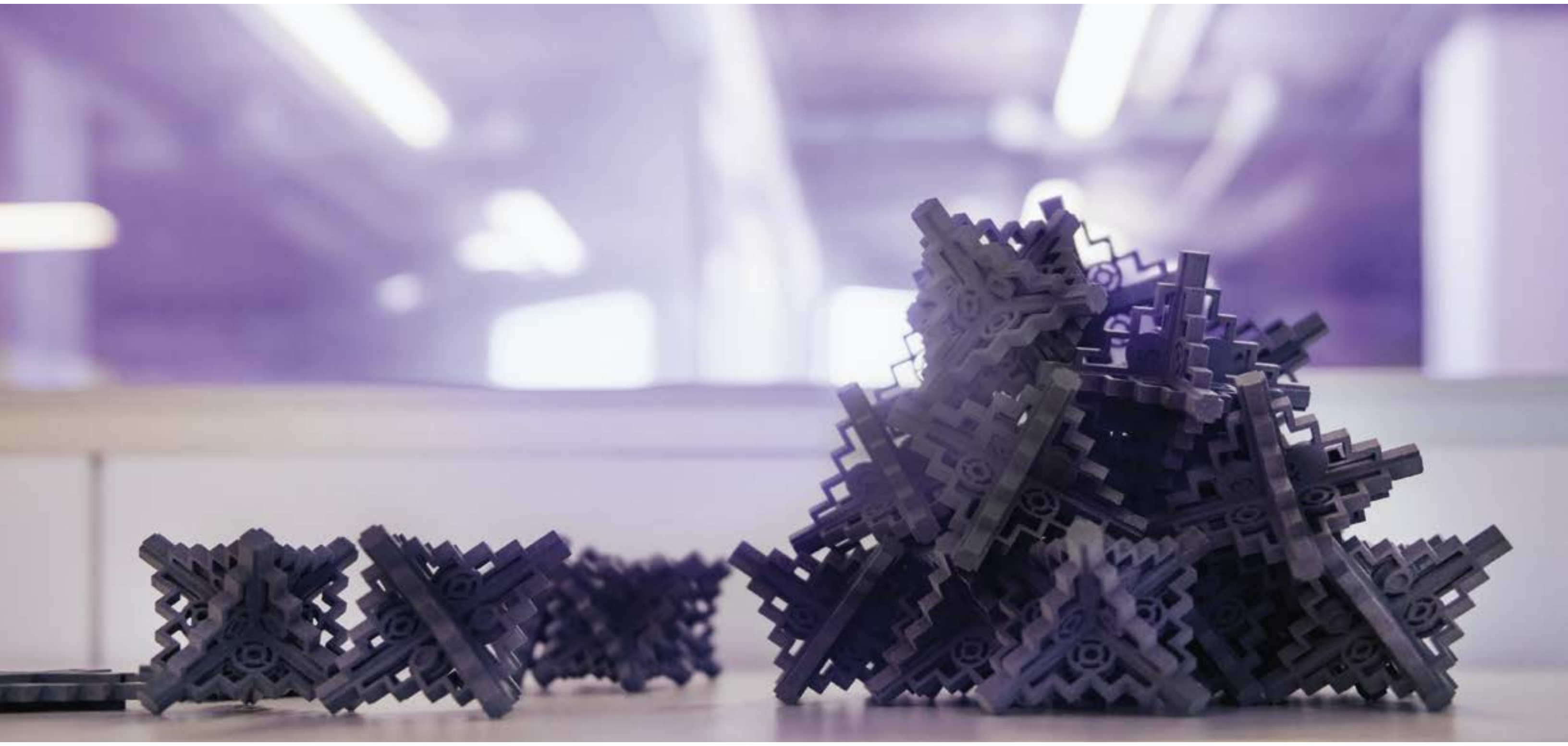
White paper

HP 3D HR CB PA 12 for HP Jet Fusion 500 Series 3D Printers

Dimensional Capability



Introduction

At HP, we are committed to providing part designers and part manufacturers with the technical information and resources needed to enable them to unlock the full potential of 3D printing and prepare them for the future era of digital manufacturing.

