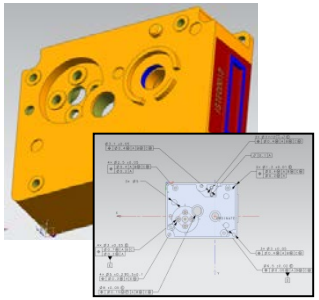
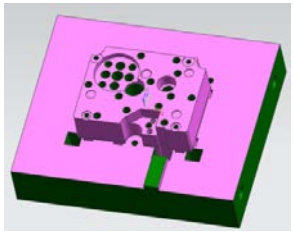
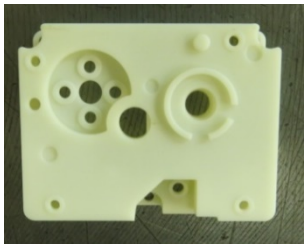
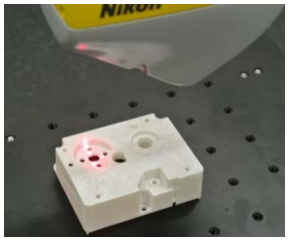
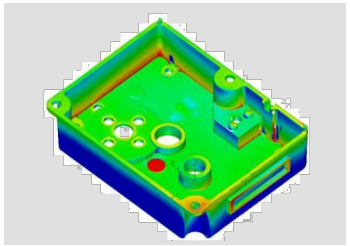
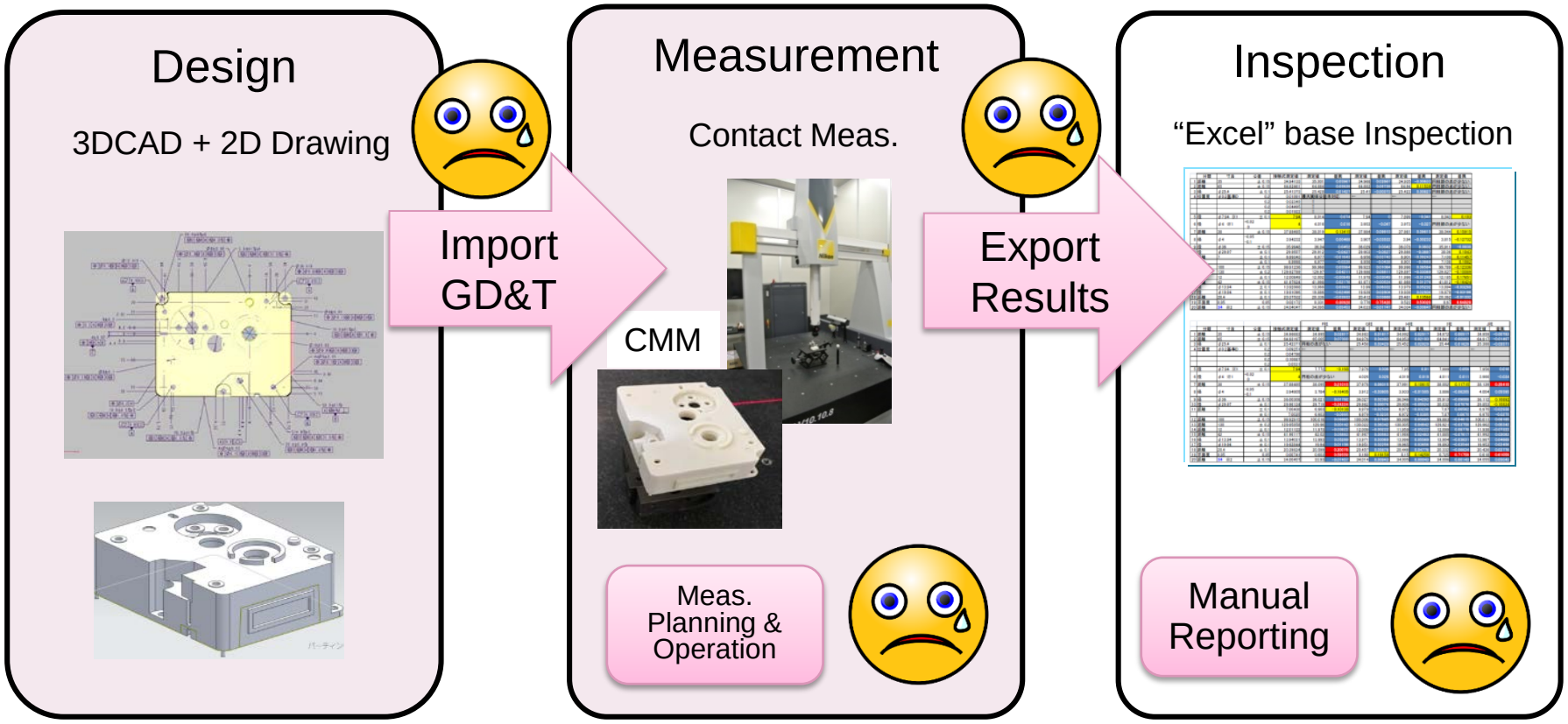
Automation of noncontact measurement processes based on MBD

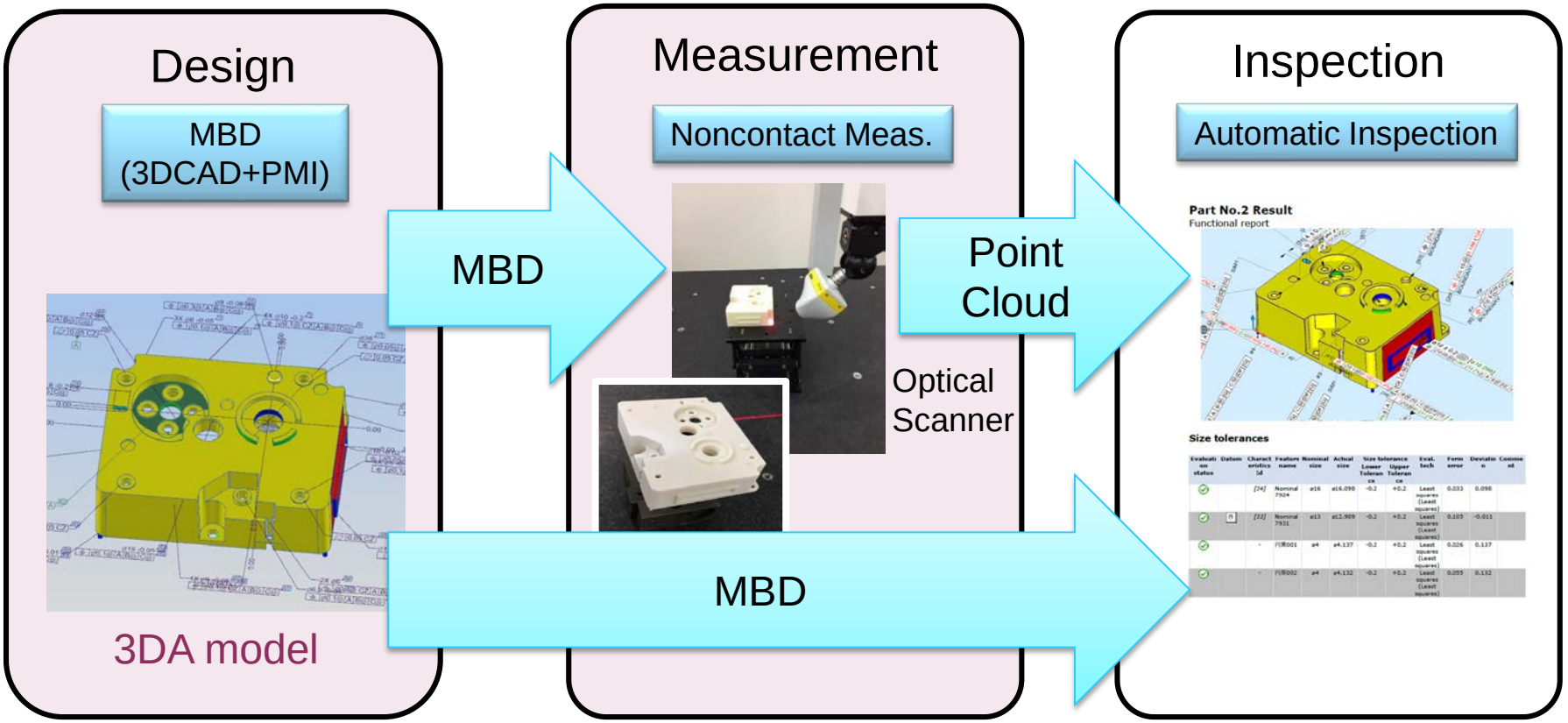
Hiromasa Suzuki, Univ. of Tokyo
Toshiaki Takahashi, 3D+1 Labo
Atsuto Soma, Elysium

Today's Inspection Process



- Human intensive process with various engineer/operator intervention
  - Manual input & output, subjective judgement, manual report generation etc.
- Large amount of non-productive rework
- Long measurement operation time by using contact measurement

