ISO 9283 Summary

Overview

1. Requirements
2. Requested Tests
3. Test Procedures
4. Report
5. SA and the ISO 9283

Requirements

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Requirements

- Ambient Temperature must stay within ±2 ºC
- Tool Load must be at 100% of manufacturers specifications
- The uncertainty of the measurements shall not exceed 25% of the characteristic under testing

Requested Tests

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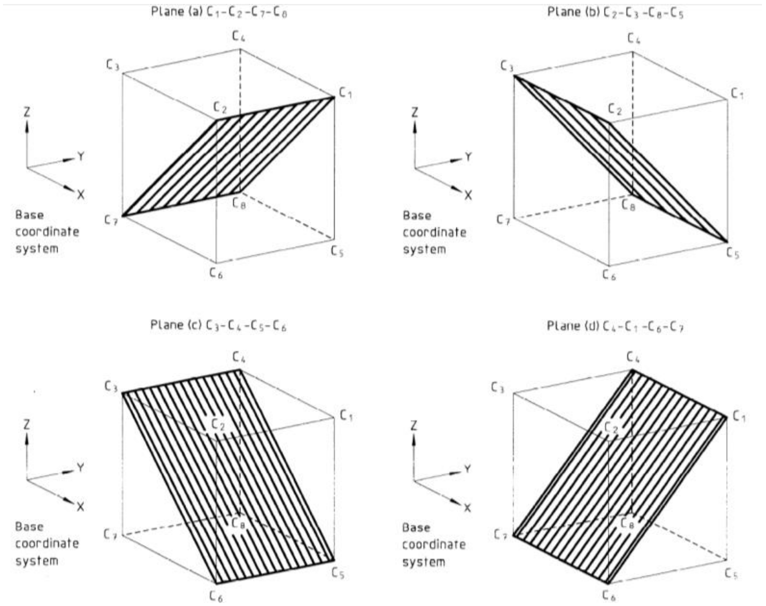
Requested Test Characteristics

- Pose accuracy and pose repeatability
- Multi directional pose accuracy variation
- Distance accuracy and distance repeatability
- Position stabilization time
- Position overshoot
- Drift of pose characteristics
- Exchangeability
- Path accuracy and path repeatability
- Path accuracy on reorientation
- Cornering deviations
- Path velocity characteristics
- Minimum posing time
- Static compliance
- Weaving deviations

How to Test

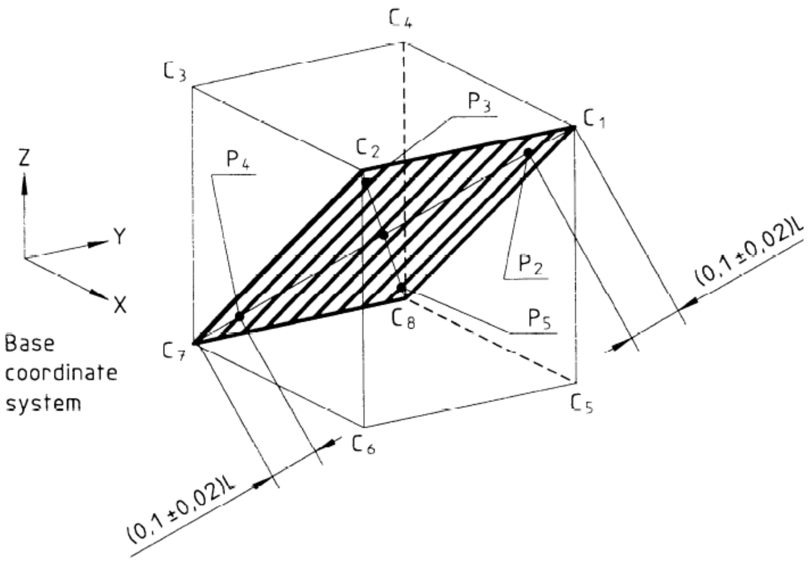
- The test shall be conducted at 100%, 50% and 10% of max velocity (50%, 10% optional for positioning tests)
- Concurrent testing is allowed, as long as the measuring device is suitable for it
- The sequence of tests can be chosen freely
- All joints shall be exercised during all movements
- The testing cube (Pt C1-C8) shall be in the working space with the greatest anticipated use and have maximum volume with its edges along the base coordinate system
- One of the following test planes must be used for pose testing
  - C1-C2-C7-C8
  - C2-C3-C8-C5
  - C3-C4-C5-C6
  - C4-C1-C6-C7



