High-End Laser Measurement as a Path to Lower Price per Weld

EPIC 2024

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mks

MKS helps the most innovative companies in the world

SOLVE COMPLEX PROBLEMS

MARKET LEADER

MKS is a leading global provider of process control solutions for

- Semiconductor
- Electronics & Packaging
- Specialty Industrial

STRATEGIC GROWTH

- Q3 2022 – acquired Atotech
  - Leader in specialty chemicals, equipment, software and services for PCBs, semi IC packaging and surface finishing
- Q1 2019 – acquired Electro Scientific Industries (ESI)
  - Leader in laser-based manufacturing for the micro-machining industry
- Q2 2016 – acquired Newport Corporation
  - Leader in sophisticated laser, light and motion products

INNOVATIVE SOLUTIONS

- Vacuum Processing
  - Pressure measurement & control, flow, power, reactive gas analysis, automation
- Laser Solutions
  - Precision laser applications
  - Laser-based process equipment
- Motion, Photonics & Optics
  - Vibration & performance motion control, gratings & optics, laser measurement
- Materials Solutions
  - Process and manufacturing technologies for advanced surface modification, electroless and electrolytic plating and surface finishing

KEY FACTS

- Founded: 1961
- HQ: Andover MA
- IPO: 1999 (NASDAQ MKSI)
- Selling in ~100 countries
- In 2022
  - Revenue: $3.5B
  - Employees: ~11,000
  - Engineers & Scientists: 1,500+
  - R&D Investment: ~$241M
  - Worldwide Patents: 4,000+(1)

(1) Patents consist of issued patents for MKS and Atotech as of December 31, 2022.

MKS – OPHIR® Brand

OPHIR ® Optics

Core Technologies

Laser Optics
- Lenses, Mirrors & Optics

Infrared Optics
- Radiometric, Athermalized & DFOV Lenses
- Zoom & Customized Lenses

OPHIR ® Photonics

Core Technologies

Power and Energy Measurement
- From pW to 120 kW

Beam Profiling
- Scanning Slit, Camera based and Non-Contact
- From µm to m wavelength

Turnkey Solutions

Helios, IPM Series
- Power and Energy Measurement

BeamWatch Integrated
- Beam Profile, Focal Shift & Power up to 30 kW

BeamWatch AM, BeamPeek
- Beam Profile, Focal Shift & Power up to 1 kW

Why Measure the Laser Beam?

- Laser quality has greatly increased over the years!
  - Decreased cost of ownership
  - Increased wall-plug efficiency
  - Decreased maintenance

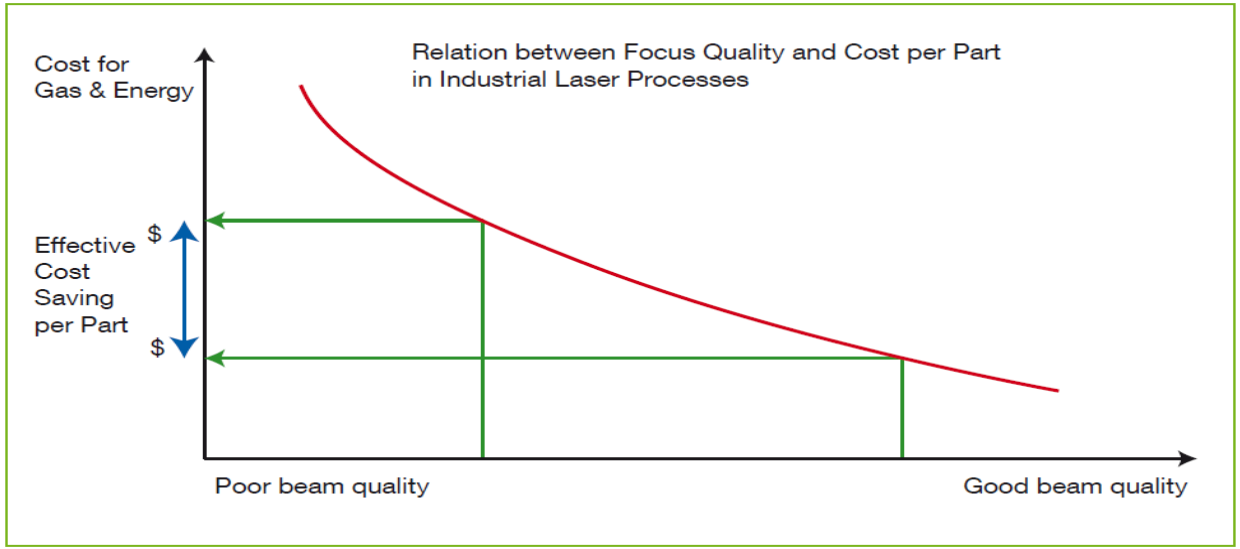
- But lasers are still made of physical matter:
  - Every laser is only as good as it's beam delivery system
  - Components degrade over time
  - Components get contaminated/dirty

- As a result, performance drifts:
  - Power decreases
  - Spot size changes
  - Focused spot location drifts

- **Time is spent. Scrap is Produced. Money is lost.**

Laser Monitoring Benefits

- Quality
  - Reduced risk of bad parts
  - Increase reproducibility
  - Increase traceability
  - Improve documentation
- Efficiency – Reduce the piece price
  - Machine (avoid unplanned stops, shorten maintenance time)
  - Process (produce more in less time)
  - Resources (less consumables - energy, gas, material)
  - Tests (Reduce the need for systematical testing of parts)



What to Monitor?

Key Laser Performance Indicators

- Laser Power
- Beam Focus Diameter
- Focus Location (X, Y, Z)
- Beam Quality (M^2, BPP)
- Dynamic effects (Focus Shift)