Goal: Automatic Inspection Process

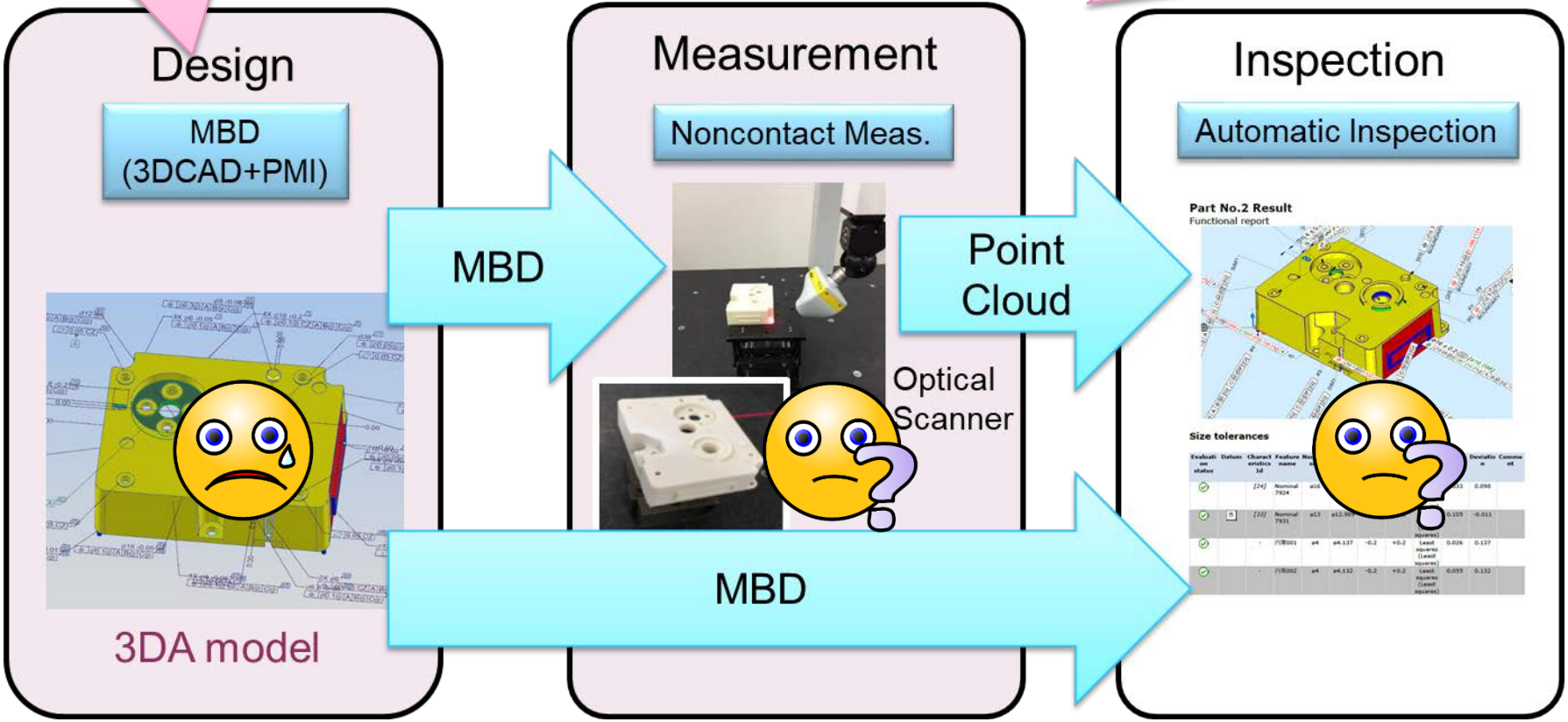


- Purpose
  - more efficient, less non-subjective and more accurate inspection process
  - No reworking by seamless integration
- Goal: Automatic inspection process with MBD + noncontact meas. + MBD based inspection

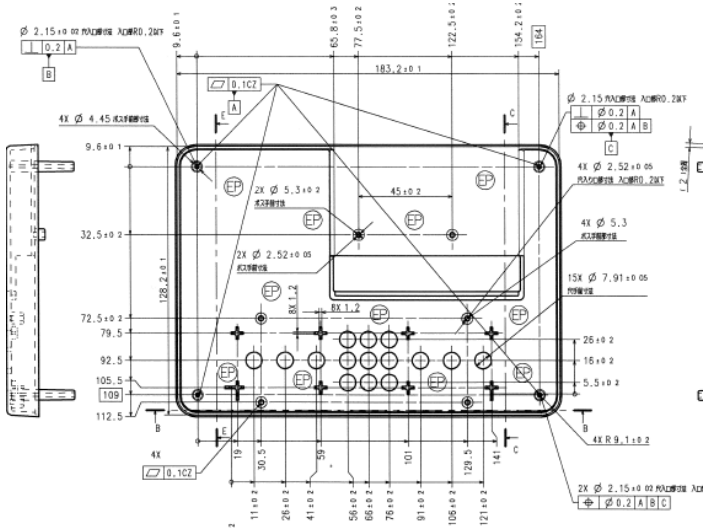
Critical Issues

3DA model
High workload on designers to fully specify geometric tolerances

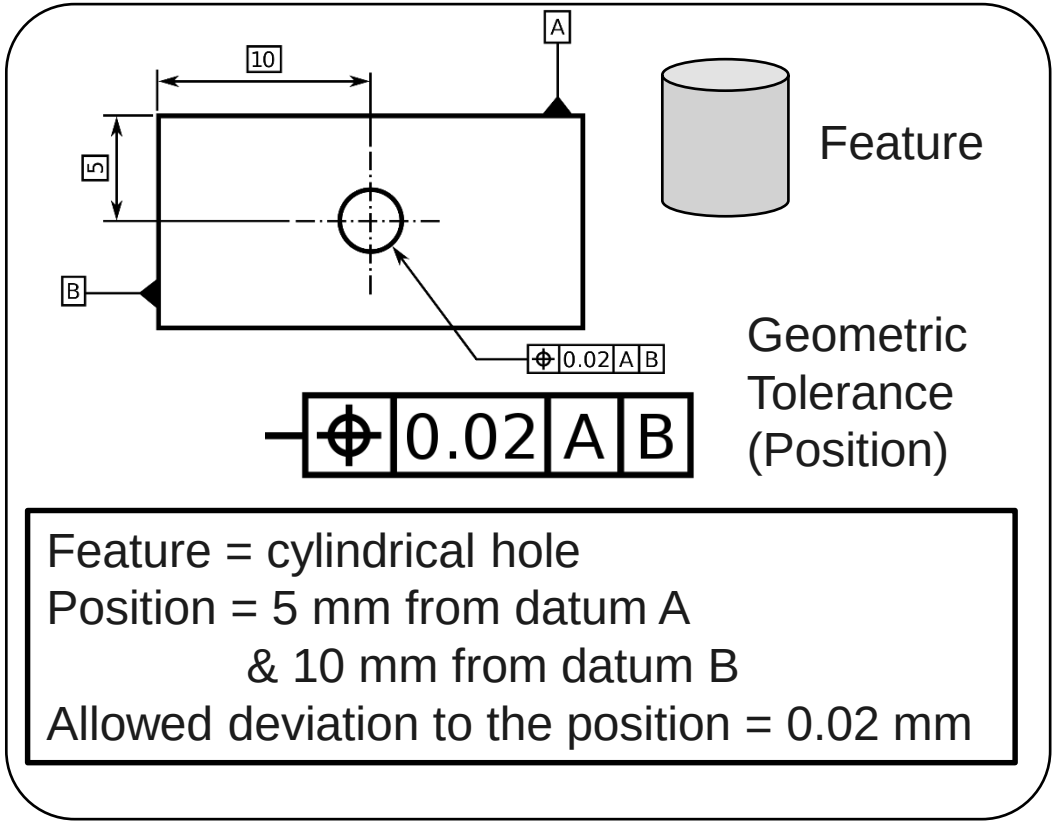
Noncontact meas.
Unstable quality of the point clouds due variation of meas. operation (operator's skill, equipment, plan etc.) causes Such instability greatly affects the reliability of judgement



Geometric Tolerancing (GD&T/GPS)



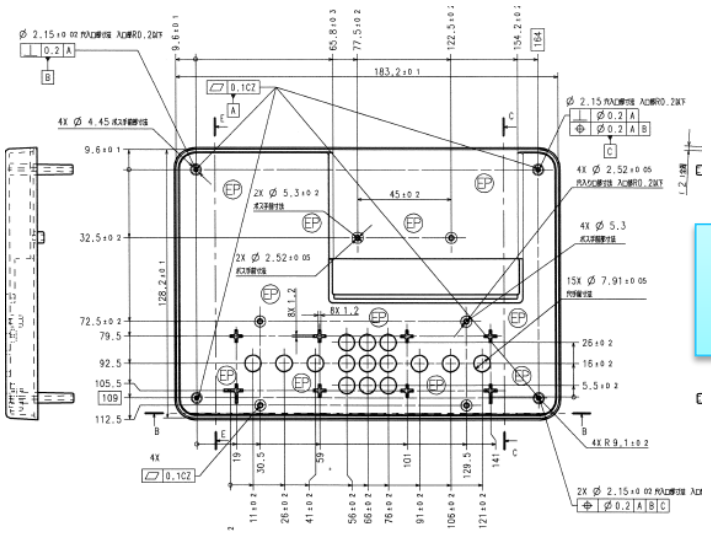
GD&T on 2D drawing



Feature = cylindrical hole
Position = 5 mm from datum A
& 10 mm from datum B
Allowed deviation to the position = 0.02 mm