How to Test

Measurement Points within Cube

P1-P5 where P1 is the center of the cube and P2-P5 are 10% of the length of the diagonal away from the corner points

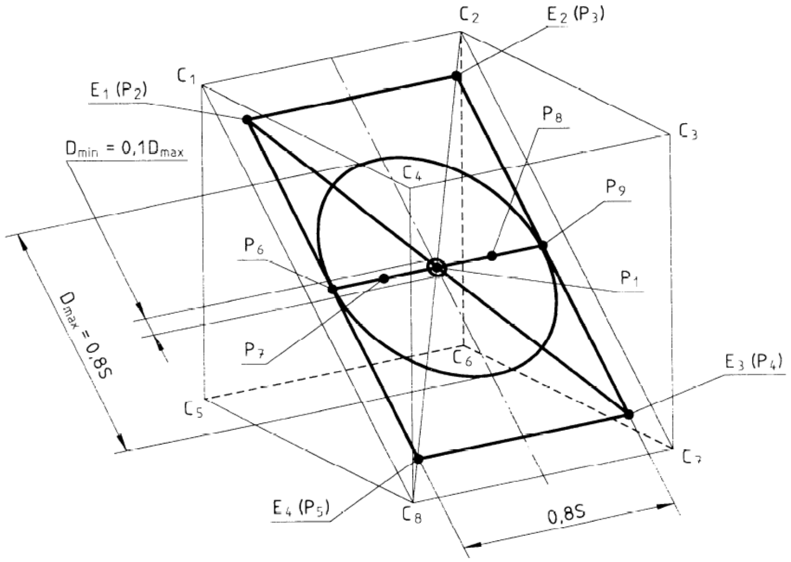


L = length of diagonal
Example showing plane a) $C_1 - C_2 - C_7 - C_8$ with poses $P_1 - P_2 - P_3 - P_4 - P_5$

How to Test

Test Paths within Cube

Two linear paths, a rectangular path and two circular paths



S = side length of cube.

How to Test

Number of Cycles per Test

Characteristic to be tested	# Cycles
Pose accuracy and pose repeatability	30
Multi-directional pose accuracy variation	30
Distance accuracy and distance repeatability	30
Position stabilization time	3
Position overshoot	3
Drift of pose characteristics	Cont. 8h
Exchangeability	30
Path accuracy and path repeatability	10
Path accuracy on reorientation	10
Cornering deviations	3
Path velocity characteristics	10
Minimum posing time	3
Weaving deviations	3

Test Procedures

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Pose Accuracy (AP)

Positioning Accuracy (P1-P2-P3-P4-P5 → 30 cycles)

The difference between the command pose and the barycenter of the attained poses

$$AP_P = \sqrt{(\bar{x} - x_c)^2 + (\bar{y} - y_c)^2 + (\bar{z} - z_c)^2}$$

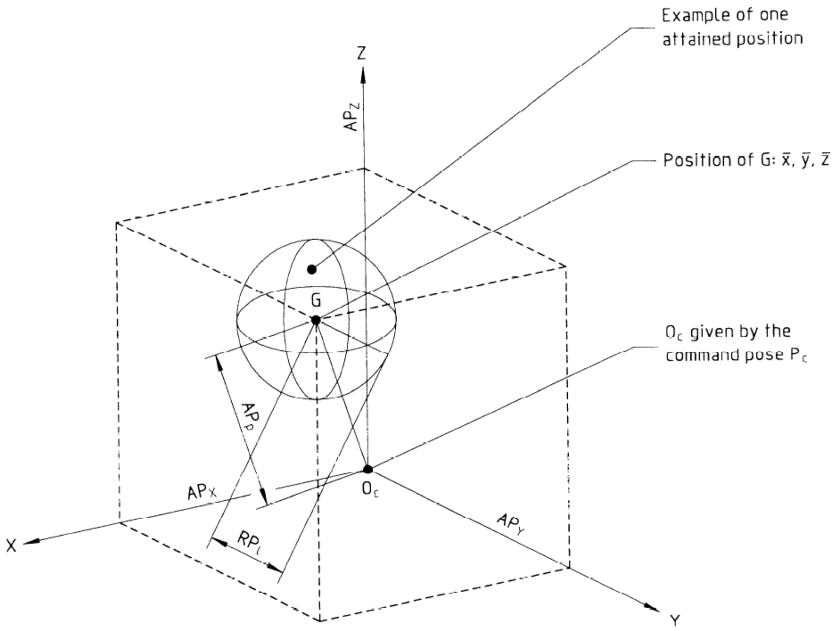
Orientation Accuracy (P1-P2-P3-P4-P5 → 30 cycles)

