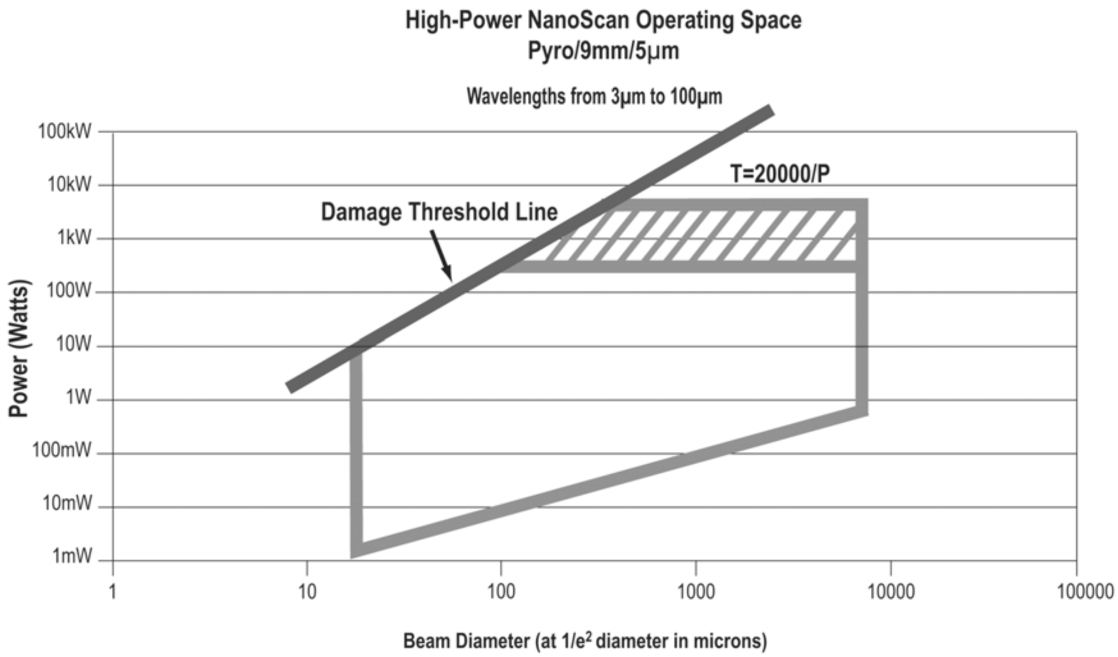
D_{min}= minimum beam diameter in µm

The larger drum used in the large aperture and High Power versions of the NanoScan cause the slits to move faster at any given rotation rate due to the larger circumference. For this reason the minimum beam sizes are larger for the large drum.

The peak connect algorithm finds the highest peak pulse, then using the frequency value entered by the operator it finds the other peaks and connects them to generate a smooth beam profile. It is important that the exact pulse frequency be entered into pulse acquisition parameters.

A.4. Operating Space Charts for High Power Measurements

A.4.1. 3µm to 100µm Wavelength Regime



This chart shows minimum and maximum measurable laser powers for various spot sizes for lasers with wavelengths in the 300µm to over 100µm, which includes the common lines for CO_2 lasers. The spot size ($1/e^2$) is in microns. The upper boundary is limited by the detector saturation and/or the maximum input power density, which is **$5x10^6$ Watts/cm^2**. The left boundary is limited by the smallest accurately measurable spot size, which is dependent on the slit width, and the right side represents the useful instrument detector diameter. Generally the largest beam size will be approximately this value divided by 1.3 to1.5. The lower boundary represents the lowest useful input power, below which the signal-to-noise ratio will be less than 10:1.

The front cap entrance aperture diameter is larger than the instrument detector diameter to prevent light reflected from the scan drum being captured on the inside of the front cap and heating it. The beam should be centered in the aperture to ensure that it will be correctly measured.

Boundary line widths are extremely wide. This is because these boundaries are imprecise due to actual detector response and slit width variations. Damage to apertures is a function of many things including surface finish, tarnish, dirt and more. Thus the boundaries are only a guide. The life of the scan head will be increased if you expose the high power for the shortest time needed to get your measurement.

