Experimental Process Characterization for Laser Cladding

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Background and Objectives

- Laser cladding is an additive manufacturing and surface engineering process in which a focused laser beam melts metal powder to form a deposited layer. Its ability to provide localized material deposition makes accurate control of energy and powder delivery important for process efficiency.
- The laser cladding system used in this study is shown in Figure 1. The efficiency and stability of the process depend on several interacting parameters, including laser power stability, beam profile, powder feed rate and distribution characteristic. Variations in these parameters can affect how effectively laser energy and powder are delivered to the deposition zone.
- Accurate characterization of the laser beam source and powder distribution is therefore necessary to establish reliable operating conditions and provide a basis for efficient laser-cladding operation

OBJECTIVES: Establish a framework for powder and laser beam characterization process.

1. Characterize the laser beam and determine its focal position over the tested laser-power range.
2. Quantify laser power delivery by comparing nominal and measured output power.
3. Characterize powder-stream behavior, determine the powder-stream focus position and mass flow rate under different delivery conditions.

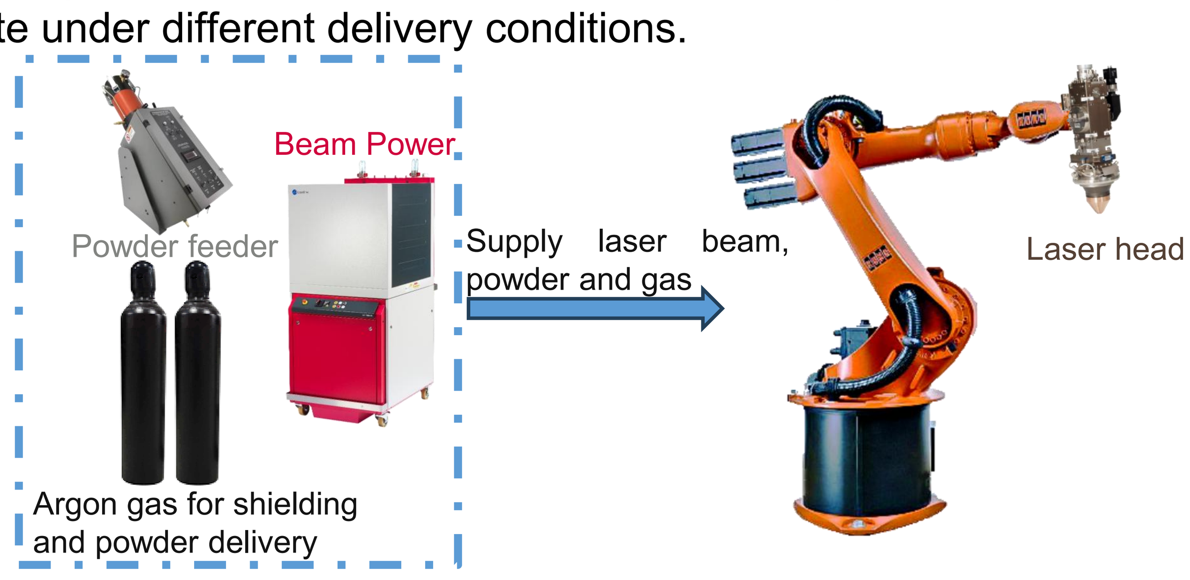


Figure 1: Laser cladding system setup in CCWJ

Methodology

1. Laser Beam Characterization by Beam Profiler

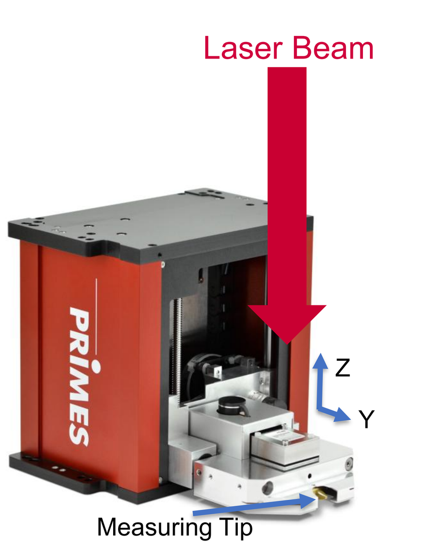


Figure 2: PRIMES FocusMonitor FM+ used for laser beam characterization.