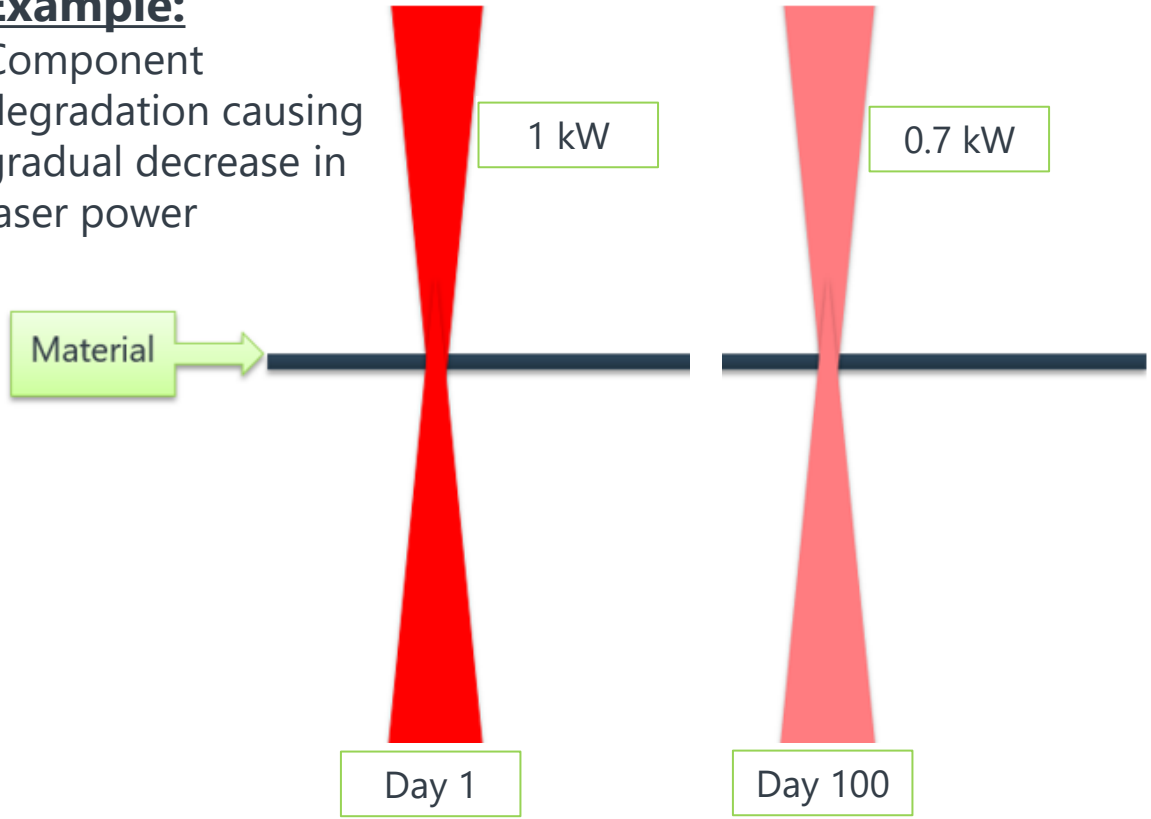
Power Density at the Work Piece

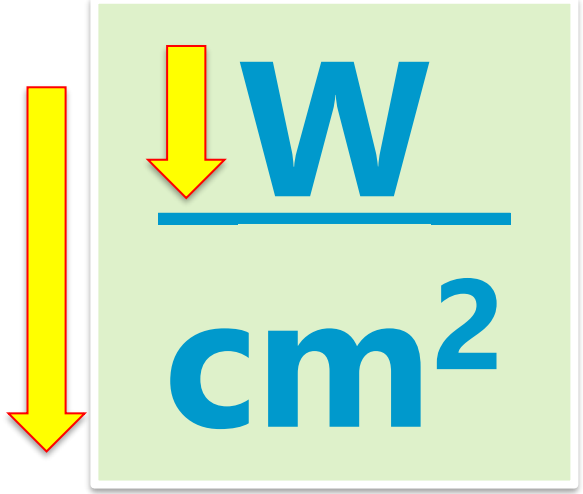
$$\frac{W}{cm^2}$$

If there was **ONE SINGLE** laser parameter that was important to measure to ensure consistent, effective laser processing, what would it be?