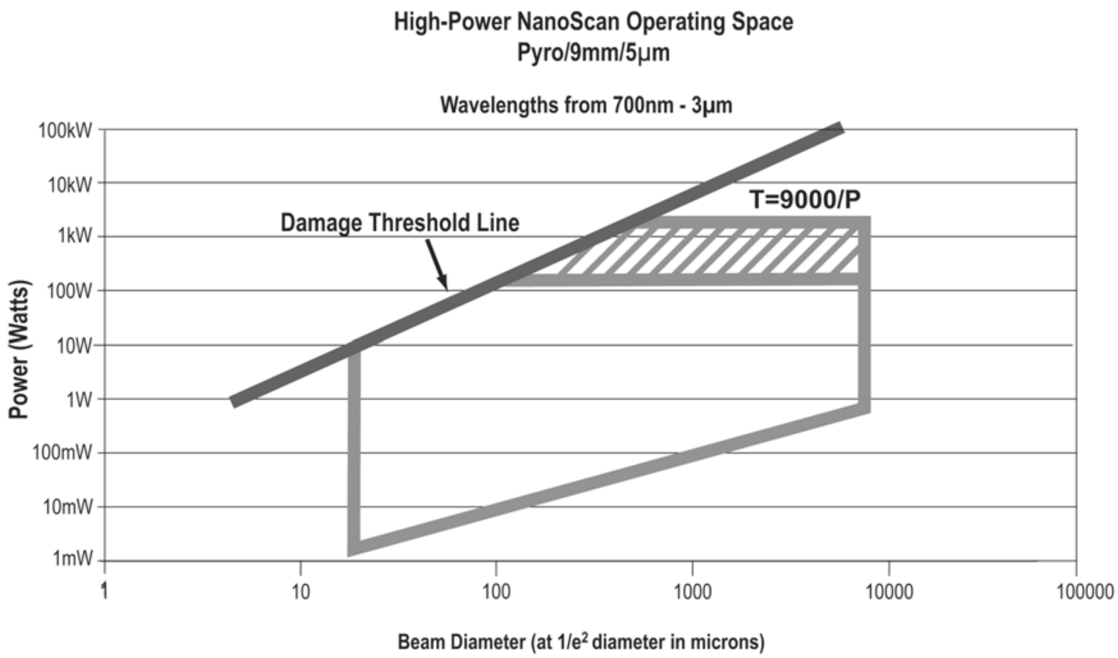
The crosshatched area indicates power levels that require limited exposure times. For example, at **5000 Watts** we suggest a four-second exposure.

The suggested maximum exposure time for powers within the crosshatched area can be estimated from the equation below.

T(sec)= 20000/laser power in watts

Below the crosshatched area and within the operating space continuous operation should be possible without heating the scanhead unduly, provided that the fan is functioning and airflow is unimpeded.

A.4.2. 700nm to 3µm Wavelength Regime



This chart shows minimum and maximum measurable laser powers for various spot sizes in the 700nm to 3µm range. The spot size ($1/e^2$) is in microns. The upper boundary is limited by the detector saturation and/or the maximum input power density, which is **$2.2x10^6$ Watts/cm^2**. The left boundary is limited by the smallest accurately measurable spot size, which is dependent on the slit width, and the right side represents the useful instrument detector diameter. Generally the largest beam size will be approximately this value divided by 1.3 to1.5. The lower boundary represents the lowest useful input power, below which the signal-to-noise ratio will be less than 10:1.

The front cap entrance aperture diameter is larger than the instrument detector diameter to prevent light reflected from the scan drum being captured on the inside of the front cap and heating it. The beam should be centered in the aperture to ensure that it will be correctly measured.

Boundary line widths are extremely wide. This is because these boundaries are imprecise due to actual detector response and slit width variations. Damage to apertures is a function of many things including surface finish, tarnish, dirt and more. Thus the boundaries are only a guide. The life of the scan head will be increased if you expose the high power for the shortest time needed to get your measurement.