The difference between the command pose and the average of the attained orientations

$$AP_a = (\bar{a} - a_c)$$

$$AP_b = (\bar{b} - b_c)$$

$$AP_c = (\bar{c} - c_c)$$



Pose Repeatability (RP)

Pose repeatability (P1-P2-P3-P4-P5 → 30 cycles)

- $\bar{l}$ is the mean deviation from the barycenter

$$RP_l = \bar{l} + 3\sqrt{\frac{\sum_{j=1}^{n}\left(l_j - \bar{l}\right)^2}{n-1}}$$

Orientation repeatability (P1-P2-P3-P4-P5 → 0 cycles)

$$RP_a = \pm 3\sqrt{\frac{\sum_{j=1}^{n}\left(a_j - \bar{a}\right)^2}{n-1}}$$

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Multi Directional Pose Accuracy Variation (vAP)

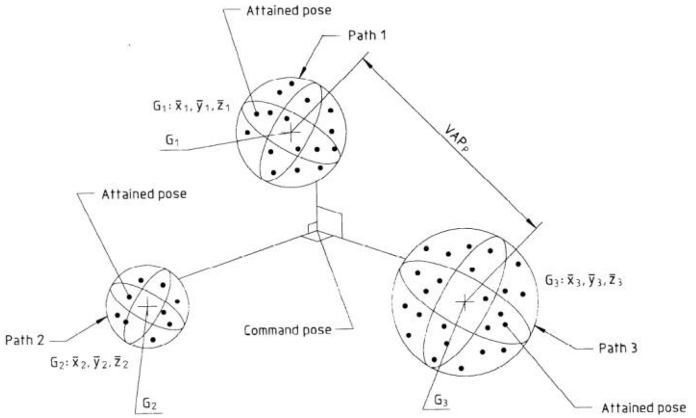
Multi Directional Pose Accuracy Variation (P1-P2-P4 → 30 cycles)

Expresses the deviation between the different mean attained poses when visiting a command pose from different directions (3 different directions necessary)

$$vAP_P = max\sqrt{(\bar{x}_h - \bar{x}_k)^2 + (\bar{y}_h - \bar{y}_k)^2 + (\bar{z}_h - \bar{z}_k)^2} \qquad h, k = 1,2,3$$

Multi Directional Orientation Accuracy Variation (P1-P2-P4 → 30 cycles)

$$vAP_a = \max|(\bar{a}_h - \bar{a}_k)| \qquad h, k = 1,2,3$$



Distance Accuracy (AD)