Component Effects on Power Density

Example:
Component degradation causing gradual decrease in laser power

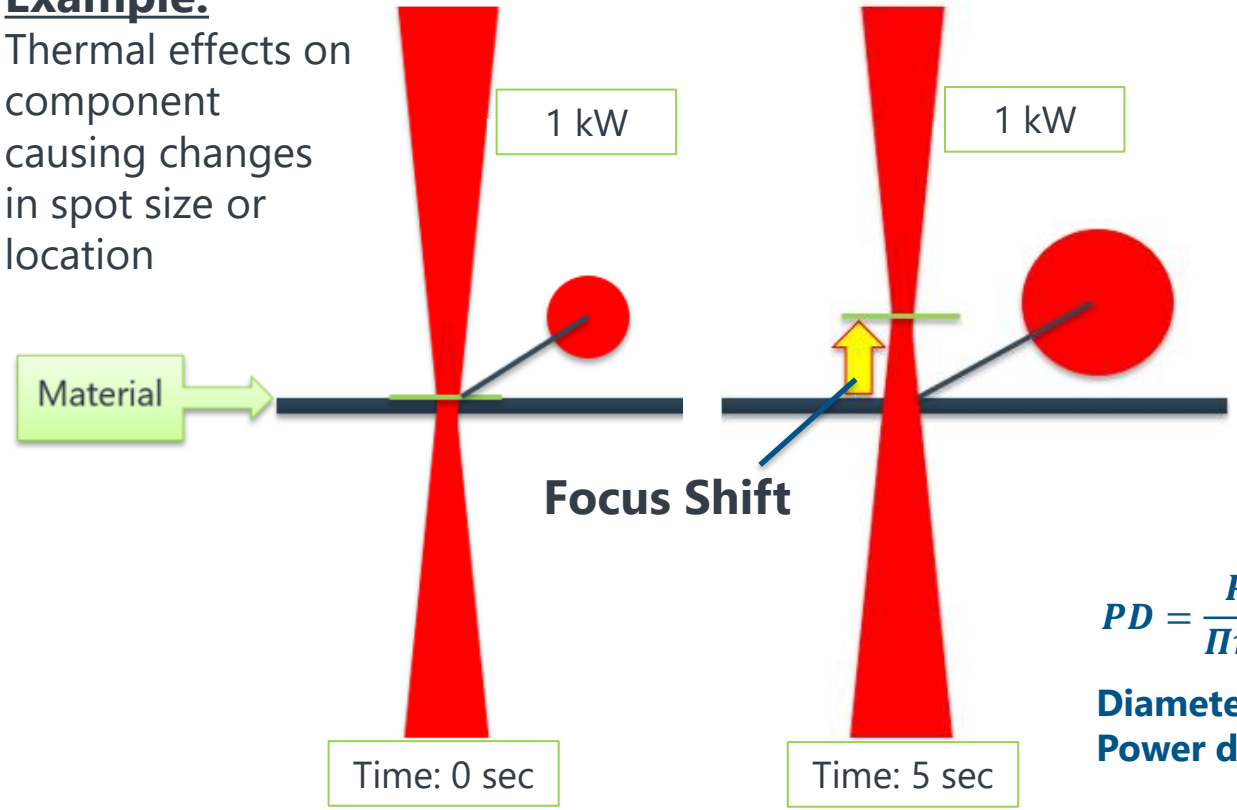




Laser Power Measurement Solutions

Thermal Effects on Power Density

Example:
Thermal effects on component causing changes in spot size or location



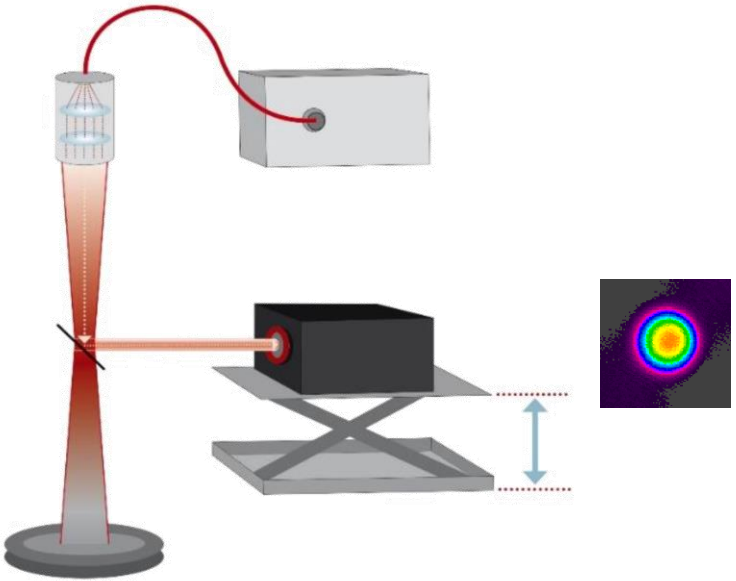
$$PD = \frac{P}{\Pi r^2}$$

$$\frac{W}{cm^2}$$

Diameter increased by two times
Power density reduced by four times

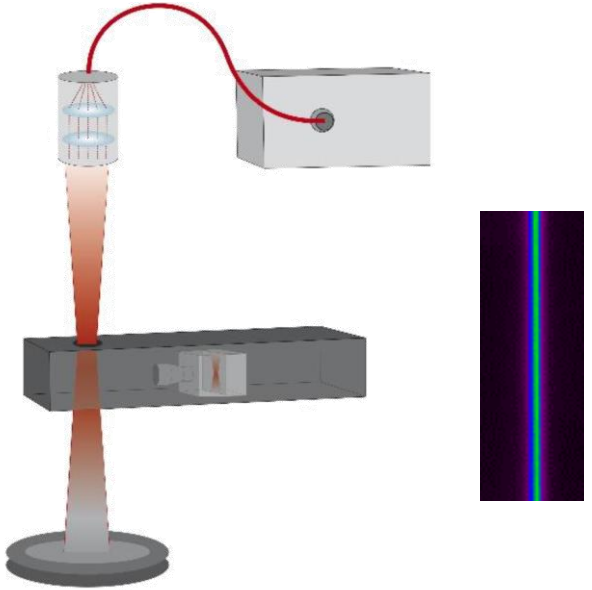
Principles of Beam Profiling

- **Splitter+Camera, Pinhole, Scanning Slit**



- Movement along the Z-axis - dynamic effects hardly detectable
- Risk of damage

- **Non-Contact: BeamWatch**



- Captures the whole beam caustic in real time
- Non-contact = no risk for the measuring device

Laser Beam Profiling Solutions

CAMERA-BASED

NON-CONTACT

FSA
Splitter+Camera

BeamPeek
All in One
Passively cooled

BeamWatch AM
All in One
Passively cooled

BeamWatch
No upper power limit

BeamWatch Integrated
All in One
Profinet
Water cooled

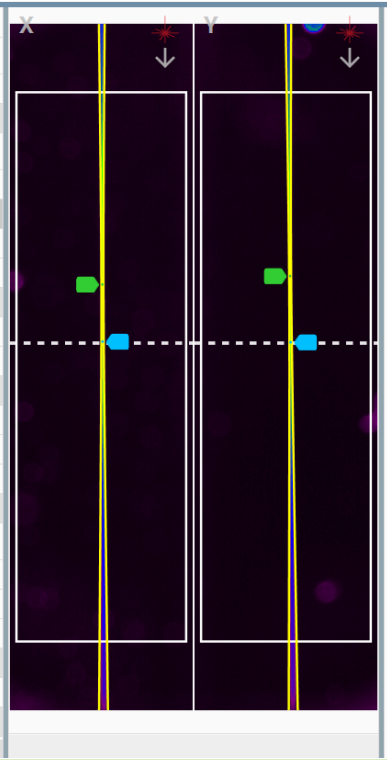
INTEGRATED POWER MEASUREMENT

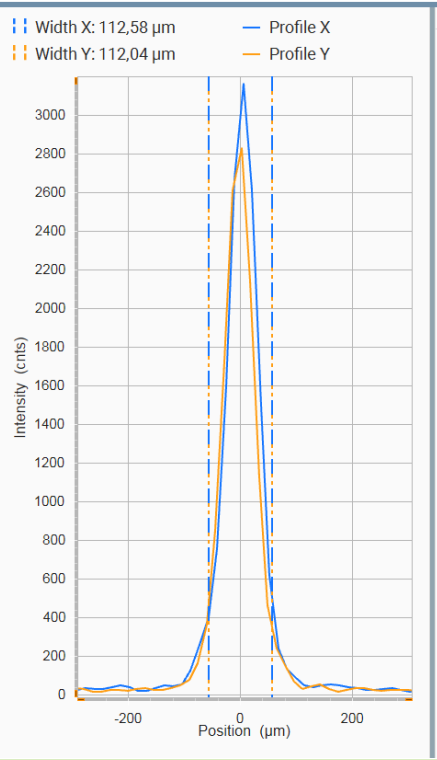
INDUSTRIAL

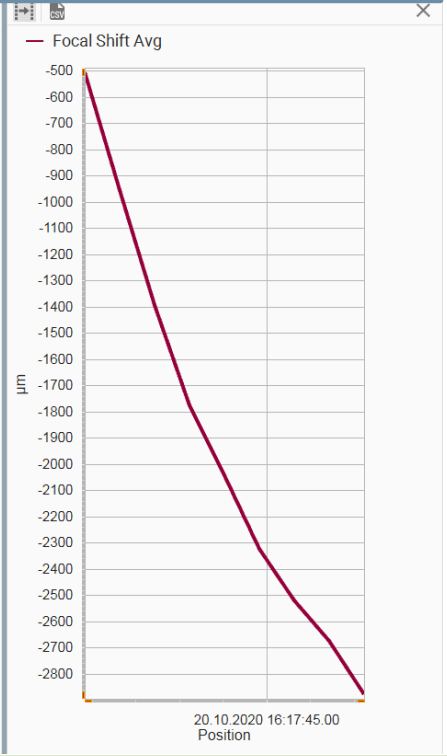
Case Study: Production Monitoring of Battery Welding

BeamWatch Integrated Non-Contact Beam Profiling at 2 kW for 7 seconds
Relatively clean protective window

Name	Value	Units
Power/Energy		
Absolute Power	1.976,000	W
Cursor Power Density	19,863	MW/cm²
Spatial		
Waist Width X ISO	98,237	µm
Waist Width Y ISO	92,739	µm
Waist Width Avg ISO	95,488	µm
Waist Location X ISO	508,360	mm
Waist Location Y ISO	507,964	mm
Waist Location Avg ISO	508,162	mm
Focal Shift X	-2.662,895	µm
Focal Shift Y	-3.090,787	µm
Focal Shift Avg	-2.876,841	µm
Cursor Width Avg	112,547	µm
Ellipticity ISO	0,995	
Rayleigh Length Avg ISO	4,712	mm
Beam Quality		
M² X ISO	1,463	
M² Y ISO	1,378	
M² Average ISO	1,420	
Divergence X ISO	20,292	mrad
Divergence Y ISO	20,240	mrad
Divergence Average ISO	20,266	mrad