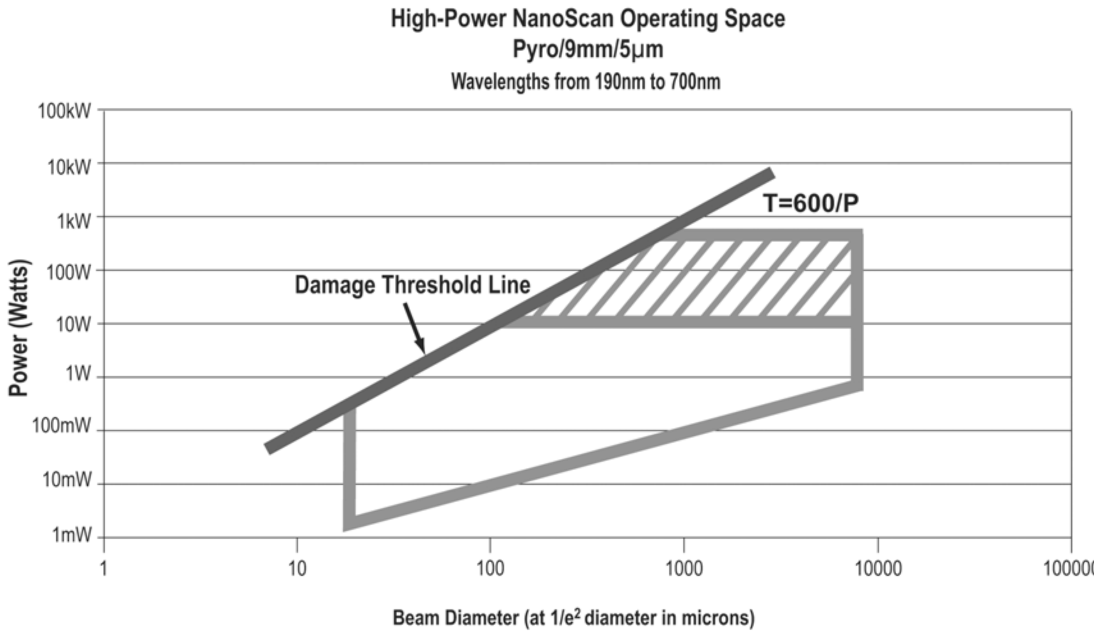
The crosshatched area indicates power levels that require limited exposure times. For example, at
2272 Watts we suggest a four second exposure.

The suggested maximum exposure time for powers within the crosshatched area can be estimated from the equation below.

T(sec)= 9000/ laser power in watts

Below the crosshatched area and within the operating space continuous operation should be possible without heating the scanhead unduly, provided that the fan is functioning and airflow is unimpeded.

A.4.3. 190nm to 700nm Wavelength Regime



This chart shows minimum and maximum measurable laser powers for various spot sizes in the 190nm to 700nm range. The spot size ($1/e^2$) is in microns. The upper boundary is limited by the detector saturation and/or the maximum input power density, which is **$0.16x10^6$ Watts/cm^2**. The left boundary is limited by the smallest accurately measurable spot size, which is dependent on the slit width, and the right side represents the useful instrument detector diameter. Generally the largest beam size will be approximately this value divided by 1.3 to1.5. The lower boundary represents the lowest useful input power, below which the signal-to-noise ratio will be less than 10:1.

The front cap entrance aperture diameter is larger than the instrument detector diameter to prevent light reflected from the scan drum being captured on the inside of the front cap and heating it. The beam should be centered in the aperture to ensure that it will be correctly measured.

Boundary line widths are extremely wide. This is because these boundaries are imprecise due to actual detector response and slit width variations. Damage to apertures is a function of many things including surface finish, tarnish, dirt and more. Thus the boundaries are only a guide. The life of the scan head will be increased if you expose the high power for the shortest time needed to get your measurement.

The crosshatched area indicates power levels that require limited exposure times. For example, at

