ANSYS Additive Print

Strain Scaling Factor (SSF) and Anisotropic Coefficients Calibration Plan

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1 OBJECTIVE

The objective of this procedure is to determine the Strain Scaling Factor (SSF) and anisotropic coefficients for use in the Additive Print software to improve the prediction accuracy of the simulation(s). Existing distortion measurement data could be applied to calculate the strain scaling factor and/or anisotropic coefficients dependent on the type of data and experiment process parameters. If users are seeking to start building simple yet representative geometries for the calibration of their machine and material, this plan includes a series of simple geometries that can be built and simulated quickly. These simple geometries are designed to provide rapid calibration of SSF and anisotropic coefficients for use in simulating larger and more complex geometries with the same machine material parameter sets. It's likely that different geometries may result in a different set of strain scaling factors and anisotropic coefficients. The effectiveness of these designs still need further validation by experimental data; hence this plan may need to be repeated for different types or classes of end-goal parts which can vary widely with respect to geometric features. The step by step calibration process described in section 2 can be applied to any part with measurment data and it should result in a full matrix of calibrated strain scaling factor and anisotropic coefficients for one material as shown in the table below. The calibration procedure may need to be iterated with new strain scaling factors and anisotropic coefficients for comparison to simulated and experimental results until the satisfied results are found.

Material	Elastic/Plastic	Assumed Strain	Scan Pattern	Thermal Strain
A	Elastic	SSF	SSF	SSF
			ASC_x	ASC_x
			ASC_y	ASC_y
			ASC_z	ASC_z
	Plastic	SSF	SSF	SSF
			ASC_x	ASC_x
			ASC_y	ASC_y
			ASC_z	ASC_z

2 STEP BY STEP CALIBRATION PROCEDURE

2.1 SSF CALIBRATION PROCEDURE (ASSUMED STRAIN MODE)

Step 1: Measure distortion of part at location of interest

- Prepare the measurement data which may come from different locations:
- measure at locations which likely to have maximal distortion,
- measure at locations which are of great interest to users, or
- measure distortion trend on a certain line/surface.

- If the geometry is built with multiple replications with same process parameters, the measured data could be averaged and used in the calibration procedures.

Step 2: Run ***Assumed Strain*** simulation with the following:

- default SSF and
- converged voxel size which can be found with running a series of simulations with coarse to fine voxel sizes; if the geometry has thin features, it's recommended to have at least 3-4 voxels at the location.

Step 3: Extract the distortion data from simulation results at locations matching the as-built part

Step 4: Calculate new SSF

- If the measurement data is a point, i.e. maximal distortion, the new SSF is the ratio of the measurement divided by simulation;
- If the measurement is a distortion distribution on a line/surface, capture the maximal distortion or best fit distortion trend line (point), and the new SSF is the ratio of the measurement divided by simulation.

Step 5: Go back to Step 2 and re-run the Assumed Strain simulation with the new SSF, and iterate Steps 2-3-4 until a satisfied result is obtained

2.2 Anisotropic Coefficients Calibration Procedure (Scan Pattern and Thermal Strain Mode)

Step 1: Measure distortion of part at location of interest

- Prepare the measurement data which may come from different locations
- measure at locations which are likely to have maximal distortion,
- measure at locations which are of great interest to users, or
- measure distortion trend on a certain line/surface
- If the geometry is built with multiple replications with same process parameters, the measured data could be averaged and used in the calibration procedures.

Step 2: Run ***Assumed Strain*** simulation with the following:

- default SSF and
- converged voxel size which can be found with running a series of simulations with coarse to fine voxel sizes, if the geometry has thin features, it's recommended to have at least 3-4 voxels at the location.

Step 3: Extract the distortion data from simulation results at locations matching the as-built part

Step 4: Calculate new SSF and Anisotropic Strain Coefficients (**EXPERIMENTAL**)

The SSF and Anisotropic Strain Coefficients can follow two methods depending on the type of measurement data. Both two methods have the following assumption:

- the anisotropic coefficient in Z direction is always 1, so that the sum of anisotropic coefficient in X and Y direction equals to 2, and
- the ratio of anisotropic coefficients in x and y is linear to the ratio of distortion difference in the two corresponding directions.