The aim of this white paper is to provide you with information on the dimensional capabilities that can be achieved with the HP Jet Fusion 500 Series 3D Printers with HP 3D High Reusability (HR)[1] CB PA 12.

In this white paper, you will find:

- Tolerances in XY and Z for nominal dimensions ranging from 0 mm to 80 mm that can be achieved with the HP Jet Fusion 500 Series 3D Printers, according to a process capability index,
- A detailed explanation of the test conditions under which these values were obtained, and
- Additional information on the concept of process capability and dimensional tolerancing, and a glossary of key terms used.

HP Jet Fusion 500 Series 3D Printers dimensional capability performance

Test job

The dimensional capability performance of the HP Jet Fusion 500 Series 3D Printers with HP 3D HR CB PA 12 was characterized using the **HP dimensional capability characterization job** (Figure 1), which contained 59 diagnostic parts distributed throughout the printable volume. The job included three different types of diagnostic parts and a total of 1,524 dimensions.

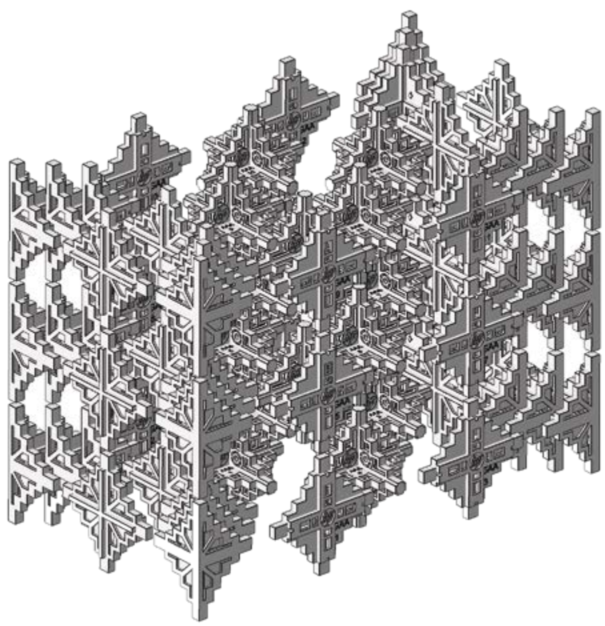


Figure 1. HP dimensional capability characterization job

1. HP Jet Fusion 3D Printing Solutions using HP 3D High Reusability CB PA 12 provide up to 80% powder reusability ratio, producing functional parts batch after batch. For testing, material is aged in real printing conditions and powder is tracked by generations (worst case for reusability). Parts are then made from each generation and tested for mechanical properties and accuracy.

Performance results for HP 3D HR CB PA 12

Testing was performed for HP 3D HR CB PA 12 with a 20% refresh ratio using the CB PA 12 Balanced print profile, and measured after bead-blasting with glass beads at 2-4 bars.

Table 1 shows the dimensional capability performance results for a target process capability[2] of C_{pk} = 1.00 (3 sigma) for white parts produced by the HP Jet Fusion 500 Series 3D Printers.

Tolerances for C_{pk} = 1.00[i ii iii] (in mm)	Nominal dimension					
	0–30 mm		30–50 mm		50–80 mm	
	XY	Z	XY	Z	XY	Z
With the **general dimensional profile** for the HP Jet Fusion 500 Series 3D Printers	0.20	0.21	0.25	0.30	0.28	0.47

i. Based on internal testing and measured using the "HP dimensional capability characterization job." Results may vary with other jobs and geometries.

ii. Using HP 3D HR CB PA 12 material, 20% refresh ratio, Balanced print profile, fast cooling, and measured after bead-blasting with glass beads at 5-6 bars.

iii. Following all HP-recommended printer setup and adjustment processes.