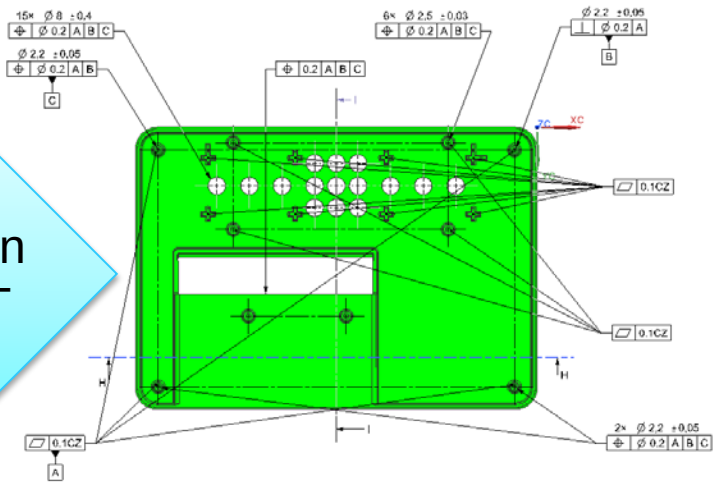
- Geometric Tolerance defines nominal geometry and its allowable variation of a feature (eg. planar surface, cylindrical hole, slots etc.)
- Designer has to specify geometric tolerances for all the features of a part.
- *It requires high workload on designers especially in 3D CAD.*

General Geometric Tolerancing (GGT)



Common GD&T

Reduction of GD&T



General Geometric Tolerancing

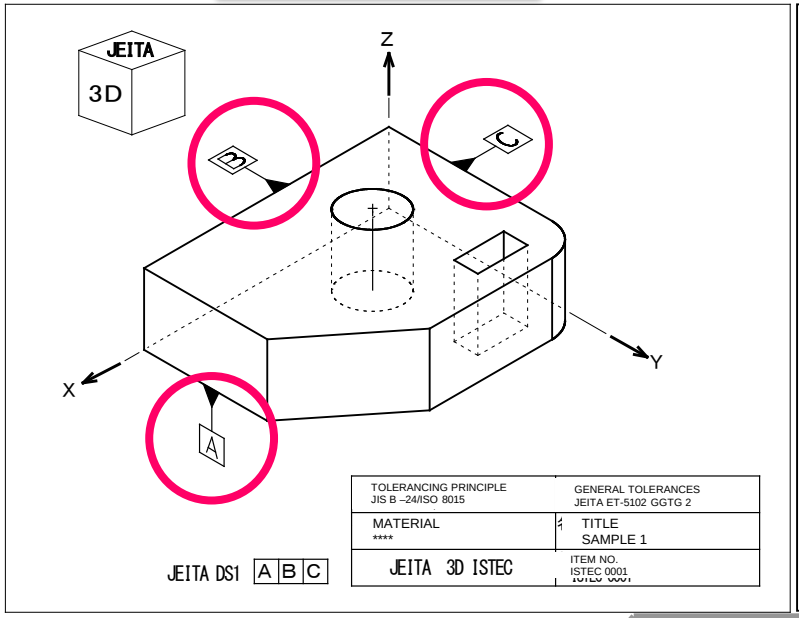
- For saving effort of the tolerancing work
  - Specify tolerances only for features with special care
  - Omit toleranecs for features whose quality requirements can be satisfied by general manufacturing process.
- General Geometric Tolerancing
  - Specify tolerance for the unspecified features with standard rules

Overview of JEITA GGT ET-5102

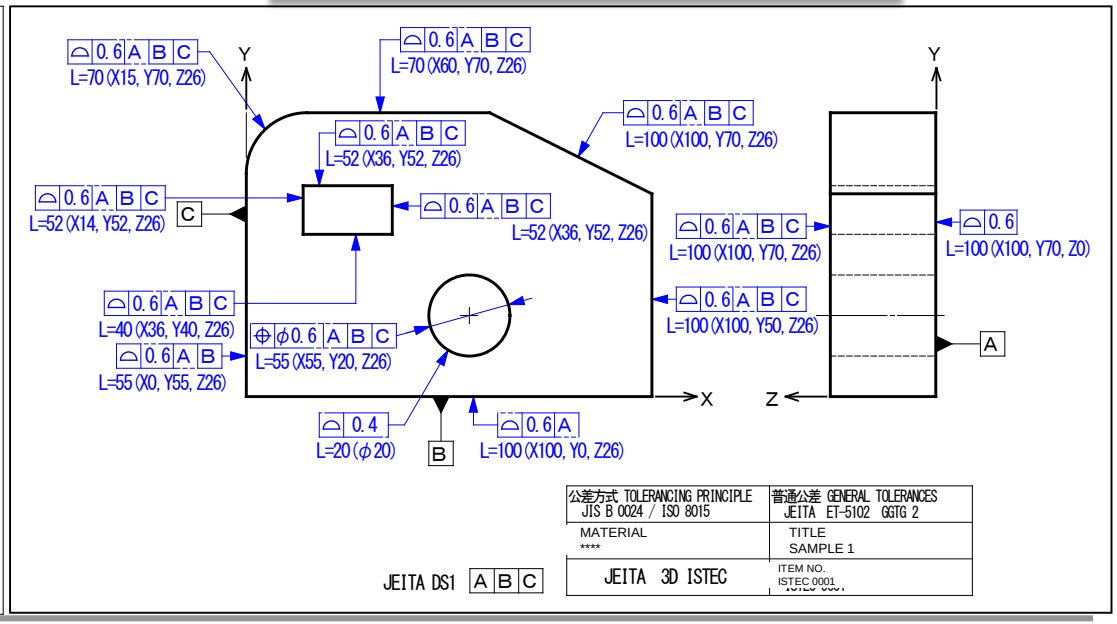
JEITA (Japan Electronics and Information Technology Industries Association)

- GGT rules [2017]
  - If a datum system of 3 planes is defined
  - tolerance zone for all of the features are defined by using profile any surface (and position)
  - Their tolerance values shall depend on the distance from the origin of the datum coordinate system.

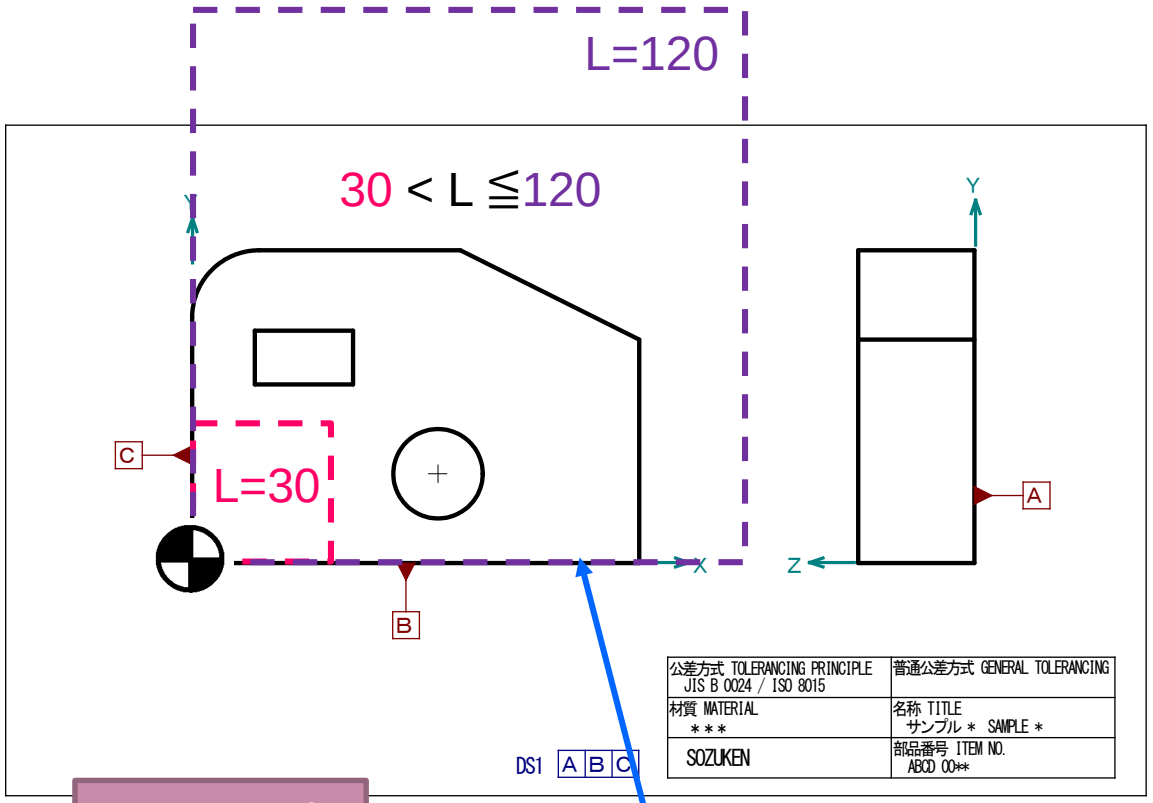
Datum System



Full indication of the tolerances



Overview of JEITA GGT ET-5102 (2)

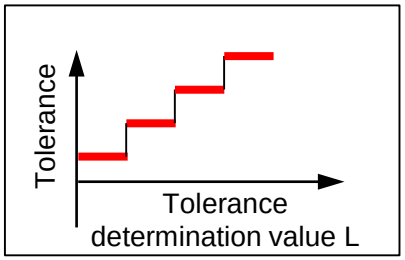


- GGT values are given in JEITA GGT Grade table
- L : tolerance det. value = distance from the datum system to a feature
- A feature at the distance L is given tolerance value defined in the table.
- Thus no need to explicitly define a tolerance for the feature.