- A PRIMES FocusMonitor FM+ was used to characterize the focused beam along the optical axis z.
- Initially a manual caustic measurement was first performed to approximately locate the focal region.
- Automatic caustic mode was then used to measure the beam at 21 axial planes, with 2 planes within the Rayleigh length on either side.
- The measuring tip rotating at 7500 rpm spatially samples the beam. A detector lies behind the pinhole that converts the optical signal to electrical signal.
- The Measurements were repeated for different laser power setting ranging from 1000 - 4000 W in steps of 500 W.
- A gaussian profile was fitted for the laser power density at each plane and MATLAB program was used to compile the results.

2. Laser Power Measurements

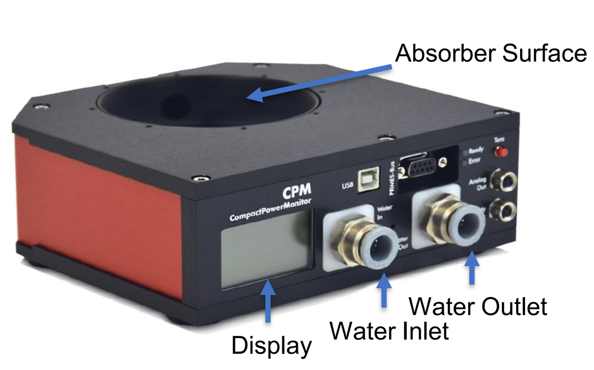


Figure 3: PRIMES Compact Power Monitor used for laser power measurement.

- PRIMES CompactPowerMonitor was used to measure the power of laser.
- The measurement position was selected from the beam-profile results to maximize usage of the monitor's 90 mm absorber and reduce the power density to avoid overheating of the laser absorber.
- The water flow rate was selected from the manufacturer's operating handbook depending on the input power ranging from 500 - 4500 W.
- The measurement is based on the principle of calorimetry where the inlet and outlet temperature of flowing water is measured and power is subsequently calculated, as shown in equation 1.

$$P = \dot{m}\, c_p\, (T_o - T_i) \quad (1)$$

3. Powder Cloud Profiling

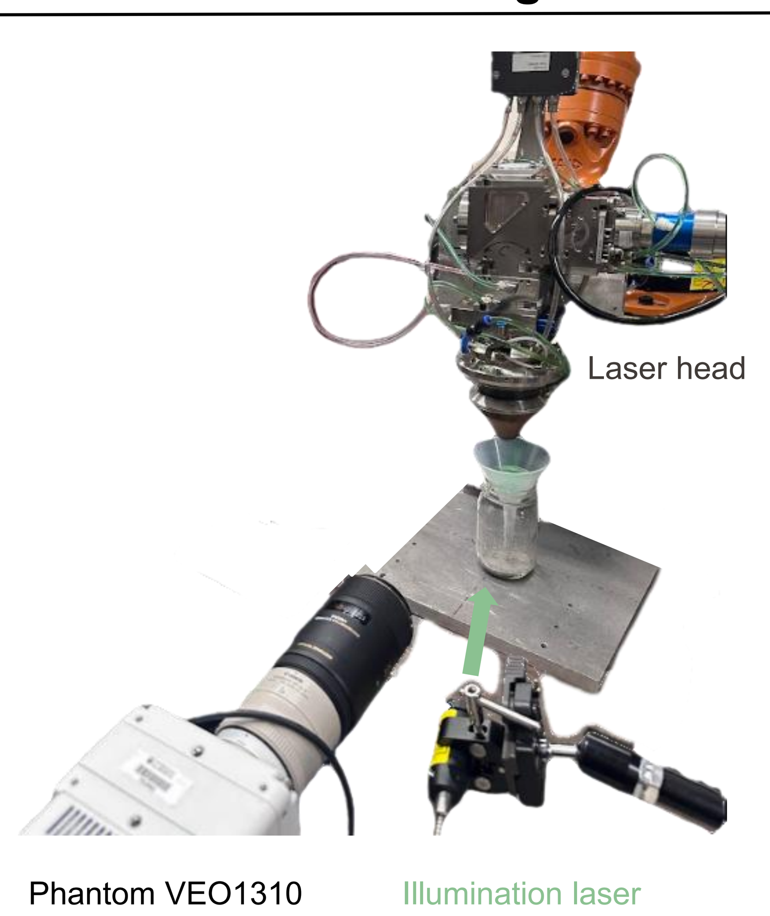


Figure 4: Phantom VEO1310 camera setup with illumination laser for high-speed videos.