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Relatively clean protective window

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Spatial		
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Waist Width Y ISO	92,739	µm
Waist Width Avg ISO	95,488	µm
Waist Location X ISO	508,360	mm
Waist Location Y ISO	507,964	mm
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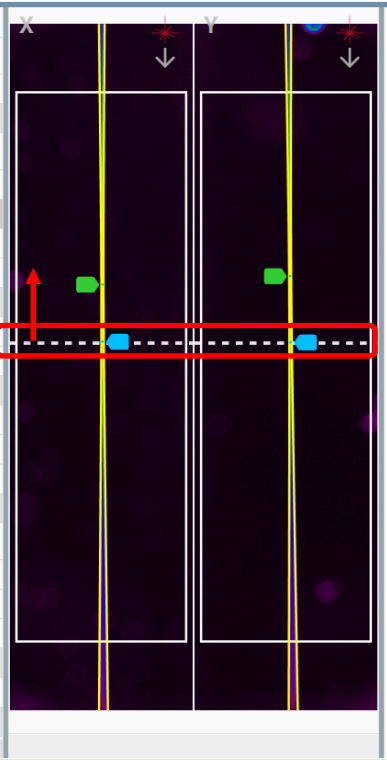

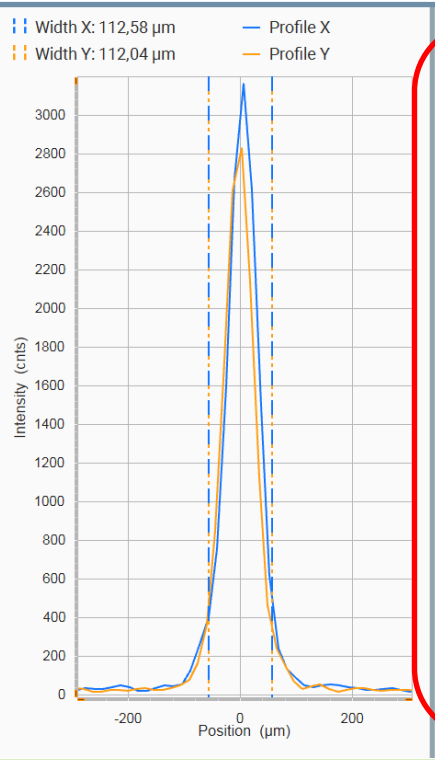

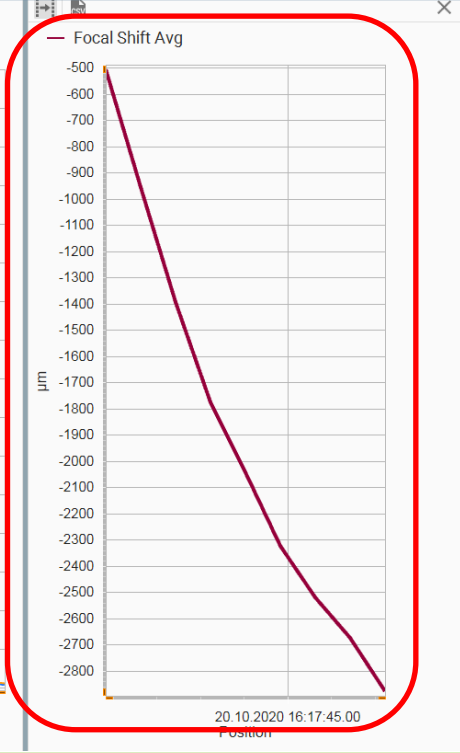

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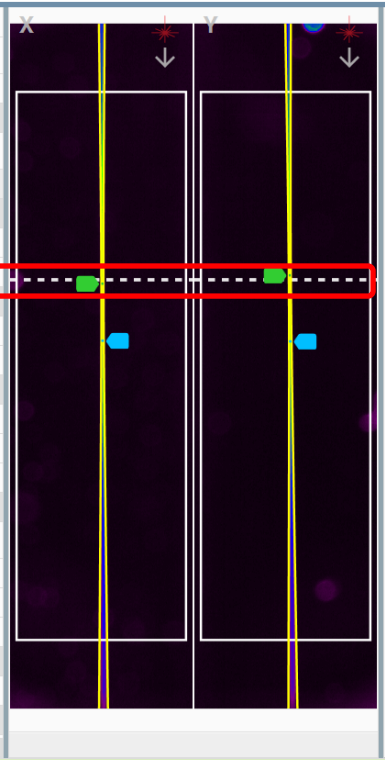
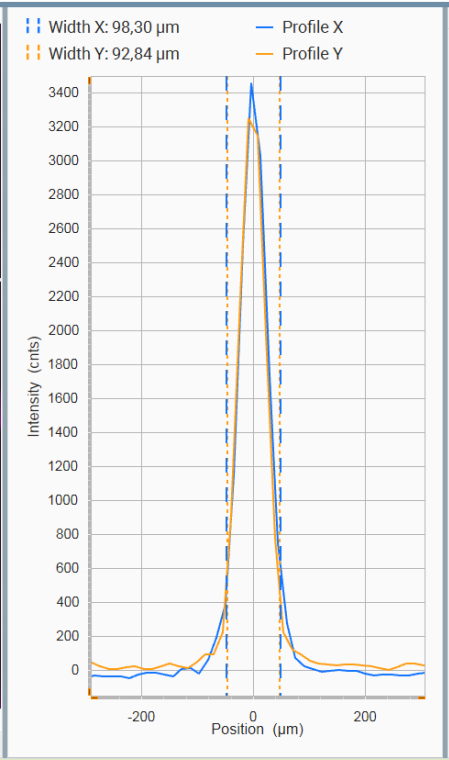
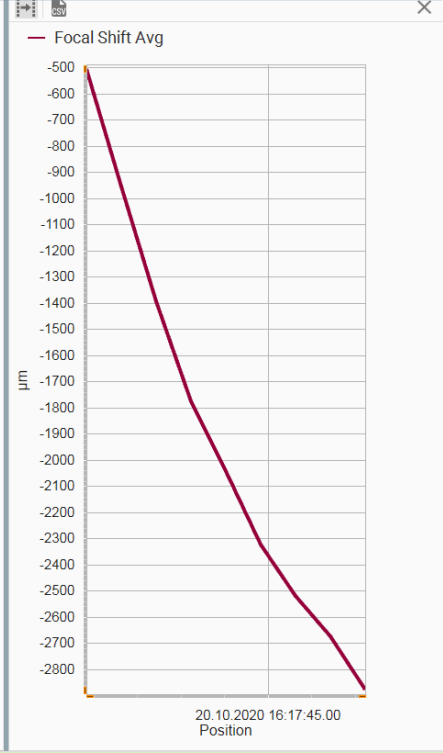
BeamWatch Integrated Non-Contact Beam Profiling at 2 kW for 7 seconds
Relatively clean protective window