GGT Grade

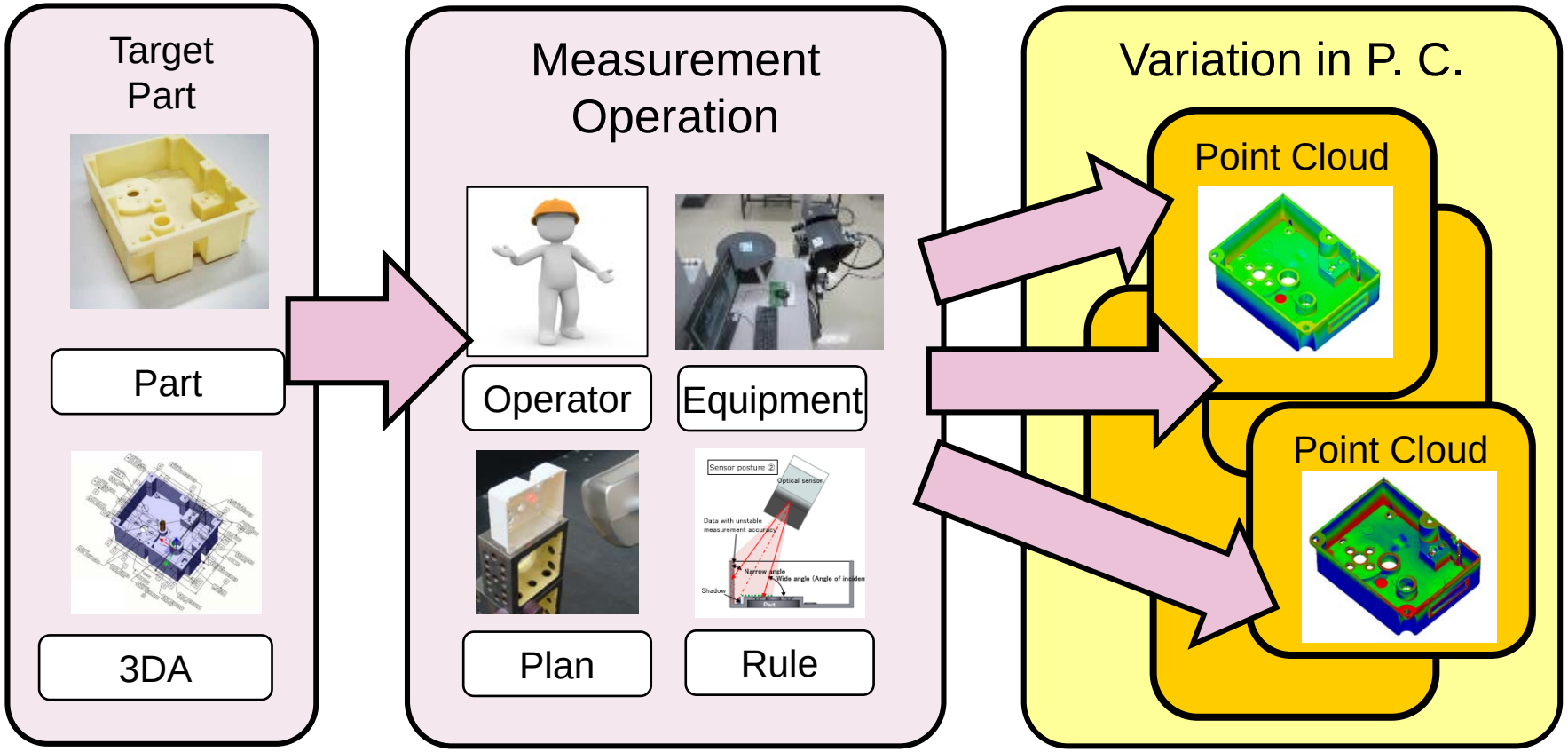
JEITA General Geometrical Tolerance Grade (plastic molding parts)

Tolerance Grade	Classification of Decided Dimension for Tolerance					
	L ≦ 6	6 < L ≦ 30	30 < L ≦ 120	120 < L ≦ 400	400 < L ≦ 1000	1000 < L ≦ 2000
GGTG 1	0.1	0.2	0.3	0.4	0.6	1
GGTG 2	0.2	0.4	0.6	1	1.6	2.4
GGTG 3	0.4	0.8	1.2	2	3	4
GGTG 4	1	1.4	2.4	4	6	8



Note GGTG stands for General Geometrical Tolerance Grade.

Importance of Standard Measurement Operation



- Unstable quality of the point clouds due to variation of meas. operation (operator's skill, meas. plan, meas. equipment etc.)
- Such instability greatly affects the reliability of judgement
- Need Standard Operation Manual to reduce such dependency.

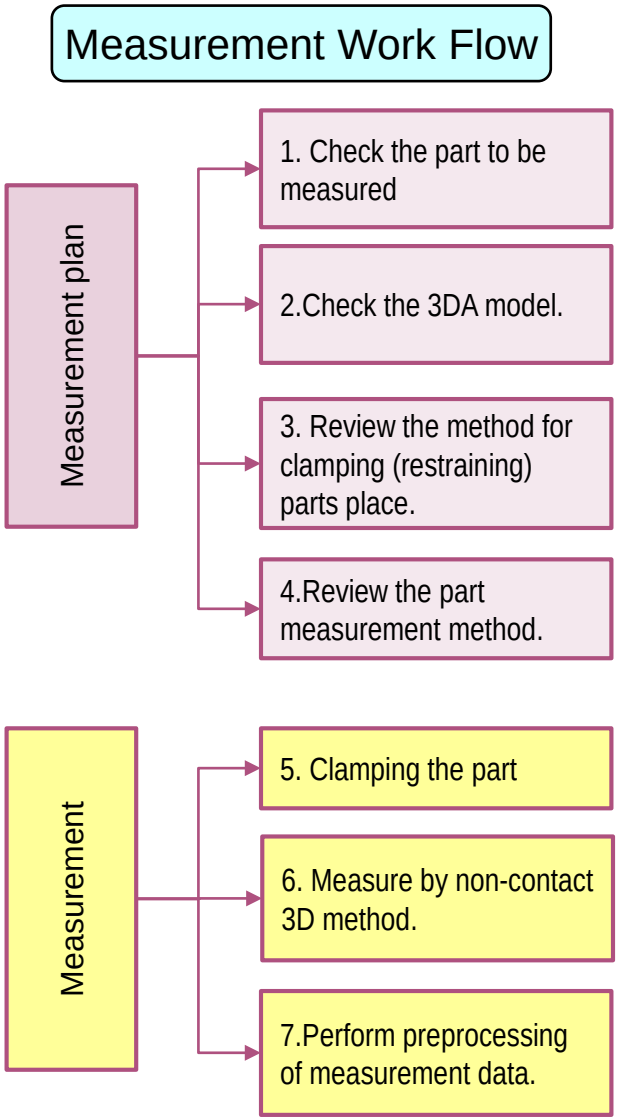
Development of Work Procedure Manual of Noncontact Meas.

Development process

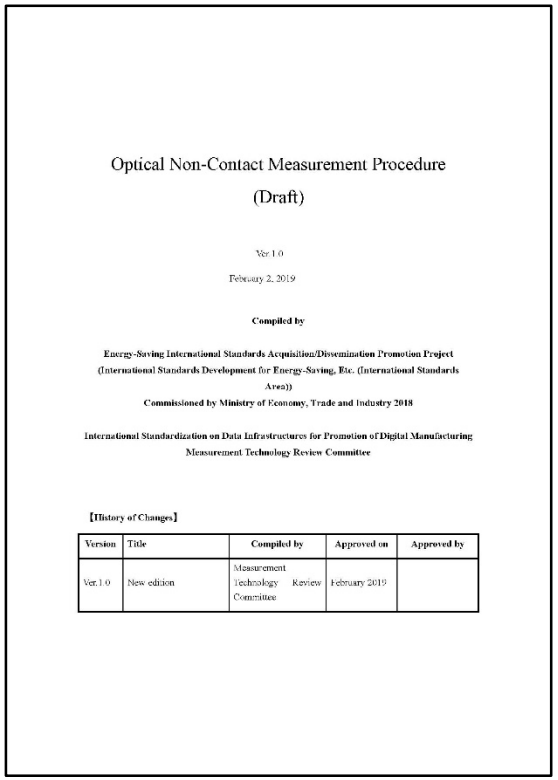
1. Formulate a workflow of measurement by the committee members

2. Conduct measurement experiments according to the document using test pieces by test users:
   - 5 companies
   - 7 public organizations

3. Evaluation & Revision of the guidelines
   - Compare the results from the test users
   - Revise the document according to the feedback from the test users



Guideline Document



Optical Non-Contact Measurement Procedure

(Draft)

Ver.1.0

February 2, 2019

Compiled by

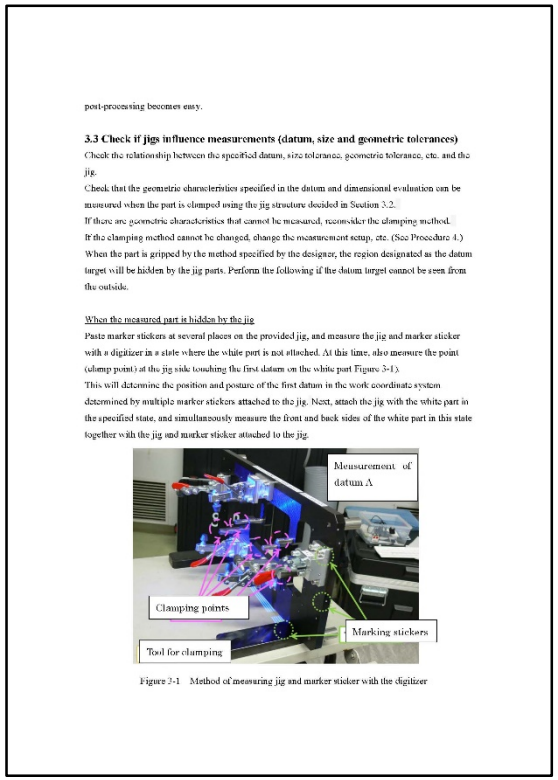
Energy-Saving International Standards Acquisition/Dissemination Promotion Project (International Standards Development for Energy-Saving, Etc. (International Standards Area))

Commissioned by Ministry of Economy, Trade and Industry 2018

International Standardization on Data Infrastructures for Promotion of Digital Manufacturing
Measurement Technology Review Committee

【History of Changes】

Version	Title	Compiled by	Approved on	Approved by
Ver.1.0	New edition	Measurement Technology Review Committee	February 2019	



post-processing becomes easy.