- Inconel 625 powder was used for this experiment with argon as carrier gas.
- The powder stream was recorded using a Phantom VEO 1310 high-speed camera assisted by CAVITAR Cavilux HF pulsed diode laser.
- The operating conditions were a frame rate of 10000 fps and exposure time of 4 μs.
- The powder was collected in a flask sitting on a weighing scale.
- The videos were captured for a combination of different carrier gas flow rate and powder feeder rpm.
- Videos were analyzed using Phantom PCC software to determine the powder-stream focal position. Furthermore, the mass at different times was measured and noted during a video and rate of mass flow was calculated.

Conclusions

- A framework for characterizing the laser beam and powder cloud for the laser cladding system was established.
- Beam focal position shifted from 20.23–21.04 mm across 1000–4000 W, with spot diameter increasing slightly (913–973 μm).
- Measured laser power tracked nominal power closely below 2500 W (<0.5% deviation) but diverged at higher powers (up to 2.42% at 3500 W).
- Powder cloud density, velocity and mass flow rate depend on gas flow rate and powder feeder rpm, while powder focus position stays largely unaffected by either.

Results and Discussion

1. Laser Beam Characterization

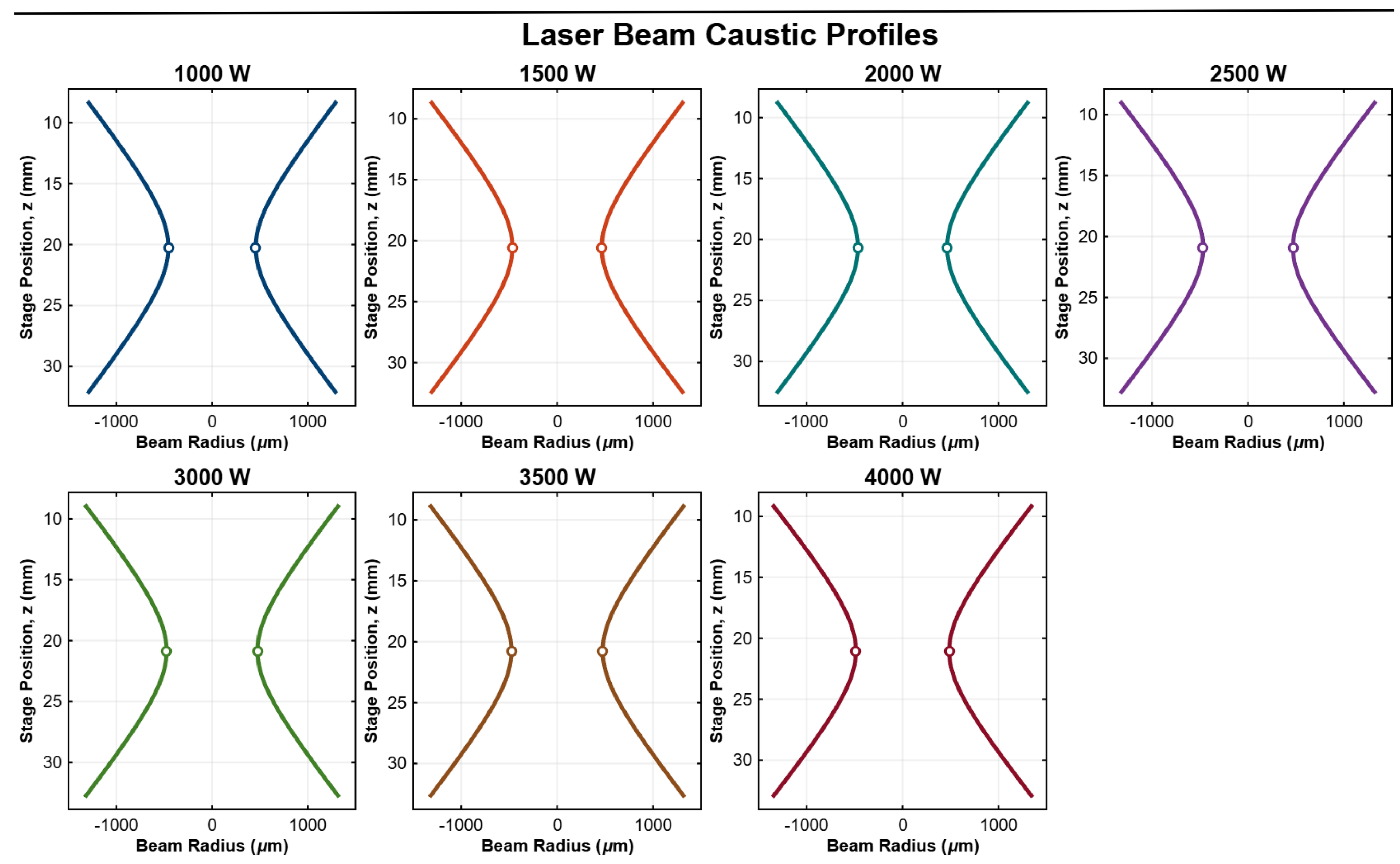


Figure 5: Gaussian-fitted beam caustics measured at laser powers from 1000–4000 W. The beam waist location and minimum beam radius were determined from the axial beam measurements.

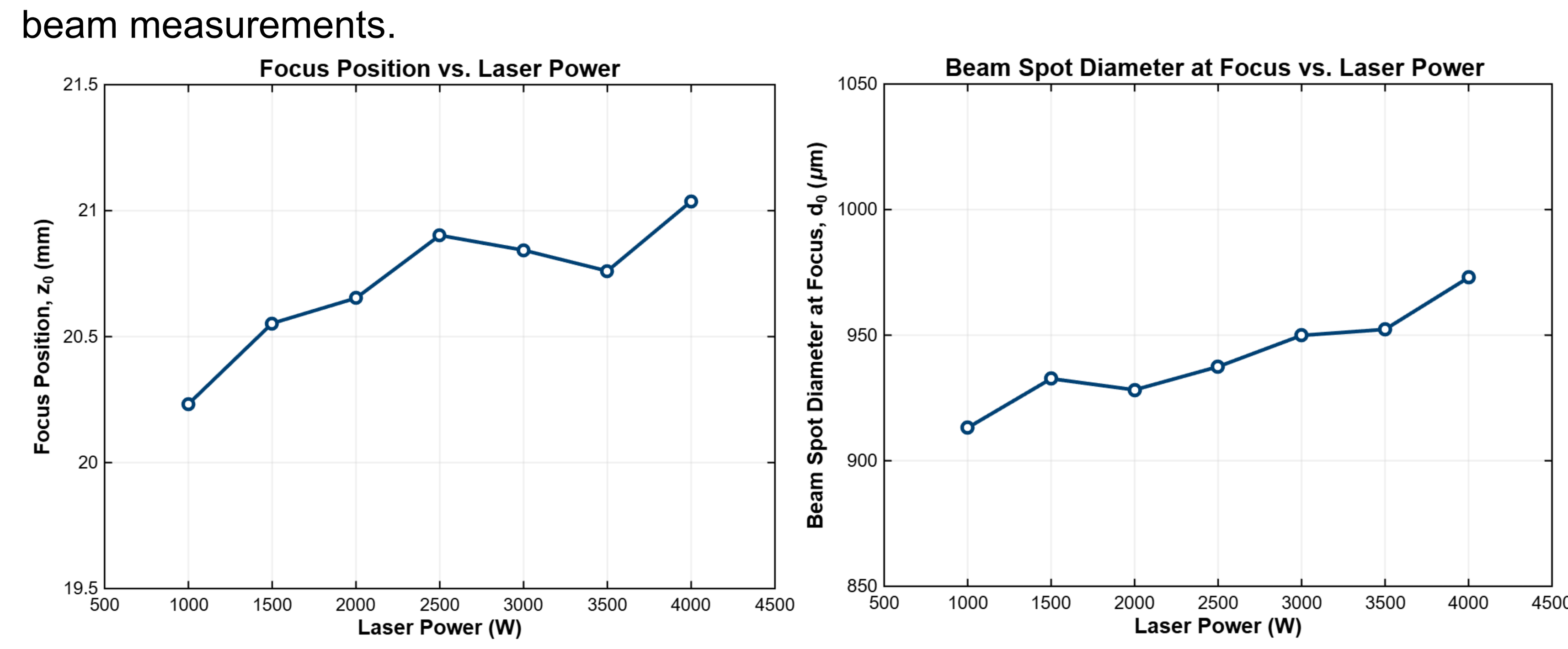


Figure 6: (a) Measured beam focus position as a function of effective laser power. (b) Beam spot diameter at the focal position as a function of effective laser power.