Method 1: if the measurement results come from a part built with only one of the ***bi-directional scan patterns (description is available in section 3.4)*** proceed with the following:

Step 4.1: Calculate new SSF:

- if the dimensions in the scan direction and perpendicular direction can be measured, then proceed with the following:
    - measure the dimensions in both scan direction and perpendicular direction and calculate the distortion, dx_m and dy_m
    - extract the distortion from simulation results, dx_s, dy_s
    - calculate the ratio of measurement and simulation, dx_m/dx_s and dy_m/dy_s
    - the new SSF equals to the sum of dx_m/dx_s and dy_m/dy_s divided by 2
- If not, then follow the same SSF calculation procedure in section 2.1 Step 4

Step 4.2: Calculate new Anisotropic strain coefficients:

- The new Anisotropic strain coefficient ASC_x equals to dx_m/dx_s divided by the new SSF from 4.1 Method 1
- The new Anisotropic strain coefficient ASC_y equals to dy_m/dy_s divided by the new SSF from 4.1 Method 1

Method 2: if the measurement results come from parts built with ***bi-directional all X and all Y scan patterns (description is available in section 3.4)***

Step 4.1: Calculate new SSF:

- if the nominal dimension in one scan direction (i.e. X) is much larger than the other (i.e. Y), then proceed as follows:
    - measure the X dimension for both parts, dx_m_p1 and dx_m_p2
    - extract the distortion from simulation results for both parts, dx_s_p1, dx_s_p2
    - calculate the ratio of measurement and simulation, dx_m_p1/dx_s_p1 and dy_m_p2/dy_s_p2
    - the new SSF equals to sum of dx_m_p1/dx_s_p1 and dy_m_2/dy_s_2 divided by 2

Step 4.2: Calculate new Anisotropic strain coefficients:

- The new Anisotropic strain coefficient ASC_x equals to dx_m_p1/dx_s_p1 divided by the new SSF from 4.1 Method 2
- The new Anisotropic strain coefficient ASC_y equals to dy_m_p2/dy_s_p2 divided by the new SSF from 4.1 Method 2

Step 5: Run ***Scan Pattern* and *Thermal Strain*** simulation with:

- new SSF and Anisotropic Strain Coefficients,
- set up corresponding scan patterns, and
- same voxel size from the Assumed Strain simulation in Step 2

Step 6: If the maximal distortion or distortion trend doesn't match with the experimental results,

- Follow Step 4 in section 2.1 to adjust the SSF;
  iterate the procedures in this step until a satisfied result is obtained

3 CALIBRATION CONSIDERATIONS

3.1 GEOMETRY

Three representative geometries (calibration parts) are suggested in this plan and users are welcome to build parts that perform better in their machine/material for the calibration purpose.

- A **cuboid wall part** dimensions of 60x10x40 (length x width), Figure 1 right.
- An **octagon thin wall** with a dimension of 50x50x20x2mm (length x width x height x thickness), Figure 1 middle.
- An **overhang part** has a dimension of 30x20x20mm (length x width x height), Figure 1 left.