3.3 Check if jigs influence measurements (datum, size and geometric tolerances)

Check the relationship between the specified datum, size tolerance, geometric tolerance, etc. and the jig.

Check that the geometric characteristics specified in the datum and dimensional evaluation can be measured when the part is clamped using the jig structure decided in Section 3.2.

If there are geometric characteristics that cannot be measured, reconsider the clamping method.

If the clamping method cannot be changed, change the measurement setup, etc. (See Procedure 4.)

When the part is gripped by the method specified by the designer, the region designated as the datum target will be hidden by the jig parts. Perform the following if the datum target cannot be seen from the outside.

When the measured part is hidden by the jig

Paste marker stickers at several places on the provided jig, and measure the jig and marker sticker with a digitizer in a state where the white part is not attached. At this time, also measure the point (dimp point) at the jig side touching the first datum on the white part Figure 3-1).

This will determine the position and posture of the first datum in the work coordinate system determined by multiple marker stickers attached to the jig. Next, attach the jig with the white part in the specified state, and simultaneously measure the front and back sides of the white part in this state together with the jig and marker sticker attached to the jig.

Figure 3-1 Method of measuring jig and marker sticker with the digitizer

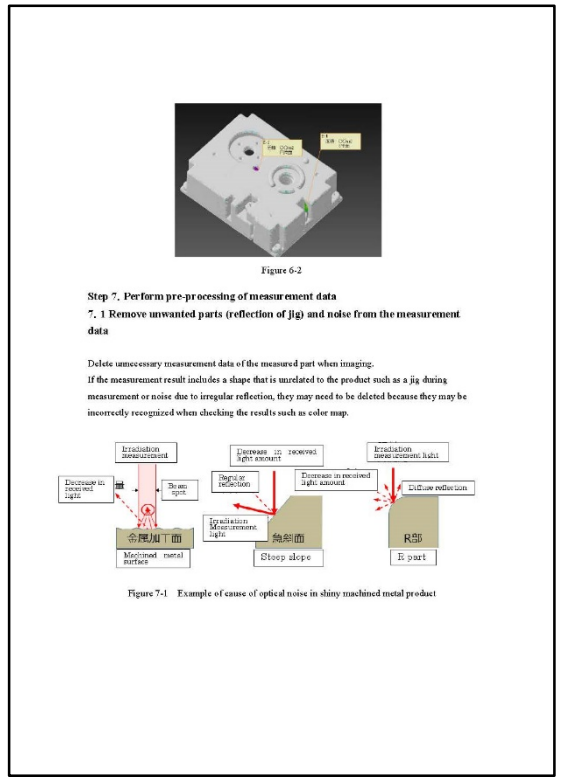


Figure 6-2

Step 7. Perform pre-processing of measurement data

7. 1 Remove unwanted parts (reflection of jig) and noise from the measurement data

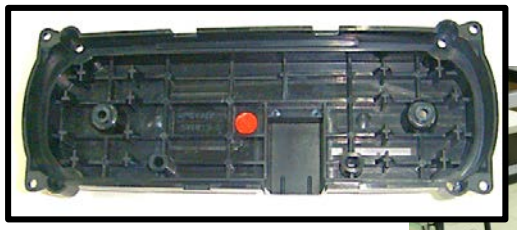
Delete unnecessary measurement data of the measured part when imaging.

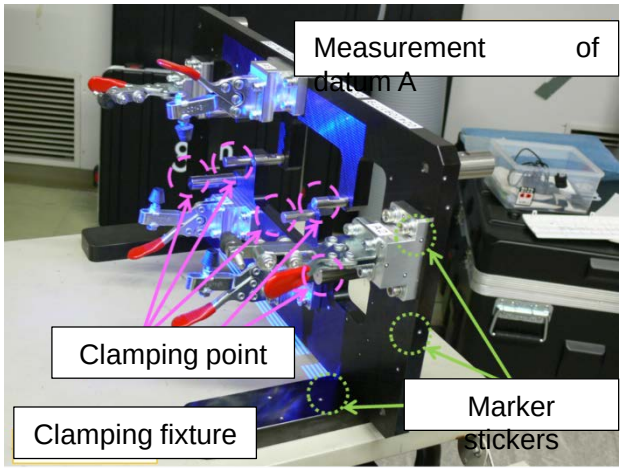
If the measurement result includes a shape that is unrelated to the product such as a jig during measurement or noise due to irregular reflection, they may need to be deleted because they may be incorrectly recognized when checking the results such as color map.

Figure 7-1 Example of cause of optical noise in shiny machined metal product

- “Optical Non-Contact Measurement Procedure”, 2019
  - a base document for more formal documentation in coming years.

Ex. Clamping Part

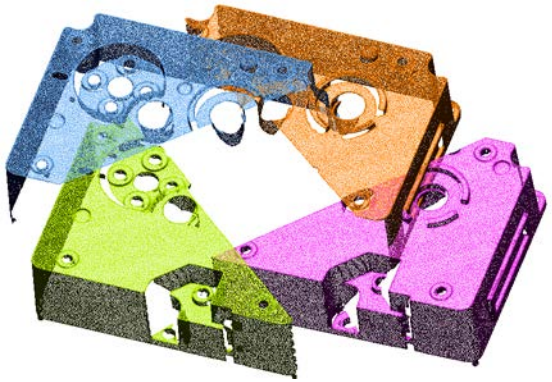




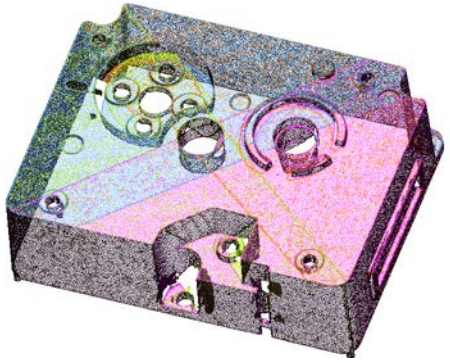
- Use of fixture
  - a fixture is used to clamp the part to determine the first datum
  - the first datum may be hidden by the fixture
- Solution
  - Paste marker stickers at several locations on the fixture
  - Measure the clamping point (on the first datum) and the marker stickers without attaching the part
  - Attach the part to the fixture and measure it with the maker stickers

Ex. Join Multiple Point Clouds of a Part

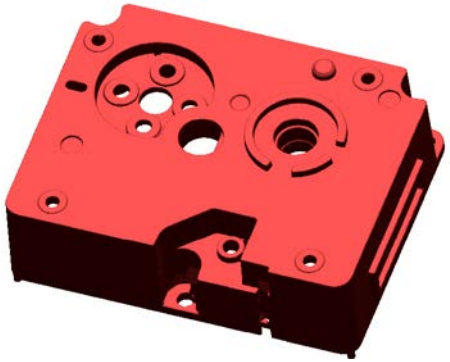
- Multiple times of measurements of a part to generate several sets of point clouds
- Need to perform registration of these point clouds
- Characteristic shapes in the overlapped area are necessary for registration
  - Overlapping areas need to be fully considered at the planning stage prior to the measurement



Multiple point clouds



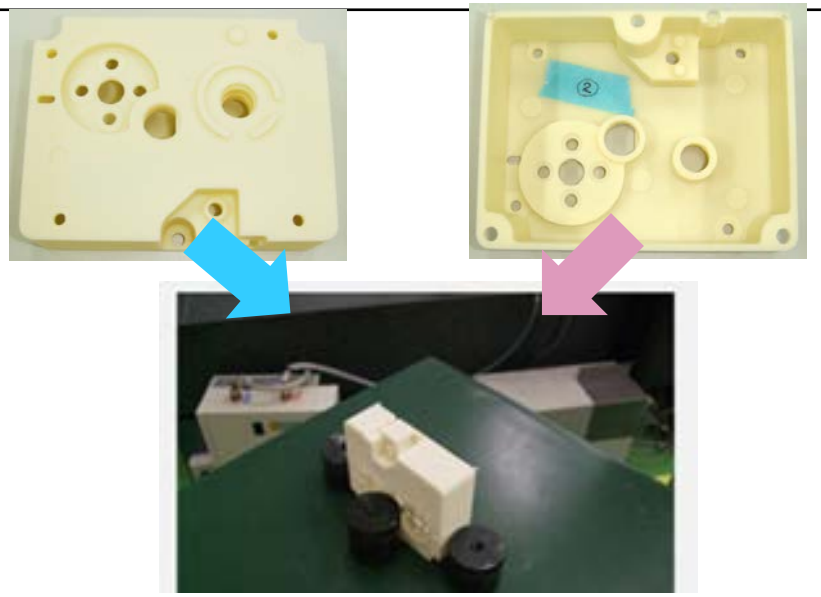
Positioning of point clouds



Integrated point clouds

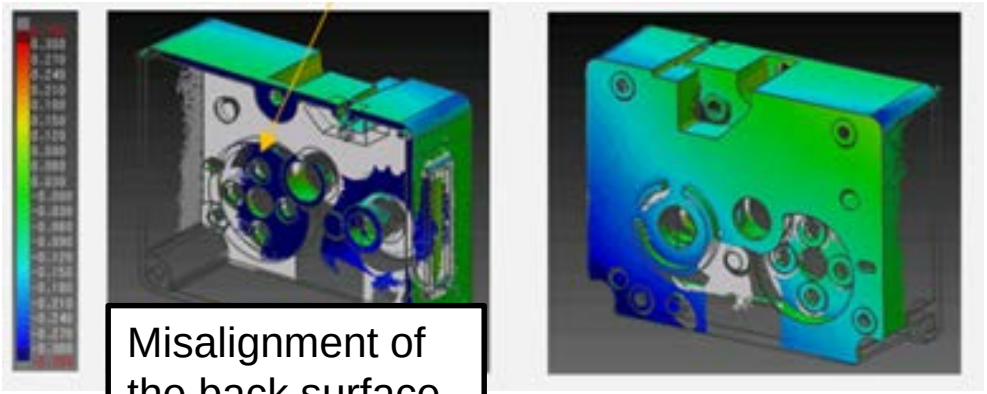
Ex. Two Sided Part (1)

- Measurement of a part with front and back surfaces
- Measure twice from the front and back then merge their point clouds
- When the overlap of the point clouds of the front and back is too little, these two surfaces cannot be aligned correctly.