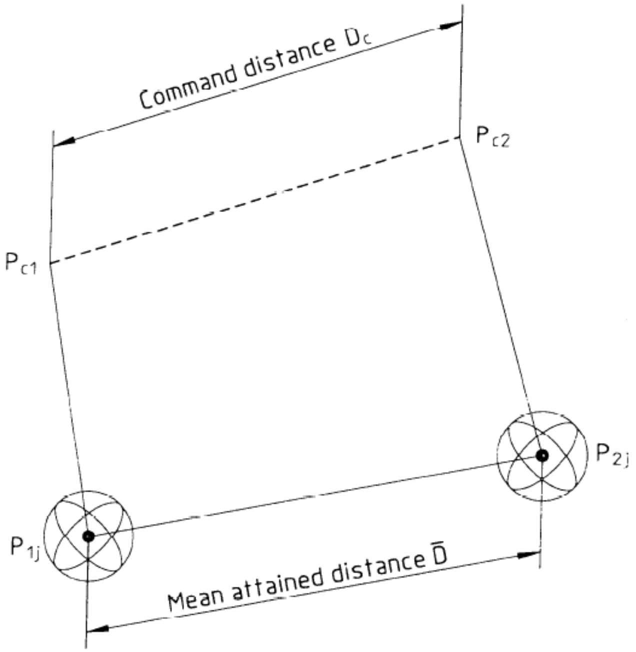
Distance Accuracy (P2-P4 → 30 cycles)

The deviation that occurs in the distance between two points when successively moving from one to another, where $\overline{D}$ is the mean measured distance. This characteristic can only be measured with nominal inputs (Numerical points, or teached point plus numerical distance)

$$AD_P = \overline{D} - D_c$$

Distance Orientation Accuracy (P2-P4 → 30 cycles)

$$AD_a = \overline{D}_a - D_{ca}$$



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Distance Repeatability (RD)

Distance Repeatability (P2-P4 → 30 cycles)

$$RD = \pm 3\sqrt{\frac{\sum_{j=1}^{n}\left(D_j - \bar{D}\right)^2}{n-1}}$$

Distance Orientation Repeatability (P2-P4 → 30 cycles)

$$RD_a = \pm 3\sqrt{\frac{\sum_{j=1}^{n}\left(D_{aj} - \bar{D}_a\right)^2}{n-1}}$$

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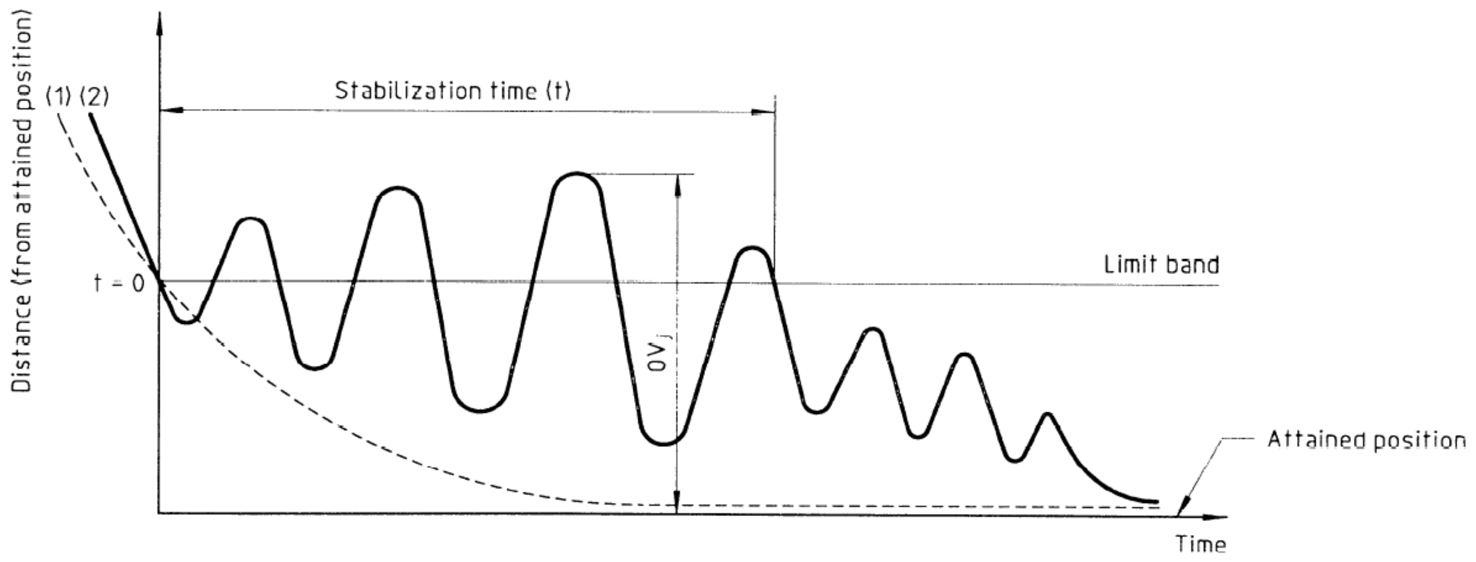
Position Stabilization Time (t)