156 Watts we suggest a four second exposure.

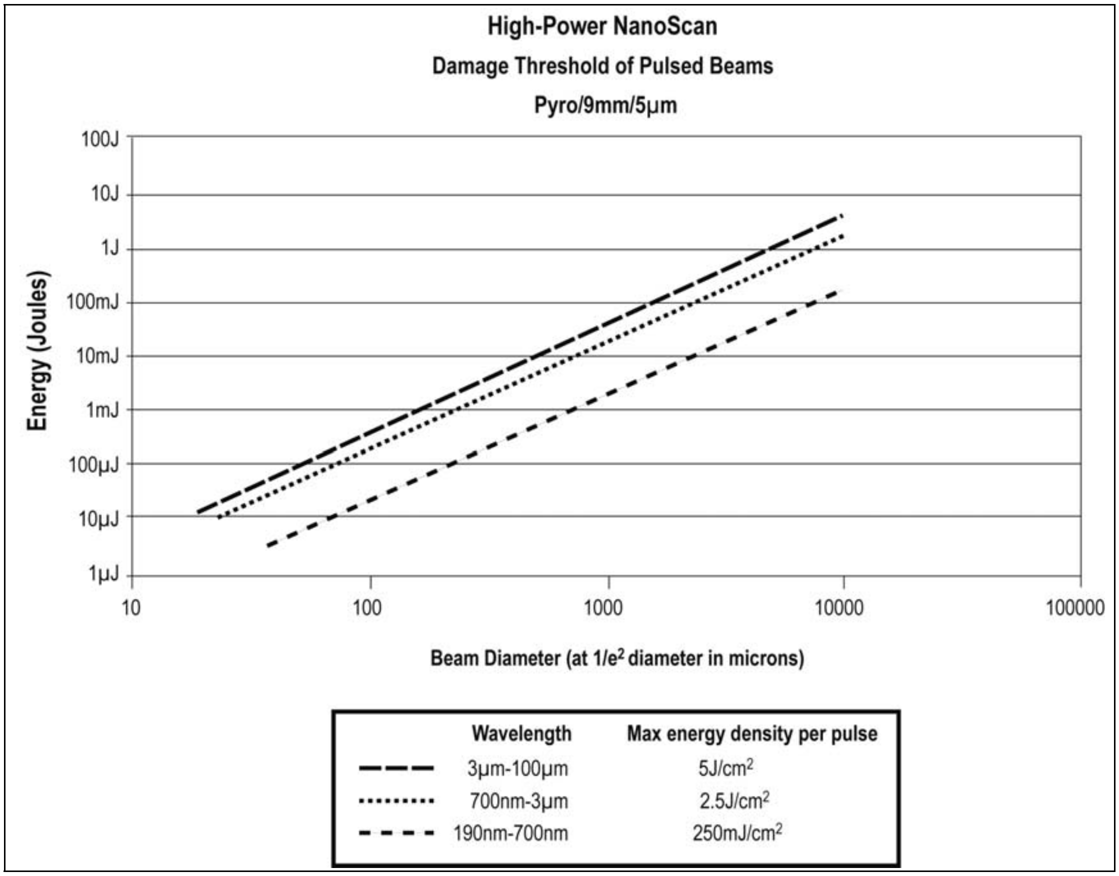
The suggested maximum exposure time for powers within the crosshatched area can be estimated from the equation below.

T(sec)= 600/ laser power in watts

Below the crosshatched area and within the operating space continuous operation should be possible without heating the scanhead unduly, provided that the fan is functioning and airflow is unimpeded.

A.5. Power Considerations for Q-Switched Pulsed Beams

The actual energy per pulse is an important additional consideration for pulsed beams. Energy is measured in joules, and as discussed above, individual pulses may damage the scanhead, even when the average power falls within the safe region of the operating space chart. For this reason it is necessary to understand the limits in Joules for lasers that use pulsing to increase the delivered energy, most commonly the Q-Switched laser.



This chart shows the damage thresholds for pulsed beam energies for the three wavelength regimes. The lines represent the maximum energies per pulse for various spot sizes that correspond to 5J/cm^2 for the 3 to 100 micron wavelengths, 2.5J/cm^2 for the 700nm to 3 micron range, and 250mJ/cm^2 for the UV-Visible range from 190nm to 700nm. When operating with pulsed lasers, calculate the energy per pulse to ensure that the values fall below these lines for the wavelength of the laser. Operation above these values will likely cause damage to the scanhead apertures.

A.6. Setup Considerations for Measuring High Power Lasers

A.6.1. Limiting High Power Exposure Time

High power lasers are designed to work materials—they cut, weld, drill, and more. Since NanoScan is based on reflective, heat-resistant metals that can be damaged by sufficiently high power density and or long exposure times. It is advised that you keep exposures to the minimum required and within the limits discussed earlier with the Operating Space Charts to maximize the life of your NanoScan profiler. Heat takes time to dissipate. Measuring your high power beams too frequently, without allowing sufficient cool-down time may cause the detector to get too hot. This can cause the DC offset to drift beyond the correction range of the NanoScan hardware. When this occurs you may get an “Error –22” message from the NanoScan software, indicating that it could not correct the offset. Allow time for the scanhead to cool down between measurements.