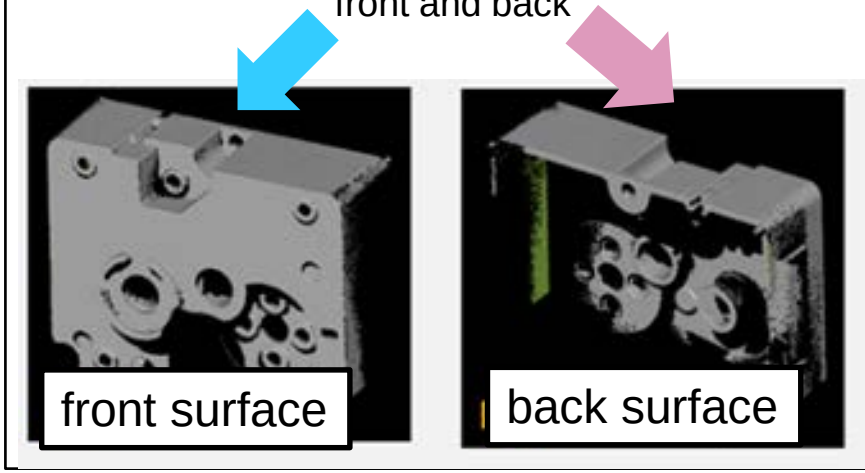


Measure twice from the front and back

Color map of deviation from 3D CAD

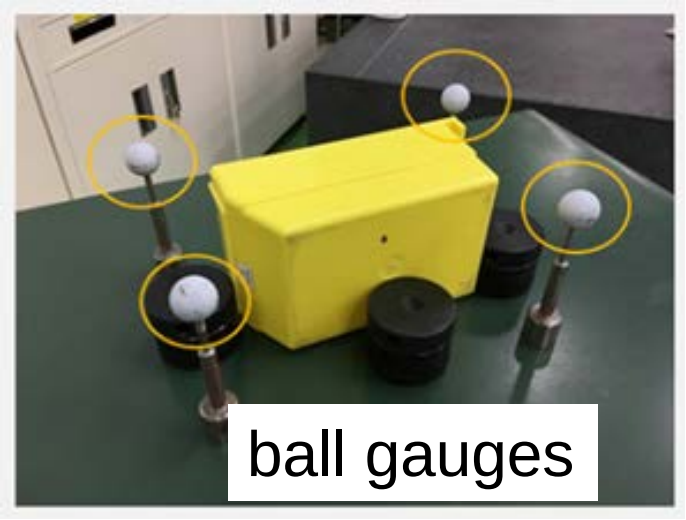


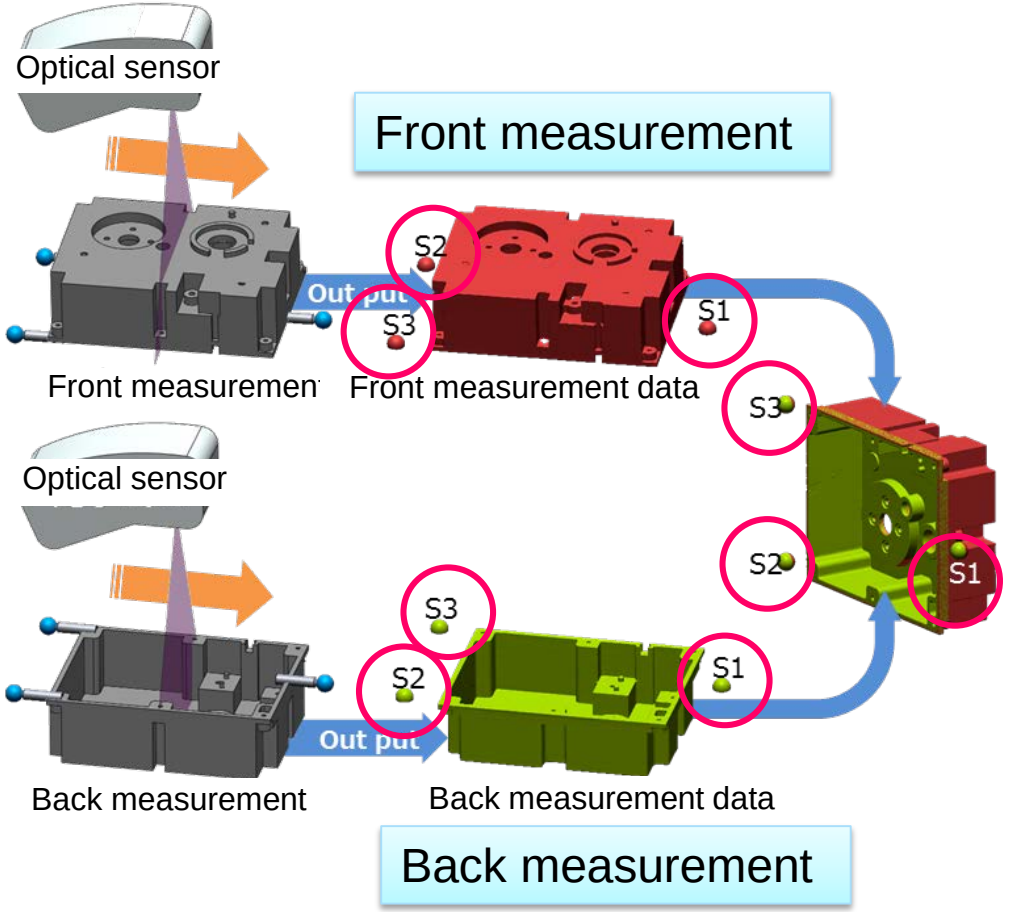
Misalignment of the back surface



Ex. Two Sided Part (2)

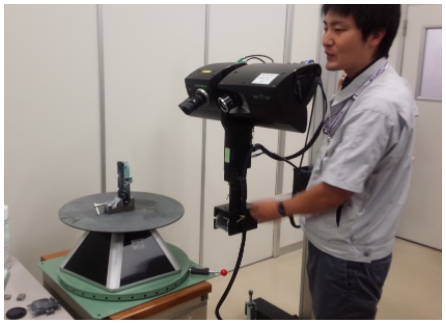
- Solution
  - Locate some positioning reference objects (ex. ball gauges) and measure them with the part
  - Use them to merge the point clouds of the front and back

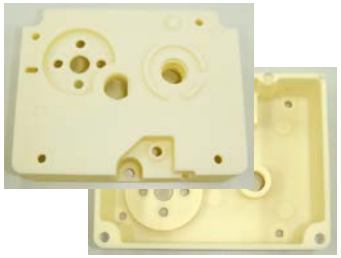


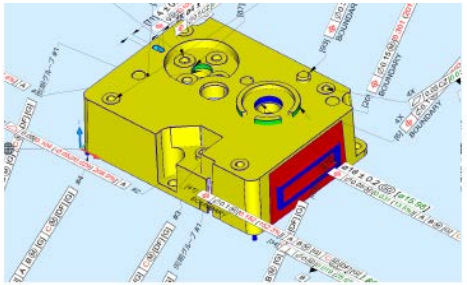


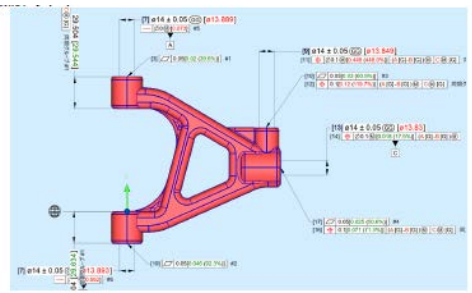
Feasibility Study

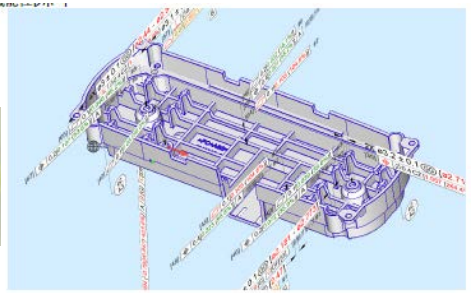
- Conduct feasibility study to evaluate the manual and to solicit comments
- Measure a set of three test pieces by following the manual
- Volunteers (5 companies and 7 local government industrial research Institutes)

