Integrating lower-quality fibre lasers in an LPBF machine: spot size at the powder bed

1 kW fibre laser at 1070 nm, two-axis galvo head and F-theta lens, 250 × 250 mm build plate

Application

A laser powder bed fusion (LPBF) process is qualified with one laser. When a machine builder switches to a cheaper or different source, the beam quality is often worse, and the spot on the powder bed grows. This note answers a simple question: how much worse can the beam be before the process changes, and what does it take to fix it?

Modelling approach

We modelled the machine from the fibre collimator to the powder bed. Four lasers are compared, with a beam quality factor M^2 from 1.0 (a perfect beam) to 2.0. We count a laser as acceptable if its spot stays between 76 and 127 µm everywhere on the plate, whether the optics are cold or hot.

1 The machine



Figure 1. The machine as modelled in etendue. The expander enlarges the beam, two galvo mirrors steer it, and an F-theta lens from a published patent focuses it on the powder bed through a protective window. **Table 1.** Main parameters.

PARAMETER	VALUE	PARAMETER	VALUE
Laser power	1000 W	Expander magnification	1.5
Process power	200 W	Galvo mirror aperture	20 mm
Wavelength	1070 nm	F-theta focal length	423 mm
Collimated beam diameter	5 mm	Build plate	250 × 250 mm

2 Spot diameter against beam quality

as built: up to M^2 1.5

How far can M^2 rise before the spot leaves the accepted range? With the machine as it is, up to M^2 1.5. A larger beam expander brings the spot back to its reference size up to M^2 1.75. Beyond that, the galvo mirrors cut off too much of the wider beam.

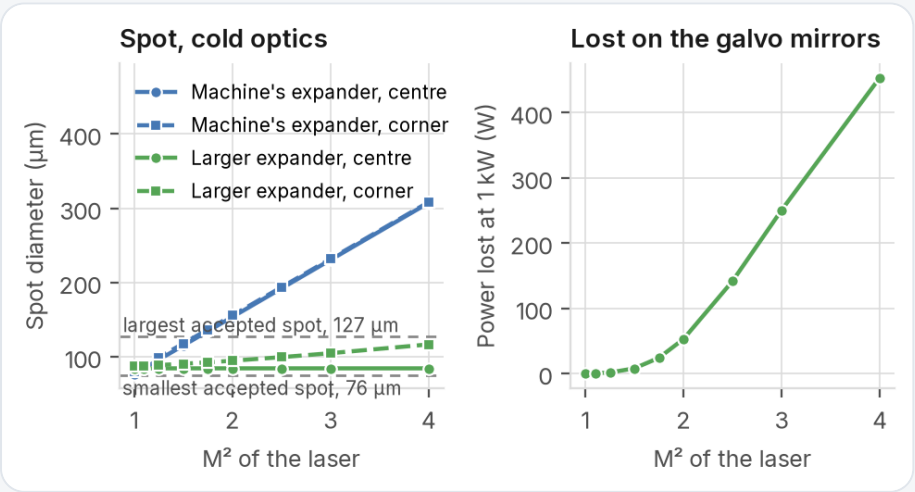


Figure 2. Left: spot diameter at the centre and at the corner of the plate, with the machine's expander and with an expander enlarged in proportion to M^2. The dashed lines mark the accepted range. Right: power lost on the galvo mirrors with the enlarged expander, at 1 kW.

85 µm

Spot diameter of the reference laser (M^2 1.1) at the centre of the plate.

M^2 1.5

The worst beam the machine accepts as it is. Its spot is 115 µm at the centre and 118 µm at the edge.

M^2 1.75

The worst beam the machine accepts with a larger beam expander, which still passes 95 % of the power at the corner.

53 W

Lost on the galvo mirrors at 1 kW when an M^2 2.0 laser is used with its larger expander.

Hot optics, dirty window, and what to change

Does the spot stay in range with hot optics and a dirty window? Up to M² 1.5 it does, at the cost of more window changes.