- Beam characterization showed that the focal position shifted from 20.23 to 21.04 mm within tested laser-power range.
- The focal spot diameter increased from approximately 913-973 μm as laser power increased from 1000 to 4000 W. These measurements establish the beam geometry and focal characteristics required for controlled laser-cladding operation.

2. Laser Power Characterization

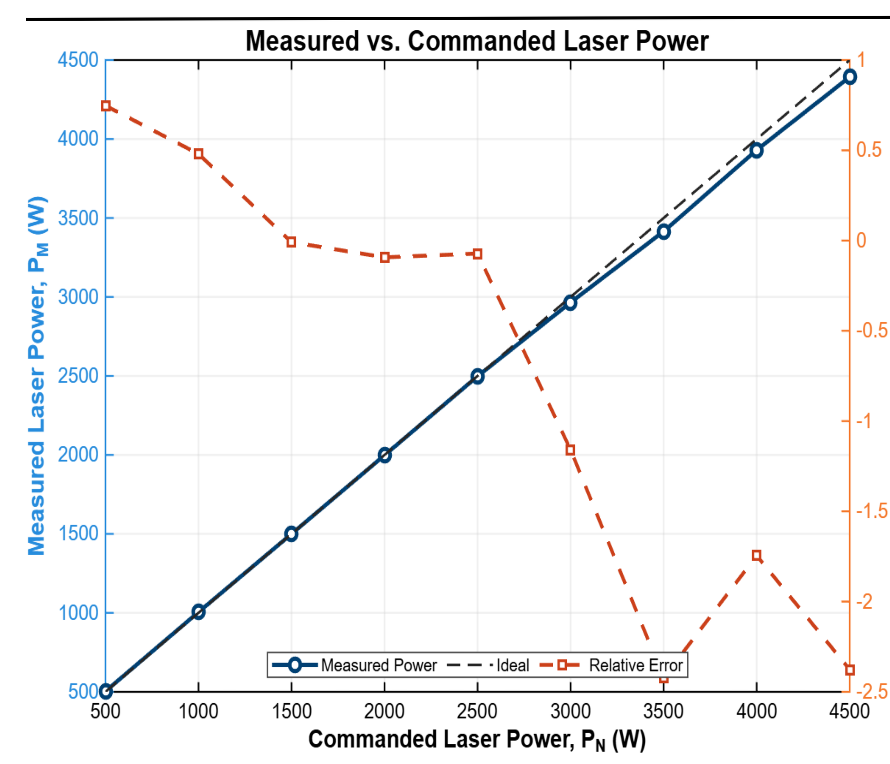


Figure 7: Measured laser power versus nominal laser power.

- Measured laser power closely followed the nominal power from 500-2500 W, with deviations below 0.5%. At higher power levels, the measured output increasingly fell below the nominal power.
- The maximum deviation of 2.42% occurred at 3500 W, where the measured power was 3415.2 W compared to the nominal 3500 W.
- The mean absolute deviation across 500-4500 W was approximately 1.0%.
- The measured output power should be therefore used to represent the actual laser power delivered during laser cladding process.