Position Stabilization Time (P1 → 3 cycles)

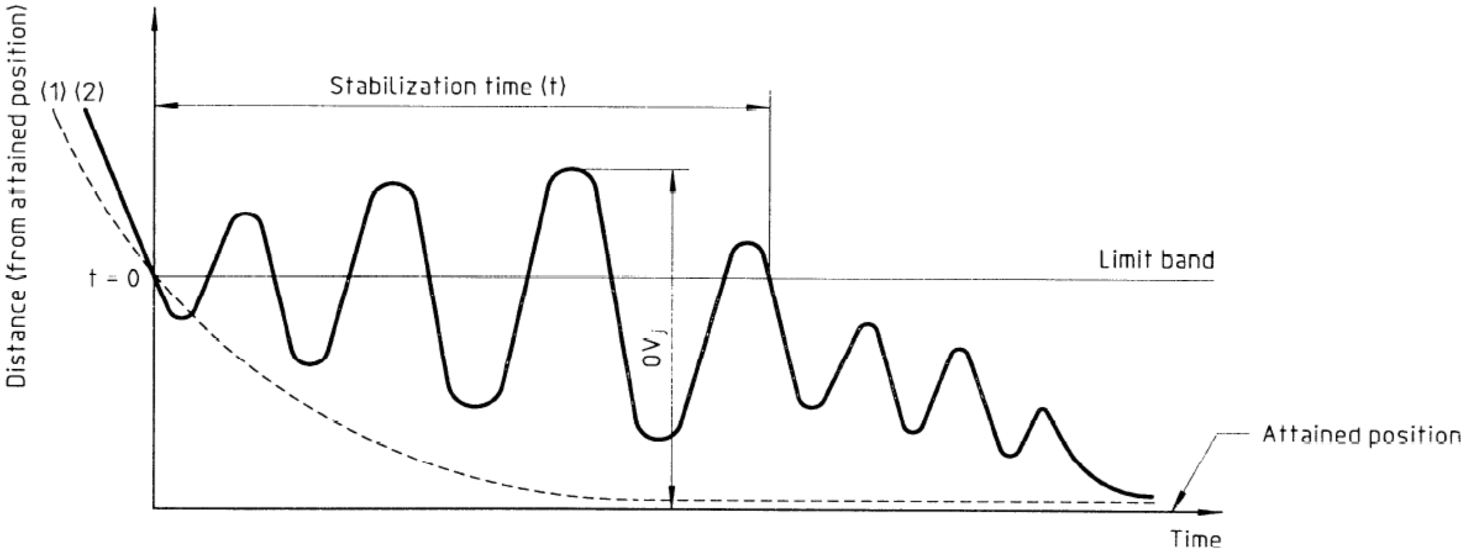
The stabilization time is measured as time from the initial crossing of the limit band of the attained pose until it stays within the limit band. The limit band is defined as the repeatability as stated by the manufacturer. Measurements must be taken continuously with the highest frequency possible.



Positon Overshoot (OV)

Position Overshoot (P1 → 3 cycles)

The overshoot is measured as the maximum distance from the attained position after the instance of the initial crossing into the limit band. The limit band is defined as the repeatability as stated by the manufacturer. Measurements must be taken continuously with the highest frequency possible.