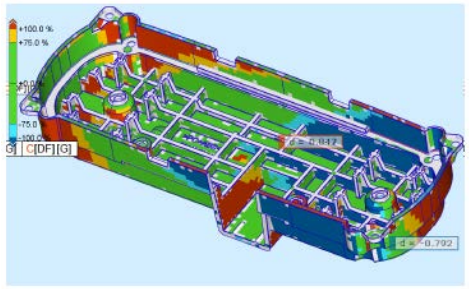












Intermediate Results

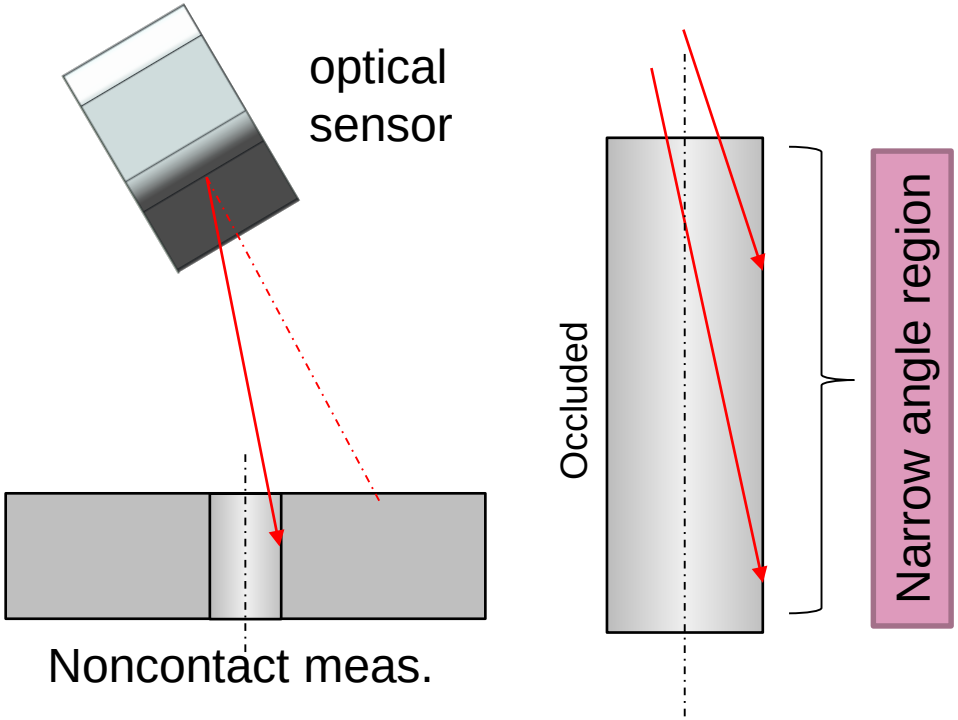
- Several issues have been raised and found for revising the manual.
- The results of tolerance evaluation with the measured point clouds are stable.

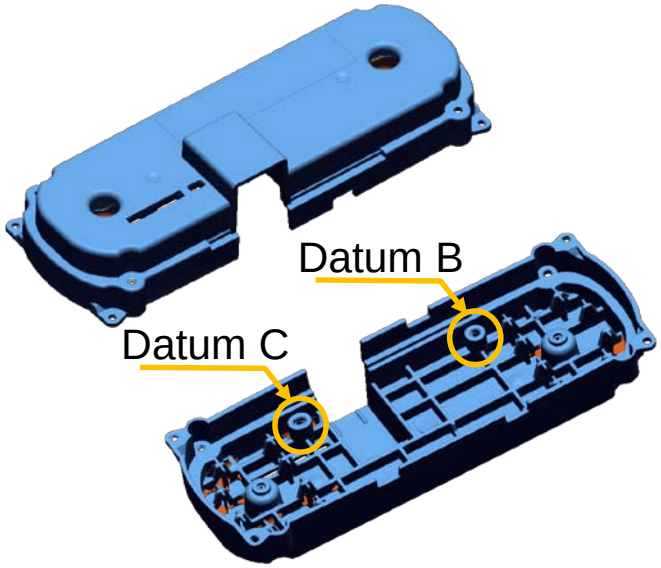
5 companies

Geometric Tolerance of Part 1

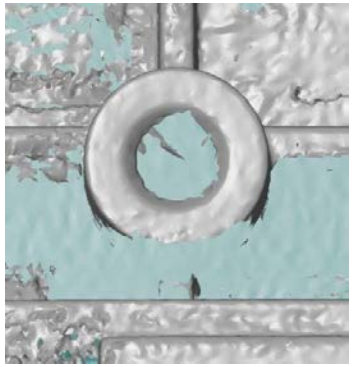
CID	Feature	Label	Nominal	Upper tol	Lower tol	A	B	C	D	E		Range
	Width(3D)001	Size「C」	3.100	0.030	-0.030	3.052	2.696	3.078	3.063	2.959		0.382
	Cyl001	Size「B」	3.100	0.030	-0.030	3.052	2.687	3.093	3.074	3.665		0.978
	Cyl002	Size	3.200	0.100	-0.100	3.127	2.774	3.154	3.146	2.380		0.774
	Cyl003	Size	3.200	0.100	-0.100	3.115	2.867	3.160	3.156	2.896		0.293
	Cyl007	Size	3.000	0.100	-0.100	2.940	2.595	2.971	2.971	3.003		0.408
	Cyl006	Size	3.000	0.100	-0.100	2.926	2.568	2.964	2.948	2.667		0.396
	Cyl005	Size	3.000	0.100	-0.100	2.958	2.484	2.980	2.966	1.783		1.197
	Cyl004	Size	3.000	0.100	-0.100	2.965	2.547	2.980	2.971	1.604		1.376
	Cyl008	Size	3.000	0.100	-0.100	2.960	2.374	2.977	2.949	3.355		0.981
	Cyl009	Size	3.000	0.100	-0.100	2.941	2.432	2.983	2.979	2.838		0.551
	Cyl010	Size	3.000	0.100	-0.100	2.959	2.460	2.994	2.988	2.546		0.534
	Cyl011	Size	3.000	0.100	-0.100	2.939	2.772	2.956	2.972	3.332		0.560
44	Width(3D)001	Position_0.1|A|B	0.000	0.100	0.000	0.102	0.076	0.099	0.110	0.402		0.326
46	Plane005	Position_0.2|A/#2	0.000	0.200	0.000	0.238	0.071	0.173	0.123	0.629		0.558
67	Plane007	Position_0.2|A/#2	0.000	0.200	0.000	0.101	0.109	0.110	0.134	1.239		1.138
39	Plane008	Position_0.4|A/#2	0.000	0.400	0.000	0.278	0.220	0.118	0.091	1.430		1.339
48	Plane004	Position_0.4|A/#2	0.000	0.400	0.000	0.289	0.242	0.142	0.107	0.741		0.634
18	Pattern002	Position_d0.4CZ|A|B|C[DF]	0.000	0.400	0.000	0.397	1.029	0.361	0.373	2.756		2.395
34	Pattern003	Position_d0.4CZ|A|B|C[DF]	0.000	0.400	0.000	0.321	1.171	0.324	0.337	1.992		1.671
35	Pattern001	Position_d0.4CZ|A|B|C[DF]	0.000	0.400	0.000	0.320	0.782	0.325	0.321	1.161		0.841
57	Cyl001	Perpendicular_d0.1|A	0.000	0.100	0.000	0.123	1.016	0.055	0.055	0.034		0.982
45	Plane004	Flatness_0.1/#2	0.000	0.100	0.000	0.074	0.106	0.064	0.069	0.430		0.366
49	Plane005	Flatness_0.1/#3	0.000	0.100	0.000	0.079	0.038	0.045	0.077	0.216		0.178
40	Plane006	Flatness_0.1/#4	0.000	0.100	0.000	0.059	0.053	0.024	0.022	0.228		0.206
65	Plane007	Flatness_0.1/#5	0.000	0.100	0.000	0.062	0.048	0.030	0.023	0.383		0.360
64	Plane009	Flatness_0.1/#7	0.000	0.100	0.000	0.085	0.104	0.243	0.143	0.909		0.824
66	Plane008	Flatness_0.2/#6	0.000	0.200	0.000	0.034	0.031	0.030	0.040	0.677		0.647
	Width(3D)001	SurfaceProfile_0.03	0.000	0.030	0.000	0.106	0.542	0.076	0.065	0.117		0.477
	Cyl001	SurfaceProfile_0.03/#8	0.000	0.030	0.000	0.070	0.681	0.023	0.050	1.113		1.090
44	Surf001	SurfaceProfile_0.4|A|B|C[DF]	0.000	0.400	0.000	0.915	1.561	1.081	1.094	1.689		0.774