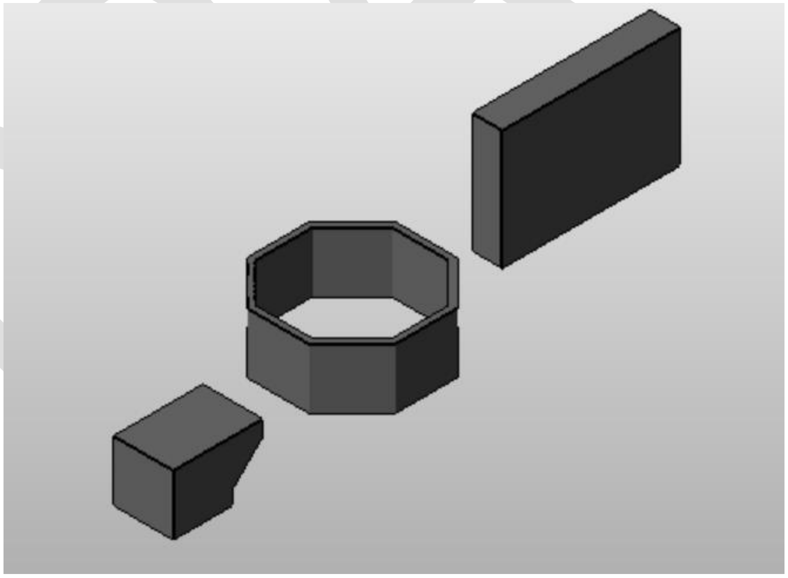

Figure 1 Calibration geometries

3.2 MACHINE AND MATERIAL

Typical DMLS machine such as EOS, SLM Solutions, Renishaw, etc. The current version of Additive Print product offers the following material: CoCr, IN718, IN625, Ti64, 17-4PH, 316L, AlSi10Mg. New materials could be added if as-built mechanical properties for new materials are known.

3.3 SUPPORT STRUCTURE

No support structure used in this calibration procedure.

3.4 PROCESS PARAMETERS AND SCAN PATTERNS

The following calibration parts should be built with default machine process parameters *(e.g. optimized material process parameters).*

Each part is suggested to be scanned with multiple scan patterns and are explained as follows.

1. The **cuboid wall (part 1)** with a dimension of 60x10x40mm should be built with three different scans:
    a. Part 1/Replicate 1: bi-directional scan (0 – 180°) along the length of the wall,
    b. Part 1/Replicate 2: bi-directional scan (90 – 270°) along the width of the wall, and
    c. Part 1/Replicate 3: typical stripe with 67-degree *(or machine's default stripe based rotational scan)* are suggested respectively as shown in Figure 2 upper-right.

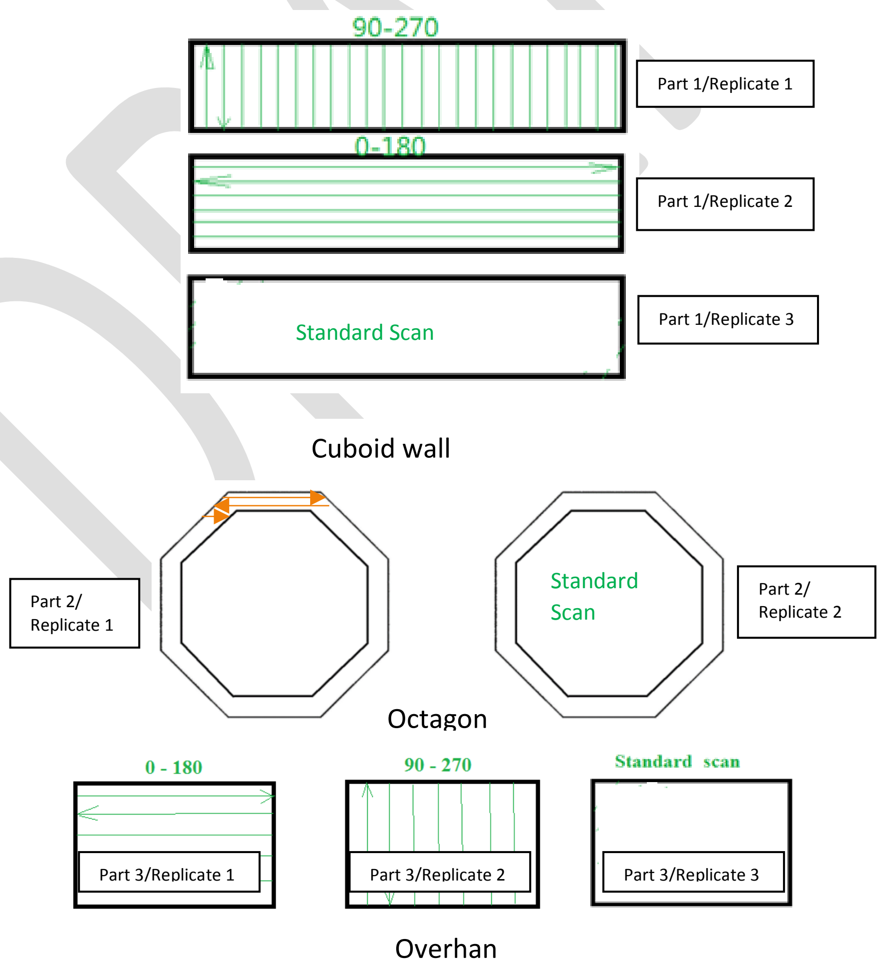

Figure 2 scan patterns

For the bi-directional scans, there should be no extra scan such as contour scan, upper and down, etc.