Name	Value	Units
Power/Energy		
Absolute Power	1.976,000	W
Cursor Power Density	27,555	MW/cm²
Spatial		
Waist Width X ISO	98,237	µm
Waist Width Y ISO	92,739	µm
Waist Width Avg ISO	95,488	µm
Waist Location X ISO	508,360	mm
Waist Location Y ISO	507,964	mm
Waist Location Avg ISO	508,162	mm
Focal Shift X	-2.662,895	µm
Focal Shift Y	-3.090,787	µm
Focal Shift Avg	-2.876,841	µm
Cursor Width Avg	95,593	µm
Ellipticity ISO	0,944	
Rayleigh Length Avg ISO	4,712	mm
Beam Quality		
M² X ISO	1,463	
M² Y ISO	1,378	
M² Average ISO	1,420	
Divergence X ISO	20,292	mrad
Divergence Y ISO	20,240	mrad
Divergence Average ISO	20,266	mrad







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Spatial		
Waist Width X ISO	98,237	µm
Waist Width Y ISO	92,739	µm
Waist Width Avg ISO	95,488	µm
Waist Location X ISO	508,360	mm
Waist Location Y ISO	507,964	mm
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Beam Quality		
M² X ISO	1,463	
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M² Average ISO	1,420	
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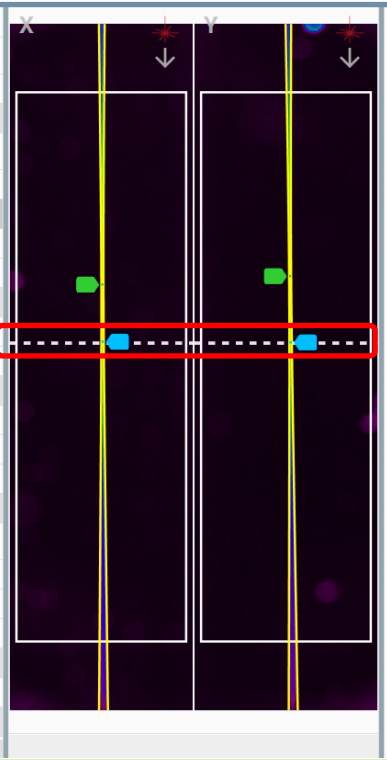
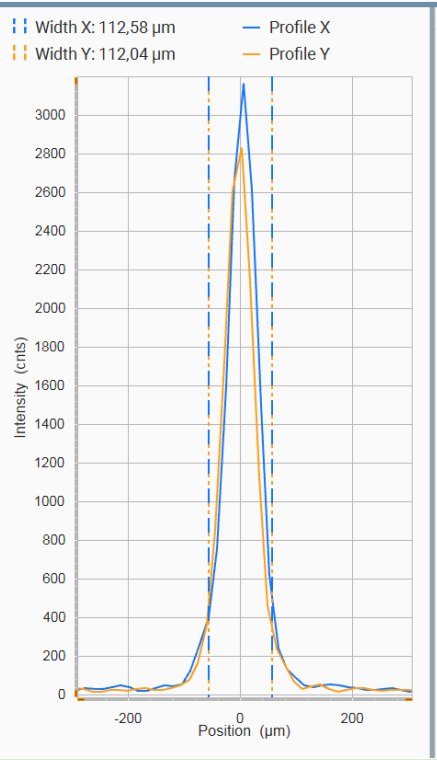
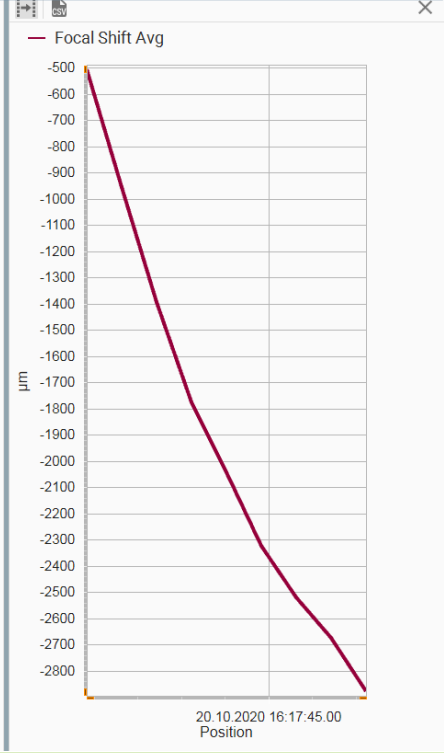