Typical Issues: Measurement of holes

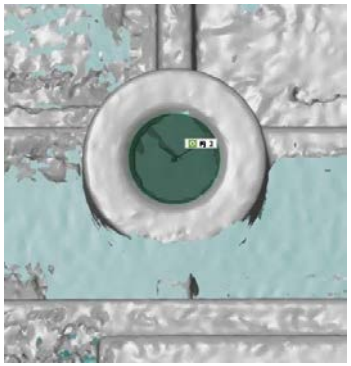




point cloud



cylinder substitute

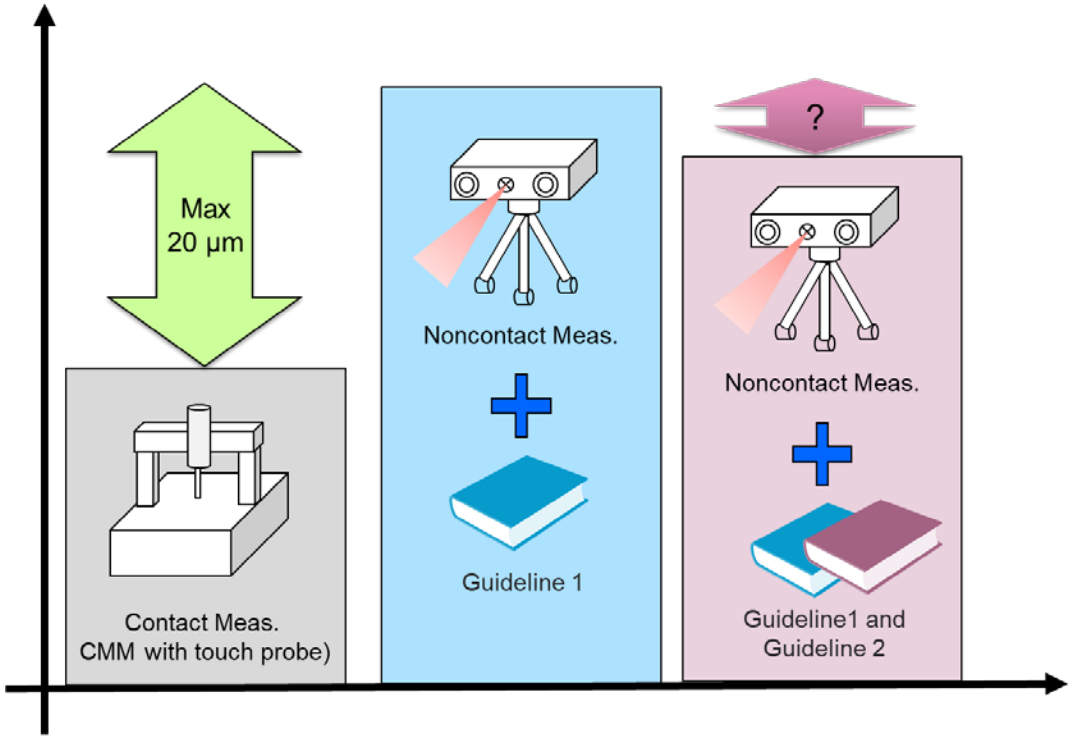


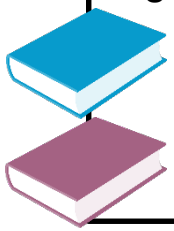
- Unstable measurement for inner hole surface to give an insufficient number of points to cover the hole surface
- Difficult to substitute a cylinder to establish a datum to the hole
  - Special treatment is needed.

How to compute the substitute cylinder
1. Compute the center by fitting a circle
2. Compute the axis vector by fitting a plane to the top surface

Acceptance Judgment of Measurement Results

- Key question?
  - Do our guidelines contribute to improve measurement accuracy?
- Experience with the 1st guideline in 2018
  - Max 20 μm difference in measurement results between CMM with touch probe and noncontact measurement using the guideline
- Investigate the measurement results with our new 2nd guideline.

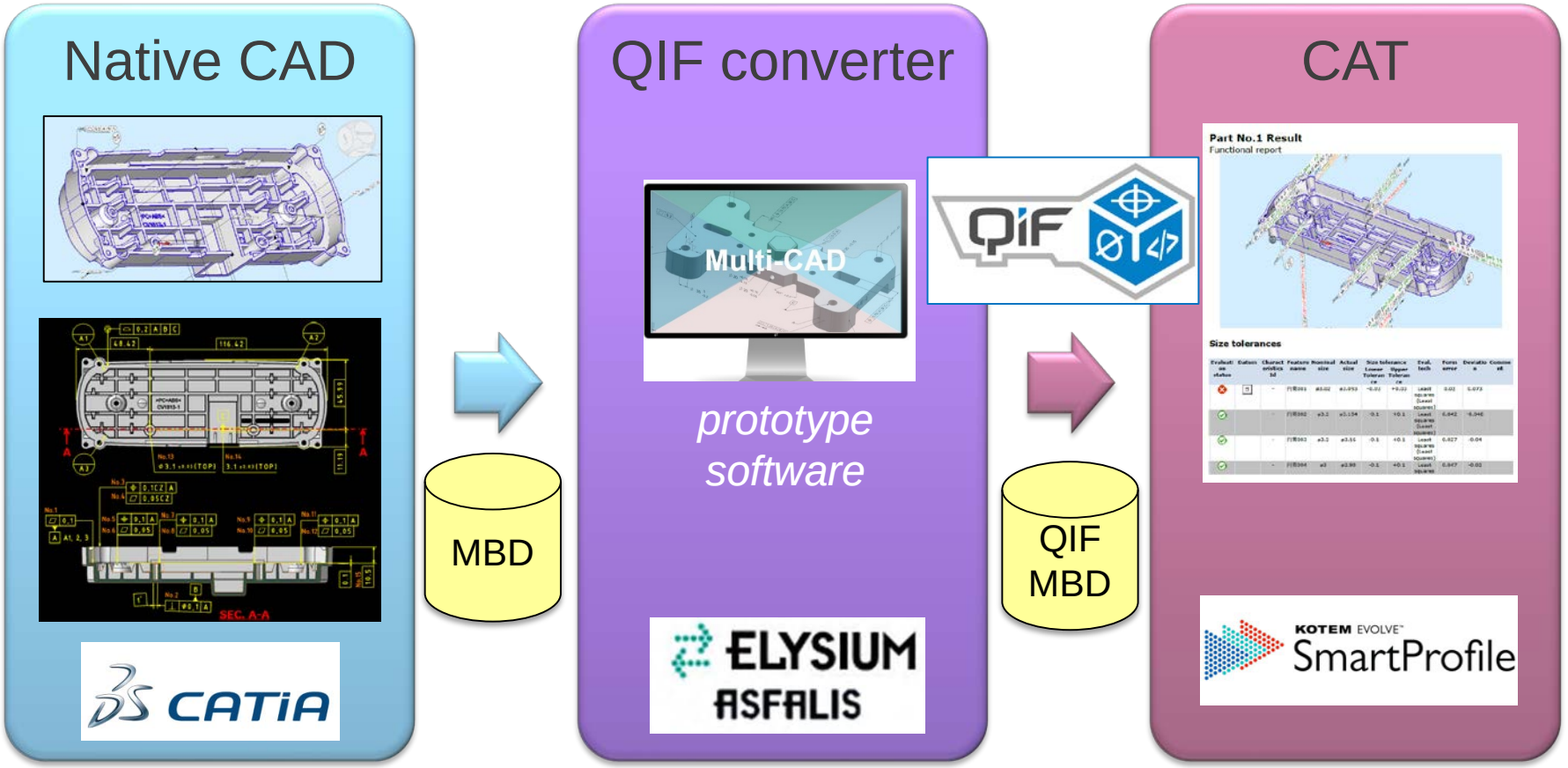




2 guidelines

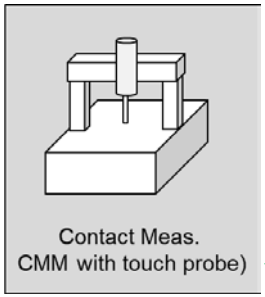
1. “Guideline for Contactless Measurement Data Processing”, 2018
2. “Optical Non-Contact Measurement Procedure”, 2019 ←*Today’s topic*

Data Flow from CAD to CAT

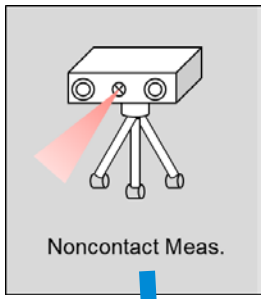


- MBD data of the test piece created by a native CAD system
- MBD data is converted to QIF MBD by a prototype software
- QIF MBD is transferred to a CAT software

Comparison of Noncontact and Contact Meas.



−



= Difference

ID	Tol. Type	#points	CMM	Noncont.	Diff.	Feature
1	Flatness	10	0.061	0.201	0.140	Large plane
3	Position	8	0.036	0.189	0.153	
4	Flatness	8	0.068	0.115	0.047	
5	Position	12	0.061	0.133	0.072	Small plane
6	Flatness	12	0.006	0.020	0.014	
7	Position	12	0.088	0.101	0.013	
8	Flatness	12	0.003	0.025	0.023	
9	Position	12	0.177	0.072	-0.105	
10	Flatness	12	0.011	0.044	0.033	
11	Position	12	0.164	0.076	-0.088	
12	Flatness	12	0.011	0.023	0.012	
2	Perpend.	24	0.168	N/A		Side of hole
13	Radius	24	3.097	3.552	0.456	use susbstitution
14	Width	6	3.095	3.586	0.491	
15	Height	6	10.536	10.528	-0.008	

Large planar features
△flatness tolerances < 150 μm
△position tolerances < 50 μm

Note: noncontact measurement based on numerous point clouds is much more realistic than those from touch probe measurement with small number of points.

Small planar features
△flatness tolerances < 30 μm
△position tolerances < 70 μm

Cylinder feature of a side face of a hole could not be evaluated its perpendicularity due to its deep interior.

Summary

- Standard procedure of noncontact measurement and that of data processing are proposed.
  - “Optical Non-Contact Measurement Procedure”, 2019
  - “Guideline for Contactless Measurement Data Processing” (post-process of the contactless measurement)
- A feasibility study using realistic test models is conducted to evaluate these guidelines and to solicit comments.
  - 5 industrial members + 7 local government research institutes
- The effects of the guidelines were well evaluated.
- We will keep improving our guidelines and solving issues identified during the feasibility study.
- In addition, they are being proposed to DMSC so that it will be included in a future version of QIF.
- Project Info.
  - International Standardization Committee for Digital Manufacturing Innovation, Japan (2018-2020)

Future Vision