2. The **octagon part (part 2)** should be built with two scans:
    a. Part 2/Replicate 1: bi-directional scan such that all scan vectors aligned in one direction that corresponds to the orientation of any of the walls, and
    b. Part 2/Replicate 2: the machine's standard stripe based rotating scan pattern respectively, as shown in Figure 2 middle.

   For the bi-directional scan, there should be no extra scan such as contour scan, upper and down skin, etc.

3. The **overhang part (part 3)** needs to be built with three different scans:
    a. Part 3/Replicate 1: bi-directional scan ($0 – 180^{o}$) along the length of the wall,
    b. Part 3/Replicate 2: bi-directional scan ($90 – 270^{o}$) along the width of the wall, and
    c. Part 3/Replicate 3: typical stripe with 67-degree *(or machine's default stripe based rotational scan)* are suggested respectively.

   For the bi-directional scan, there should be no extra scan such as contour scan, upper and down skin, etc.

3.5 Part Layout

An appropriate layout, consistent with best practice, should be implemented to ensure there is enough space between parts to accomplish the selected measurement procedure *(such as CMM, laser scanner, or caliper)* *before the parts are cut from the baseplate*. All the calibration parts need to be measured while they are fixed to the plate; hence, it's important to keep sufficient space between neighboring parts. If gas flows from one direction to another inside the chamber, it is suggested to rotate the part away from the gas flow direction to reduce the impact.

3.6 Part Measurement

All the measurement should be performed *before the parts are cut from the baseplate*.

3.6.1 CMM Measurements

For the **cuboid wall** part, as shown in the following picture, select sufficient *points (i.e. one point every 1-2mm)* along the central line of each surface to line to be measured. And also the average thickness of built part.

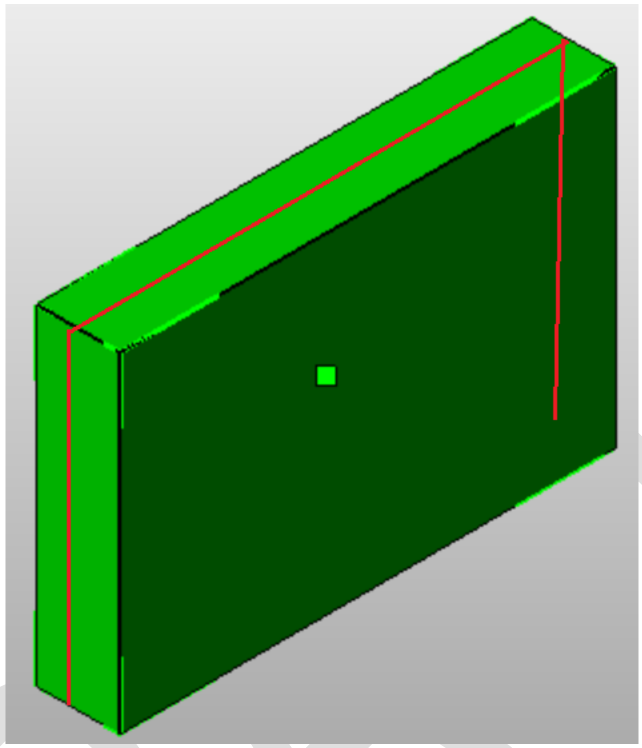

Figure 3 CMM measurement locations

For the **octagon part**, select sufficient points (i.e. one point every 1-2mm) on the vertical central line of the eight side surfaces to be measured. And also sufficient points along the outer surface in the middle of the z direction to have the measured contour distortion.