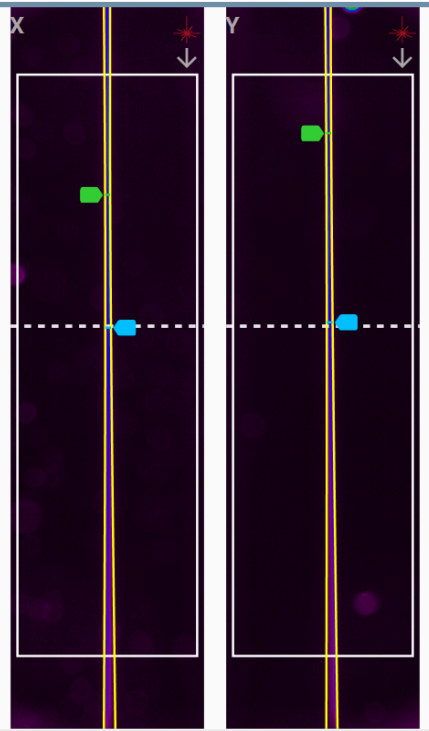


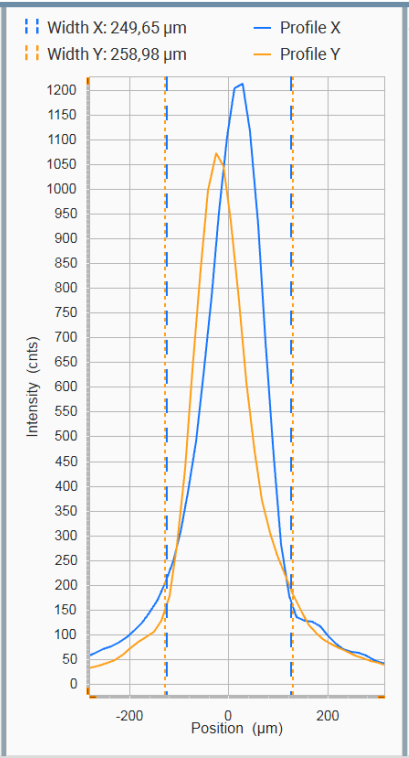


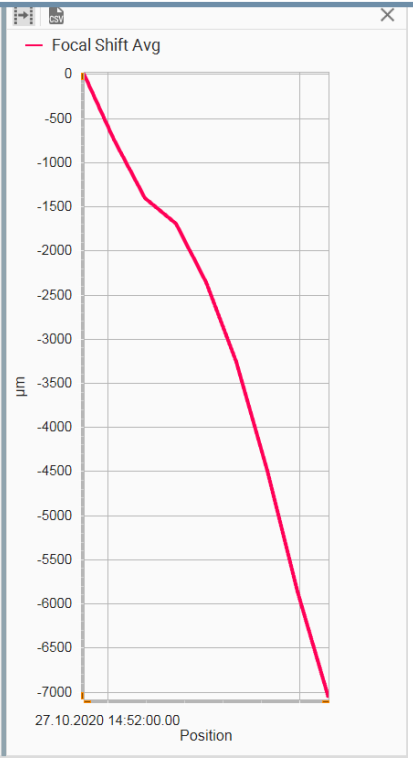
Case Study: Production Monitoring of Battery Welding

BeamWatch Integrated Non-Contact Beam Profiling at 2 kW for 7 seconds
Dirty protective window

Name	Value	Units
Power/Energy		
Absolute Power	1.970,000	W
Cursor Power Density	3,873	MW/cm²
Spatial		
Waist Width X	223,479	µm
Waist Width Y	216,223	µm
Waist Width Avg	219,851	µm
Waist Location X	504,708	mm
Waist Location Y	502,004	mm
Waist Location Avg	503,356	mm
Focal Shift X	-5.826,220	µm
Focal Shift Y	-8.299,276	µm
Focal Shift Avg	-7.062,748	µm
Cursor Width Avg	254,520	µm
Ellipticity	0,964	
Rayleigh Length Avg	12,190	mm
Beam Quality		
M² X	3,173	
M² Y	2,675	
M² Average	2,924	
Divergence X	19,345	mrad
Divergence Y	16,856	mrad
Divergence Average	18,100	mrad







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Focal Shift Y	-8.299,276	µm
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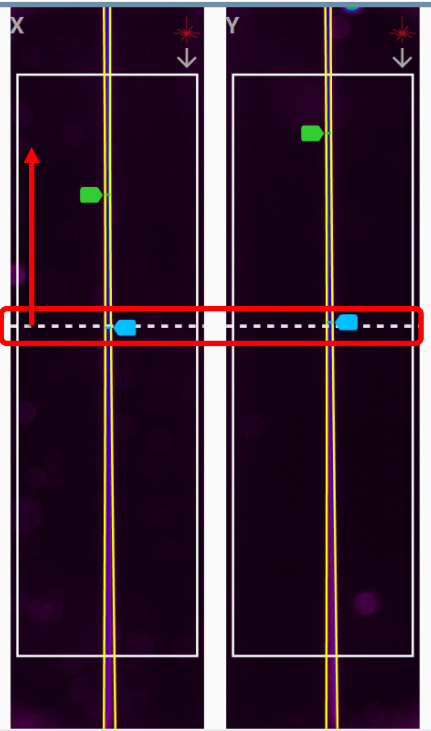
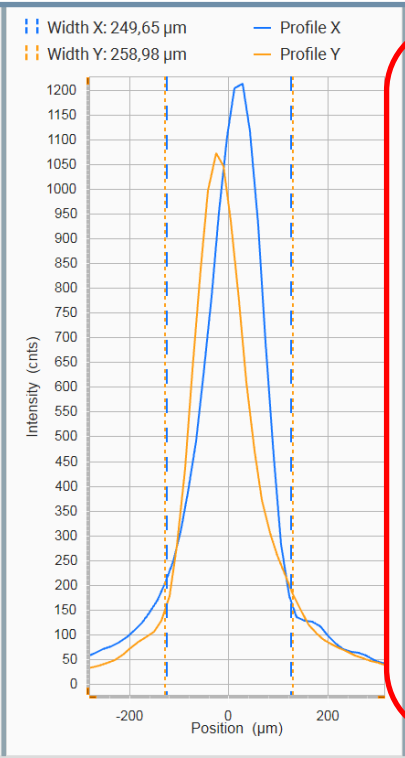
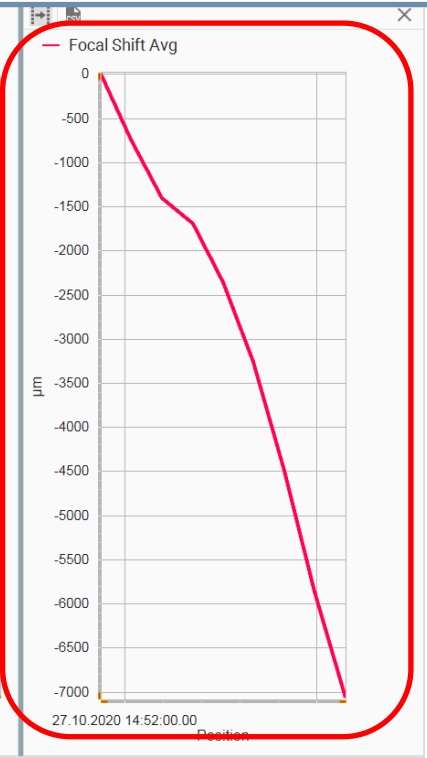
Cursor Width Avg	254,520	µm
Ellipticity	0,964	
Rayleigh Length Avg	12,190	mm
Beam Quality		
M² X	3,173	
M² Y	2,675	
M² Average	2,924	
Divergence X	19,345	mrad
Divergence Y	16,856	mrad
Divergence Average	18,100	mrad