A.6.2. Control Reflections from Drum and Apertures

The High Power NanoScan’s drum and slits are constructed from highly reflective material making it possible to handle very high power beams. Nonetheless, measuring high-power beams can be tricky. The lasers have the potential to damage the scanhead, and any reflected light can be dangerous to both the operator and the surroundings. Because of the high reflectivity it is important to manage the reflected beam so that it neither reenters the laser cavity nor sends stray beams into the surrounding area.

Measuring high power beams can be dangerous. Most of the beams that comprise the array of industrial applications are invisible to the eye. Thus we only see the stray beams from the damage they do, and that can be too late. It is important that any reflected beams be directed into a safe beam dump.

When setting up the NanoScan for high power measurements it may be necessary to tilt the scanhead slightly to direct any reflections into the controlled beam dump. A tilt of a few degrees will increase the measured size of the beam by the cosine or the angle of incidence. For example, a 15-degree tilt will cause a 4% spot size error. Usually a tilt of one or two degrees is sufficient and will only cause a 0.2% error.

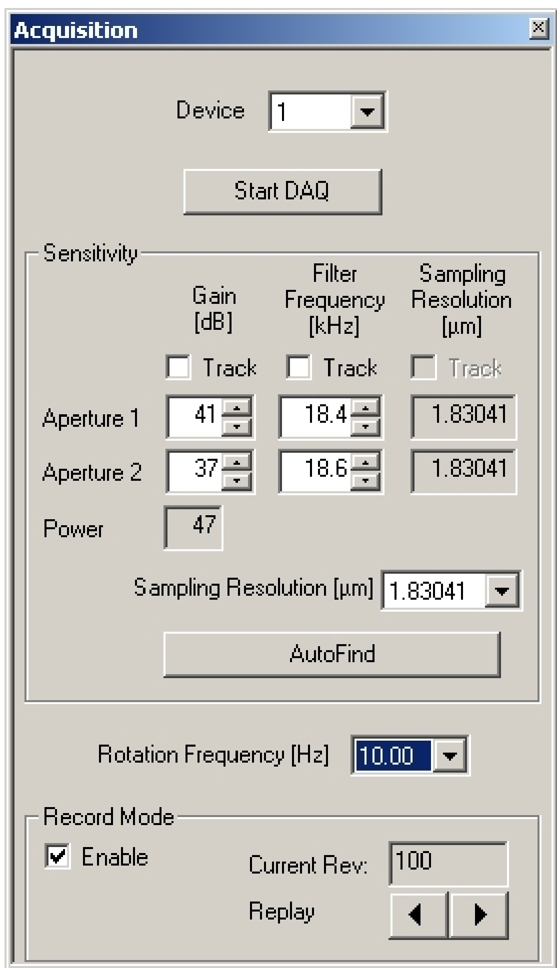
Sometimes the laser will have a delivery nozzle that makes it difficult to reflect the beam away from the system. If possible, remove the nozzle to provide more clearance to reflect he beam in to a safe dump.

Remember, when designing a reflected beam control system, it must not impede the airflow to or from the cooling fan, or create and “oven” to trap heat.

A.7. Record Mode Software Use

In order to make measurements of beams with powers falling in the “crosshatched” section of the operating space chart, the NanoScan software allows you to record up to 100 sequential profile sets (100 drum revolutions). The maximum number of scans depends on the sampling resolution (the finest sampling resolution is 0.00572 µm at 1.25Hz). The software will compute the memory needed to record one full scan and then, based on the total memory of the computer, it will set the maximum number of scans that can be recorded (not greater than 100).

When **Record Mode** is enabled, data acquisition stops automatically after the 100th revolution. The actual time that data are collected depends on the head rotation frequency; e.g., at 10Hz, 10 seconds of data will be acquired; at 2.5Hz, 40 seconds are acquired. The laser should be shuttered on for the data collection time, and then shuttered off or diverted to a beam dump to allow the scanhead to cool This should be long enough to gather data about your spot. After you review the collected data another timed exposure maybe collected to observe the results of any adjustments.



The **Record Mode** with **AutoTrack** enabled will take three or four revolutions to set the proper gain values. Thereafter, good data will be collected. Changing the head rotation frequency, changing the sampling resolution or performing an AutoFind will clear the data recording buffers. Gain and filter frequency settings for both apertures are stored for each recorded revolution. The data can be reviewed and analyzed frame-by-frame and statistics gathered for selected frames. The recorded revolutions data can be saved only as an *.nsd* file.