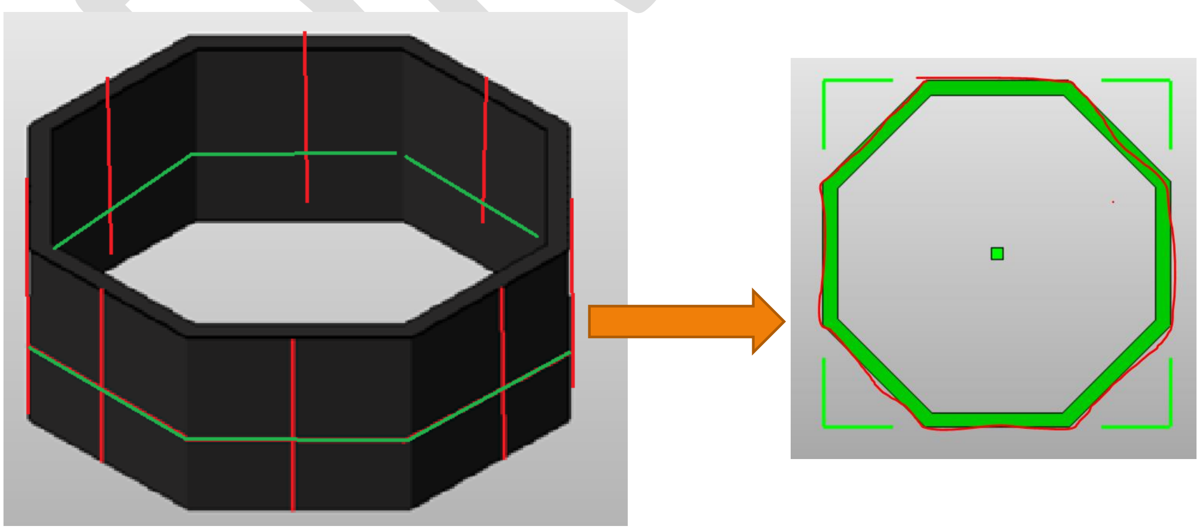

Figure 4 CMM measurement locations

For the **overhang part**, select sufficient points *(i.e. one point every 1-2mm)* along the central line of each surface to line to be measured. And also the average thickness of built part.

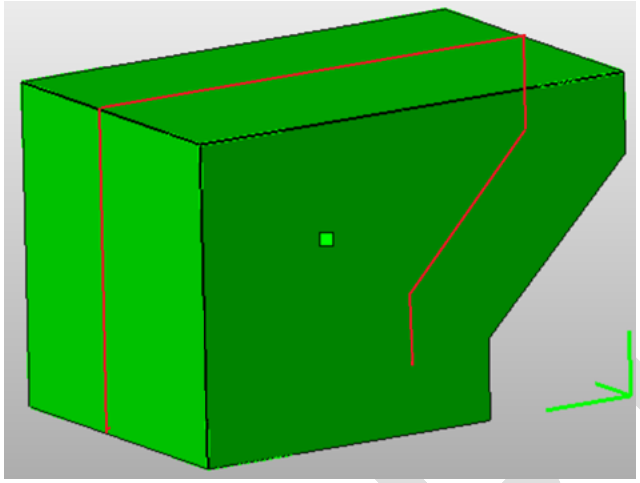

Figure 5 CMM measurement locations

3.6.2 Laser scanner

If laser scanner is available, points cloud or scanned STL file of each part should be generated.

3.6.3 Quick measurement with caliper/micrometer

If caliper must be used for the measurement, it's recommended to add some detents to the STL file, so the measurement could be taken precisely at the specified location. Taking the cuboid wall for example, measuring the distortion of the side surface at the detents before all the parts are cut off from the baseplate as shown in Figure 6. If there is any obvious distortion or other interesting behaviors observed along the side wall at locations other than the detents, the distortion and location shall be measured and recorded respectively as well.

Figure 6 Part with detents on the side walls helping to measure the distortion

The distortion in the width direction may not show significant distortion, measuring the overall width as well.

3.7 Part Documentation

Physical parts should be marked clearly and measurement results should be recorded accordingly for each part.