Case Study: Production Monitoring of Battery Welding

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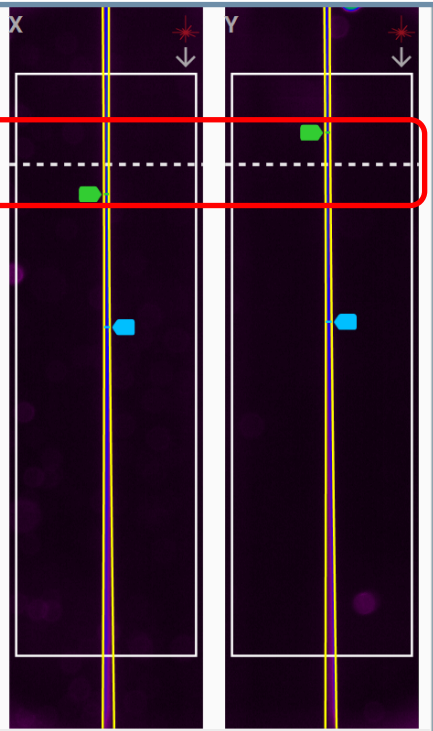
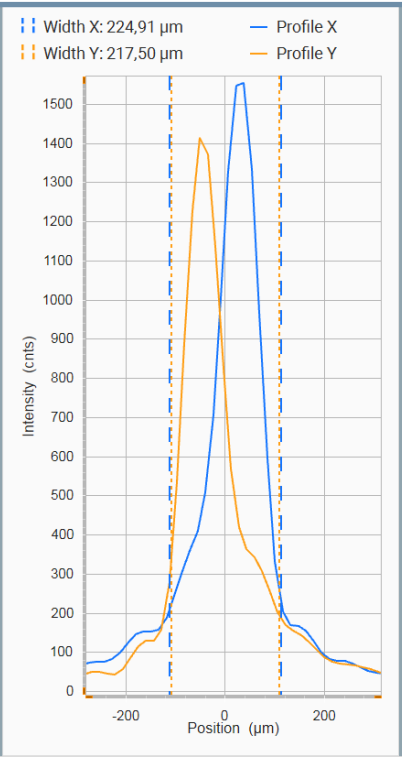
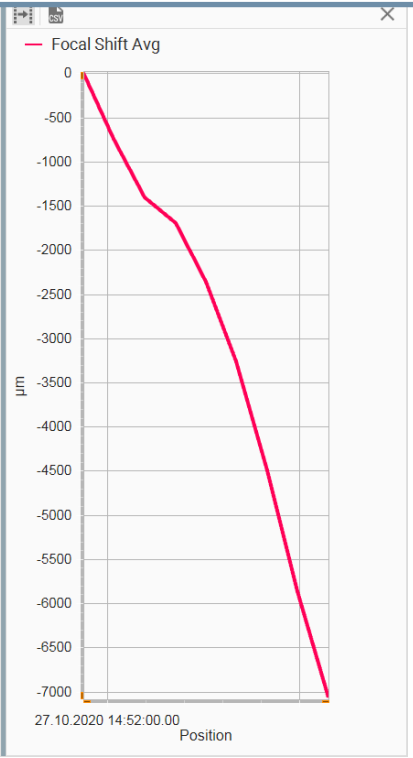
Dirty protective window

Name	Value	Units
Power/Energy		
Absolute Power	1.970,000	W
Cursor Power Density	5,129	MW/cm²
Spatial		
Waist Width X	223,479	µm
Waist Width Y	216,223	µm
Waist Width Avg	219,851	µm
Waist Location X	504,708	mm
Waist Location Y	502,004	mm
Waist Location Avg	503,356	mm
Focal Shift X	-5.826,220	µm
Focal Shift Y	-8.299,276	µm
Focal Shift Avg	-7.062,748	µm
Cursor Width Avg	221,170	µm
Ellipticity	0,967	
Rayleigh Length Avg	12,190	mm
Beam Quality		
M² X	3,173	
M² Y	2,675	
M² Average	2,924	
Divergence X	19,345	mrad
Divergence Y	16,856	mrad
Divergence Average	18,100	mrad







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M² X	3,173	
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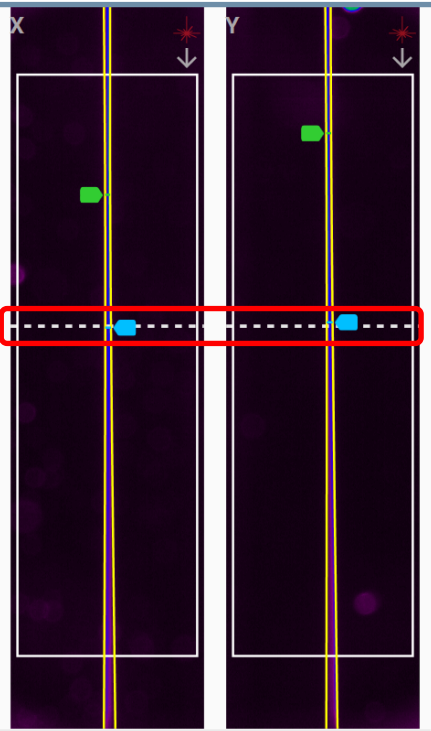
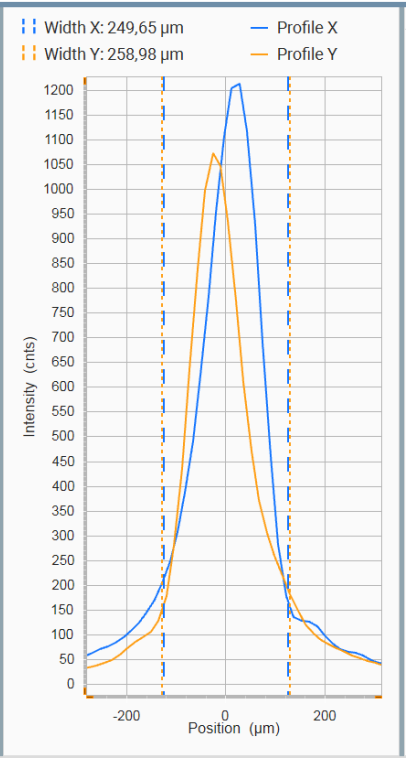
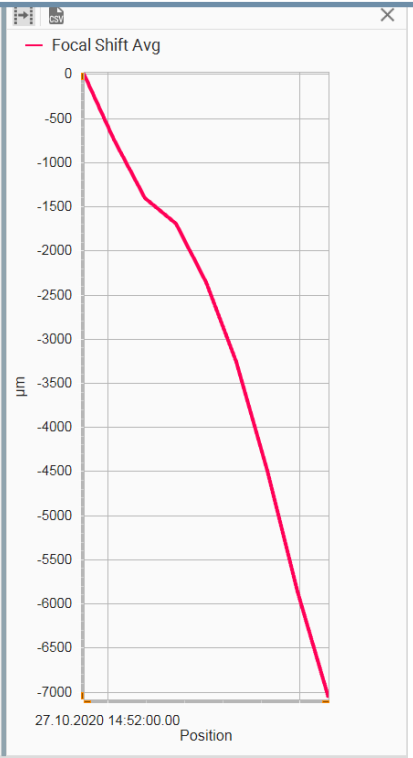


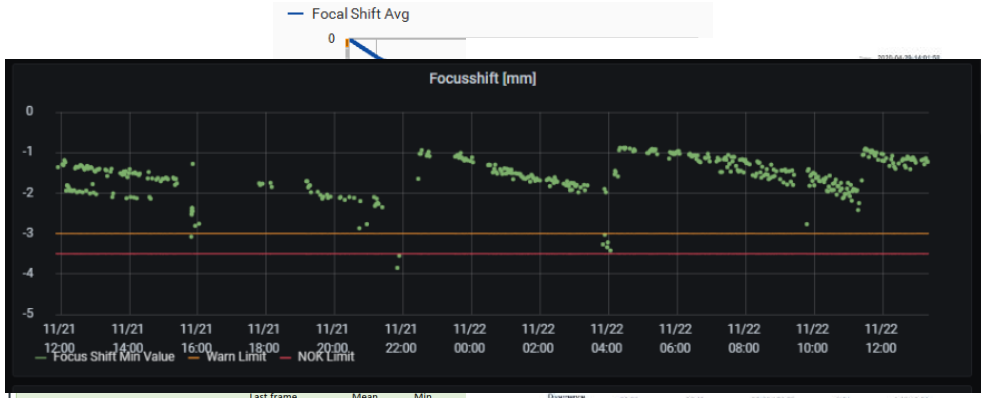




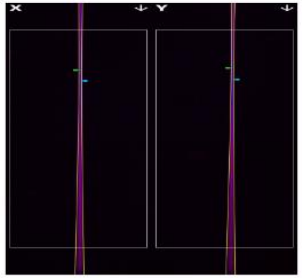
Case Study: Production Monitoring of Battery Welding