Table 1. Dimensional capabilities for white parts produced with HP 3D HR CB PA 12

Table 2 shows the dimensional capability performance results for color parts produced by the HP Jet Fusion 580 Color 3D Printer.

Tolerances for C_{pk} = 1.00[i ii iii] (in mm)	Nominal dimension					
	0–30 mm		30–50 mm		50–80 mm	
	XY	Z	XY	Z	XY	Z
With the **general dimensional profile** for the HP Jet Fusion 500 Series 3D Printers	0.20	0.21	0.25	0.30	0.28	0.47

i. Based on internal testing and measured using the "HP dimensional capability characterization job." Results may vary with other jobs and geometries.

ii. Using HP 3D HR CB PA 12 material, 20% refresh ratio, Balanced print profile, fast cooling, and measured after bead-blasting with glass beads at 5-6 bars.

iii. Following all HP-recommended printer setup and adjustment processes.

Table 2. Dimensional capabilities for white parts produced with HP 3D HR CB PA 12

2. For more information on process capabilities, see Appendix 1: Understanding process capabilities.

Appendix 1: Understanding process capabilities

Test job

Process capability determines whether a process meets a specification. The process capability index or process capability ratio, or C_{pk}, is a statistical measure of process capability. It quantifies the ability of a process to produce output within specification limits.

When talking about a dimensional specification, the C_{pk} measures the statistical probability that a certain process can produce a dimension within its tolerance range. The higher the C_{pk} value the better, meaning that more measurements will be within its tolerance range.

For a process to be capable, it needs to be both **repeatable and accurate.**

Repeatability is how close multiple measurements are to each other (also called **precision**).

Accuracy is how close a measurement value is to the specified nominal.

The capability of a process is then a function two parameters:

- How **repeatable** it is compared to the width of the specification limits, measured by the $\mathbf{C_p}$.
- How **accurate** it is, measured by the **bias**.

$$Capability = C_{pk} = C_p * (1-2*bias)$$

Figure 2. Relationship between bias and variability

This concept only holds meaning for processes that are in a state of statistical control with an output that is approximately normally distributed.

Both conditions happen when dealing with the dimensional quality control of HP MJF–produced parts where the output is the dimensional value of the different geometrical features of a part.

Dimensional quality control processes define an upper specification limit (USL) and a lower specification limit (LSL), also called “tolerance range” of the process. The target of the process is the center of this range, typically the nominal dimension value.

The objective to have a well-controlled dimensional process is to have its normal distributed population of measurements:

- With a variability (calculated as standard deviation) that “fits” in the tolerance range. $\mathbf{C_p}$ measures how well the variability fits in the tolerance range.
- With a mean (average) as close as possible to the target. The deviation is measured by the **bias**.

Only if both conditions are met, process capability measured by $\mathbf{C_{pk}}$ is good:

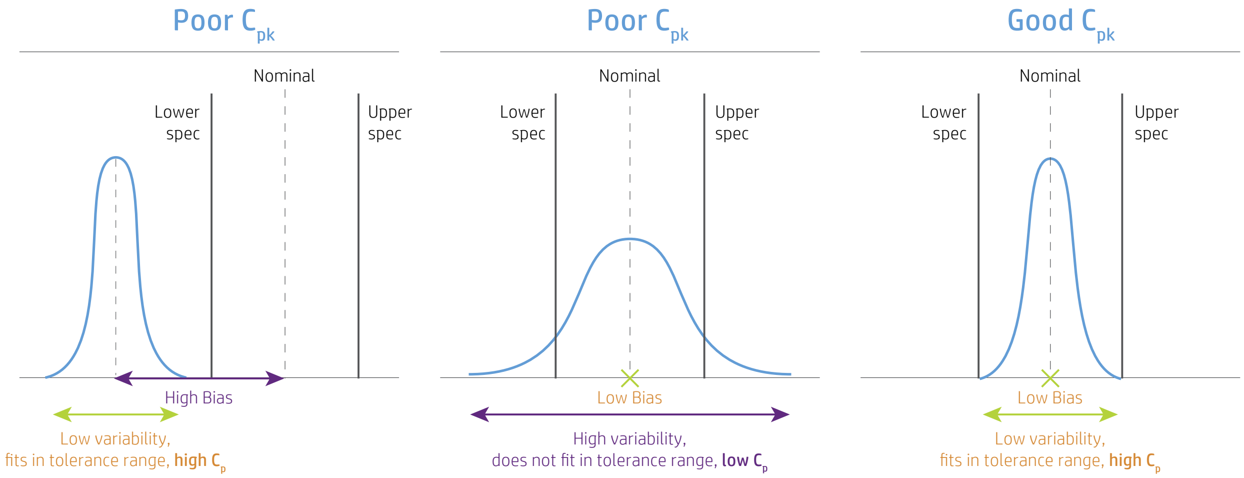


Figure 3. Process capability C_{pk} scenarios

The mathematical calculation of these parameters is as follows:

$$C_p = \frac{\text{Specification width}}{\text{Process width}} = \frac{(USL - LSL)}{6\sigma}$$

Standard deviation estimates the sigma and quantifies the variability and dispersion of the process.

C_p should always be greater than 1.00 for the variability to fit within the tolerance range.

$$C_{pk} = \min\left\{\frac{[USL - \mu]}{3 \cdot \sigma}, \frac{[\mu - LSL]}{3 \cdot \sigma}\right\}$$

The statistical mean estimates the mu (μ).

Therefore:

- C_{pk} “measures” the distance of the mean to the closer specification limit, which could be the upper or the lower limit.
- C_{pk} takes into account how centered the process is ($C_{pk} \leq C_p$).
- For a perfectly centered process, $C_p = C_{pk}$.
- If $C_p > C_{pk}$, it is possible to increase the C_{pk} by readjusting the mean of the process.

Table 3 displays the relevant C_{pk} values and their correlation with process yields.

	C_{pk}	Sigma level	Dimensions within specs (%)	Dimensions out of specs (units per million)	Part yield for a part with 10 dimensions (%)	
100% inspection	0.33	1	68.27	317,300	2.20	
	0.67	2	95.45	45,500	62.77	
Statistical process control	1.00	3	99.73	2,700	97.33	
	1.33	4	99.9937	63	99.94	Desired
	1.50	5	99.99966	3.4	100	
	1.67	6	99.99997	0.6	100	

Table 4. C_{pk} and process yield correlation

In terms of dimensional quality control and for a part to be considered good, all the specified dimensions need to be good, therefore the part yield is a metric that can be calculated as the statistical sum of probable dimensional tolerance failures. The previous table shows an example of a part with 10 dimensions in the far-right column. Cosmetic quality control and other part requirements should also be taken into account as possible factors for decreasing the total part yield.

Appendix 2: Dimensional requirements & IT grades

The International Tolerance grades (IT grades) defined in ISO 286/ANSI B4.2-1978 provide standardized tolerance ranges. The smaller the IT grade, the smaller the tolerance range, meaning better dimensional performance (less variability).

Each IT grade has a tolerance range that varies depending on the nominal value of the dimension. The larger the specified dimension, the larger the tolerance range for accuracy.