Table 2. Spot diameter on the powder bed for each laser, at the 200 W process power

Laser	Cold, centre (µm)	Cold, worst edge (µm)	Hot, clean window (µm)	Hot, dirty window (µm)	Peak irradiance, cold (MW/cm²)	Window absorption tolerated (ppm)
M² 1.0	77	81	85	101	8.2	—
M² 1.1 (reference)	85	88	92	107	6.8	2320
M² 1.5	115	118	121	132	3.8	548
M² 2.0	154	156	158	167	2.1	—

The accepted range is 76 to 127 µm. Hot: optics heated by the process beam, largest spot on the plate. The dirty window absorbs 1000 ppm (0.1 %) on its chamber side. The tolerated absorption is the one at which the spot leaves the range while a 20 × 20 mm part is built (a dash: not computed, or out of range cold).

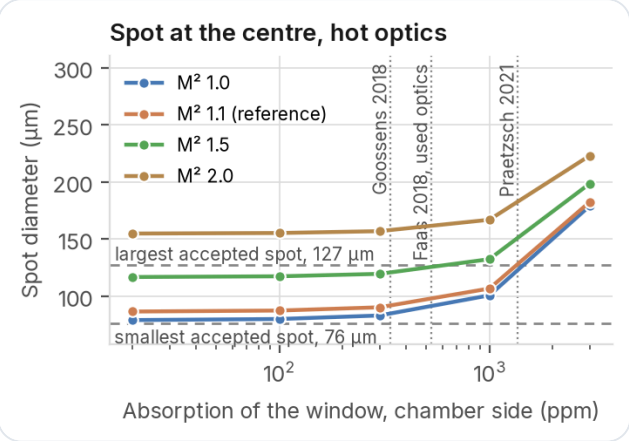


Figure 3. Spot diameter at the centre of the plate as the window absorbs more, optics heated by the 200 W beam. The dotted lines place the focal shifts published for used optics on this scale.

Table 3. Larger beam expander, cold optics

Laser	Magnification	Spot, centre (µm)	Spot, worst edge (µm)	Power lost at 1 kW (W)
M² 1.5	2.04	85	91	8
M² 2.0	2.73	85	96	53

Why the spot grows

The spot diameter grows in proportion to M². At M² 1.5 the peak irradiance at 200 W is 3.8 MW/cm², against 6.8 MW/cm² with the reference laser.

Heat in the optics moves the focus. At 1 kW with a clean window, the focus moves 3.45 mm towards the lens when the beam is held at the centre. When the beam is scanned over the plate, the shift drops to 1.23 mm.

A dirty window absorbs more and makes the shift larger. While a typical part is built, the reference laser keeps its spot in range up to 2320 ppm of window absorption. The M² 1.5 laser leaves the range at 548 ppm.

What to do

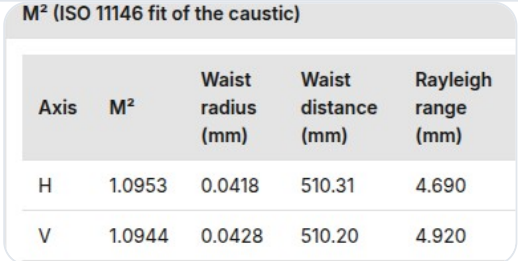
Up to M² 1.5, the laser goes into the machine as it is, but the protective window has to be replaced about 4 times as often.

From M² 1.5 to 1.75, a larger beam expander restores the reference spot (Table 3). Beyond that, the galvo head and the F-theta lens need a larger aperture.

Write the M² into the specification of any new laser. Power and scan speed do not show a change of spot size.



Thermal lens at 1 kW, centre of the plate, clean window. Look at the first tile: the focus moves 3.45 mm towards the lens. The waist radius grows from 42.3 to 43.4 µm.


M² (ISO 11146 fit of the caustic)

Axis	M²	Waist radius (mm)	Waist distance (mm)	Rayleigh range (mm)
H	1.0953	0.0418	510.31	4.690
V	1.0944	0.0428	510.20	4.920

Beam quality at the edge of the plate, cold optics. Look at the M² column. It reads 1.10 on both axes, as at the centre: the galvo mirrors and the lens do not degrade the beam.

Figure 4. Two results of the model in etendue, cropped to the values discussed in the text.

Spot diameter as in ISO 11146. The accepted range comes from a published melt-track model for 316L steel (arXiv:2409.14548).