3. Powder Cloud Distribution

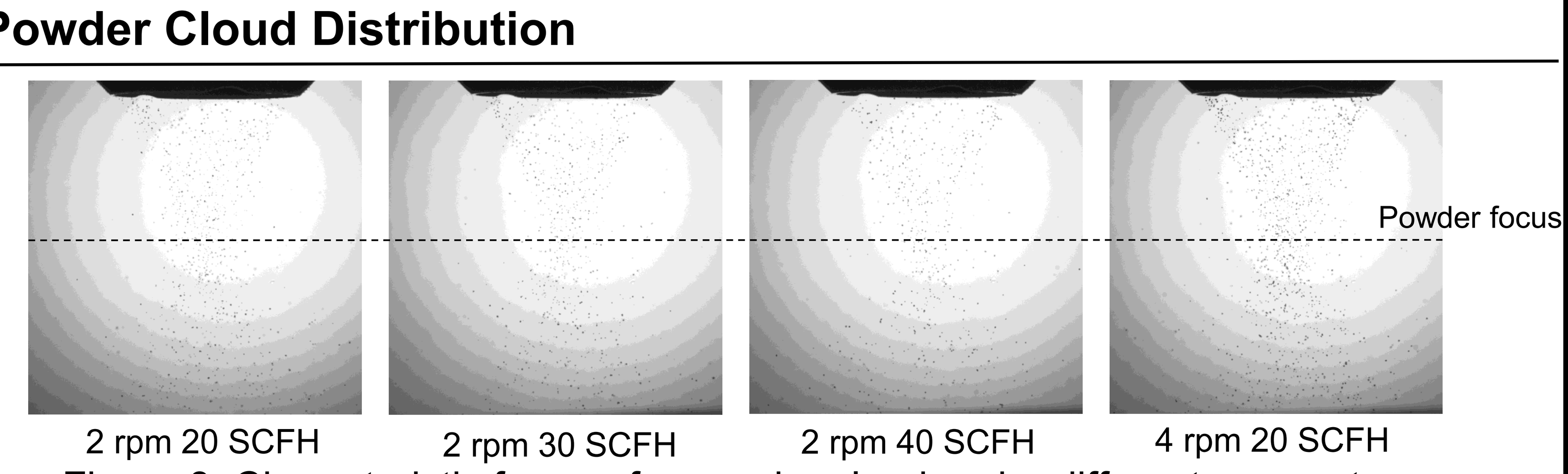
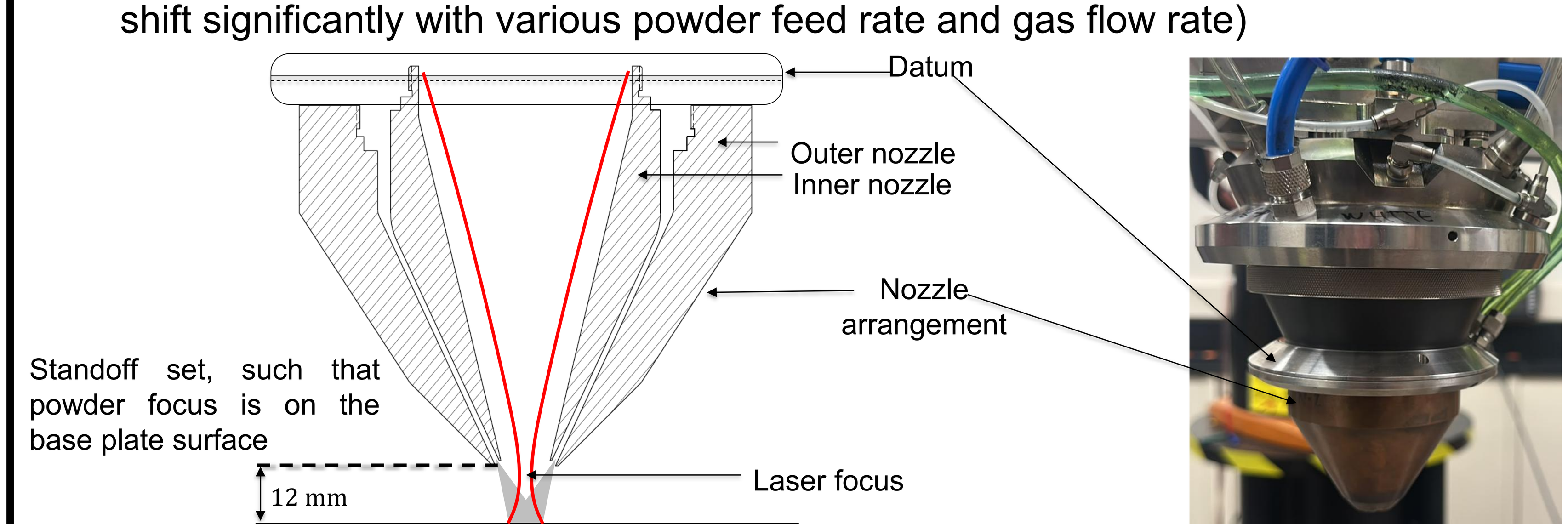


Figure 8: Characteristic frames for powder cloud under different parameters.

- As shown in Figure 8, for the same feed rate (rpm) from the powder feeder, increasing the carrier gas flow rate (SCFH-Standard Cubic Feet per Hour) will decrease the density of the powder cloud as powder velocity will increase.
- With higher powder feeder rate, mass flow rate (g/s) will increase.
- The powder cloud focus is around 12 mm from the tip of the nozzle and it does not shift significantly with various powder feed rate and gas flow rate)



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