Results:

- A **dirty protective window** drastically **increases focus shift and beam diameter** at the work piece – Although the weld is visually ok, the **weld depth is insufficient**.
- **Measurement takes a few seconds only** BeamWatch Integrated measures the laser for each produced part during loading and unloading.
- Each time a **Good/Bad output** is generated, and a detailed report is archived.
- The **trending capability** is used to determine as when to clean or replace the protective window **before producing bad parts**.



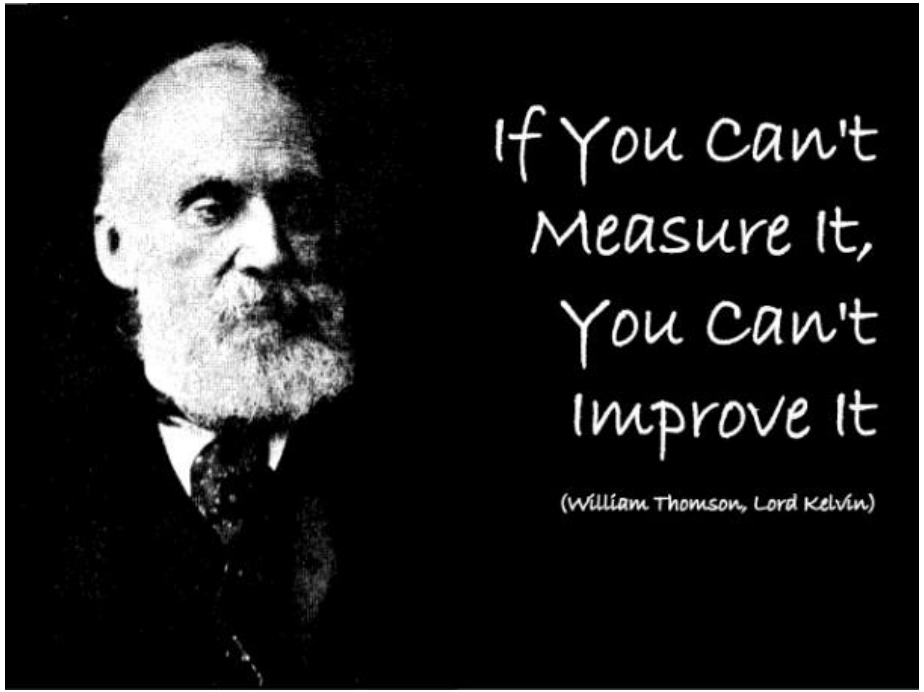
	Last frame	Mean	Min
Power[W]	1933.000		
Focus diameter[µm]	93.28	98.88	92.60
Focus diameter X[µm]		98.34	
Focus diameter Y[µm]		99.41	
Focus position[mm]	38.85	39.16	38.55
Focus position X[mm]		38.88	
Focus position Y[mm]		39.44	
Focus shift[mm]	-0.89	-0.89	-1.06
Focus shift X[mm]		-1.06	
Focus shift Y[mm]		-0.72	
Centroid[µm]	342.54	341.23	254.25
Centroid X[µm]		255.34	
Centroid Y[µm]		427.13	
Ellipticity	0.98	0.99	0.98
Rayleigh length[mm]	4.53	4.83	4.49
Divergence[mrad]	20.60	20.51	20.45
Divergence X[mrad]		20.55	
Divergence Y[mrad]		20.46	
M2	1.41	1.49	1.40
M2 X		1.48	
M2 Y		1.49	
BPP[mm mrad]	0.48	0.51	0.48
BPP X[mm mrad]		0.51	
BPP Y[mm mrad]		0.51	
K	0.71	0.68	0.67
K X		0.68	
K Y		0.67	



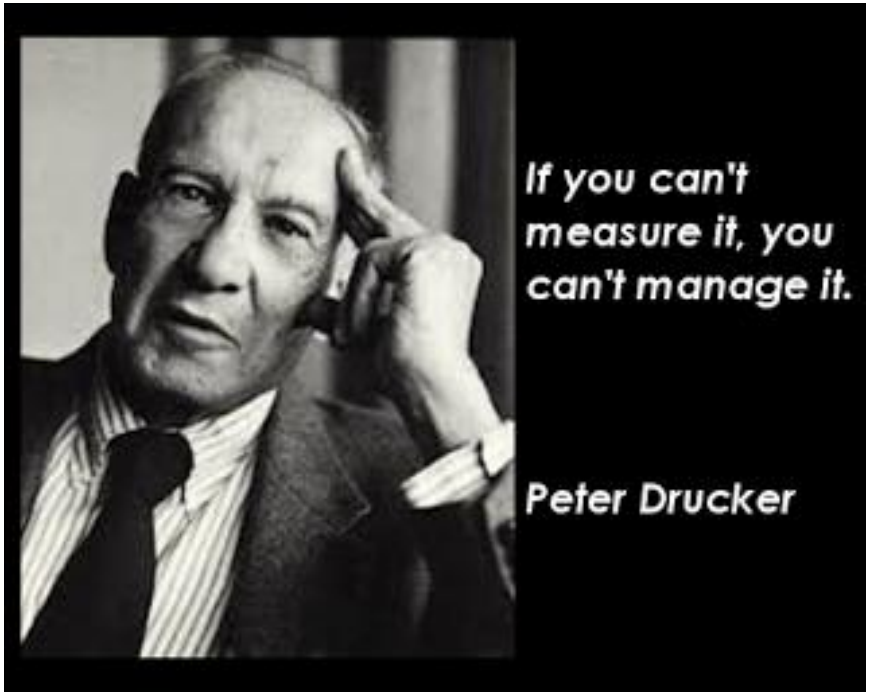
Summary

- Defining and maintaining **proper laser parameters** is paramount to any **performant laser process**.
- **Modern laser beam measurement solutions** make it possible to obtain **more data in less time**, including **fast changing parameters over time** or at varying power levels.
- **Regularly checking** the laser quality will **lower the price per weld**, **avoid performance drift** and **prevent the production of bad parts.**

Food For Thought



Speaking of physical science



Speaking of workplace efficiency

Thank You For Joining!
Any Questions?

... or feel free to contact me later:

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