Dimension (mm)		IT1	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	IT10	IT11	IT12	IT13	IT14	IT15
Above	Up to and including						µm			Tolerance ranges						mm
-	3	0.8	1.2	2	3	4	6	14	10	25	40	60	0.10	0.14	0.25	0.4
3	6	1	1.5	2.5	4	5	8	18	12	30	48	75	0.12	0.18	0.30	0.48
6	10	1	1.5	2.5	4	6	9	22	15	36	58	90	0.15	0.22	0.36	0.58
10	18	1.2	2	3	5	8	11	27	18	43	70	110	0.18	0.27	0.43	0.70
18	30	1.5	2.5	4	6	9	13	33	21	52	84	130	0.21	0.33	0.52	0.84
30	50	1.5	2.5	4	7	11	16	39	25	62	100	160	0.25	0.39	0.62	1.00
50	80	2	3	4	8	13	19	46	30	74	120	190	0.30	0.46	0.74	1.20
80	120	2.5	4	6	10	15	22	54	35	87	140	220	0.35	0.54	0.87	1.40
120	180	3.5	5	8	12	18	25	63	40	100	160	250	0.40	0.63	1.00	1.60
180	250	4.5	7	10	14	22	29	72	46	115	185	290	0.46	0.72	1.15	1.85
250	315	6	8	12	16	23	32	81	52	130	210	320	0.52	0.81	1.30	2.10
315	400	7	9	13	18	25	36	89	57	140	230	360	0.57	0.89	1.40	2.30
400	500	8	10	15	20	27	40	97	63	155	250	400	0.63	0.97	1.55	2.50
500	630	9	11	16	22	32	44	100	70	175	280	440	0.70	1.10	1.75	2.80

Table 4. Standard international tolerance grades

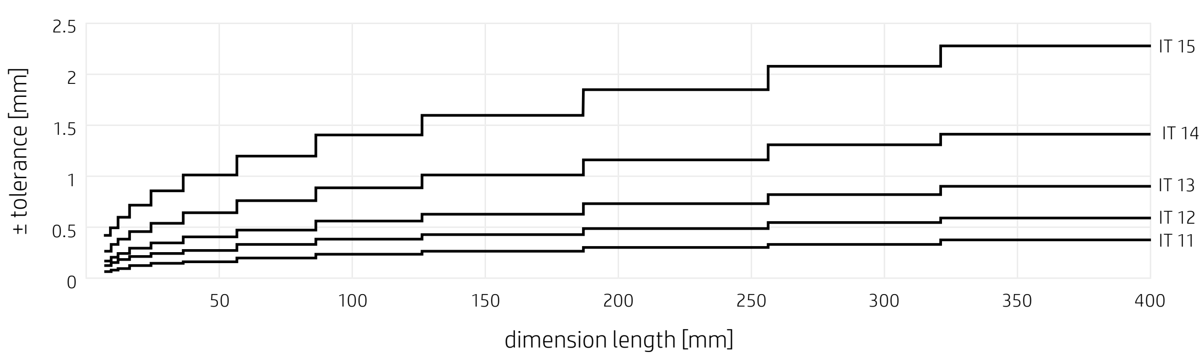


Figure 4. Tolerance range vs. dimension length

IT grades provide a standardized reference to compare typical manufacturing process capability in terms of dimensional tolerance for a given dimension, as shown in Table 5.

	Measuring tools									Material								
IT Grade	01	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							Fits							Large manufacturing tolerances				

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Table 5. IT Grades for measuring tools & materials

Appendix 3: Key terms

- **Process capability**: Statistical measurement of a process's ability to produce parts within specified limits on a consistent basis.
- **International Tolerance Grade (IT Grade)**: Grade used to identify the tolerances a given industrial process can produce for a given dimension.
- **Repeatability**: Ability of a process to consistently produce the same output; in this case, the same part dimensions.
- **Bias**: Difference between the average of the population for a given dimension and the target value of that dimension.
- **C_p**: Process capability index that measures of the ability of a process to produce consistent results – the ratio between the permissible spread and the actual spread of a process. This does not take into account how well the output is centered on the target (nominal) value.
- **C_{pk}**: Process capability index that estimates what the process is capable of producing, considering that the process mean may not be centered between the specification limits. $C_{pk} < 0$ if the process mean falls outside of the specification limits.

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