Drift Of Pose Characteristics (dAP)

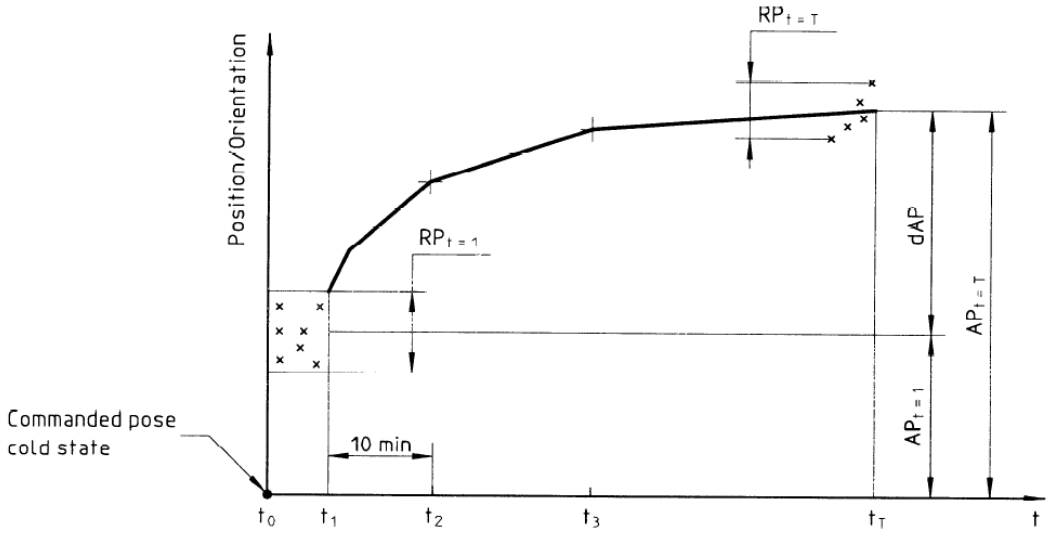
Drift Of Pose Accuracy (P1 → 8h cont. cycling)

Start from a cold robot. Measure P1 (coming from P2) 10 times sequentially and calculate AP. Wait 10 min, then repeat until stability is reached (max. 8 h)

$$dAP_P = |AP_{t=1} - AP_{t=T}|$$

Drift Of Pose Repeatability (P1 → 8h cont. cycling)

$$dRP_P = |RP_{t=1} - RP_{t=T}|$$

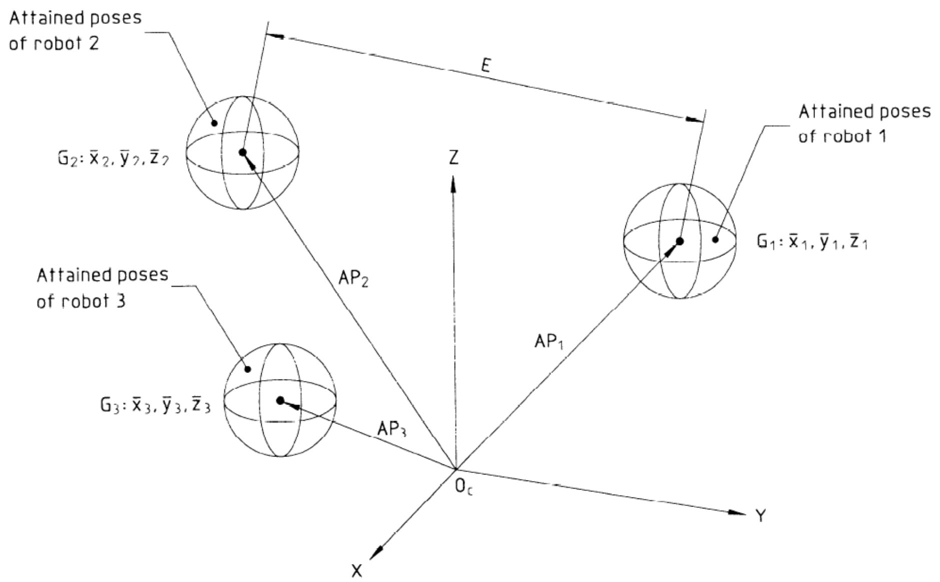


Exchangeability (E)

Exchangeability (P1-P2-P3-P4-P5 → 30 cycles with 5 different robots)

Exchangeability is the distance between the barycenter of the two robots which have the maximum deviation to the command pose. The command poses are defined with the first robot and shall stay the same.

$$E = max\sqrt{(x_h - x_k)^2 + (y_h - y_k)^2 + (z_h - z_k)^2} \qquad h,k = 1,2,3,4,5$$



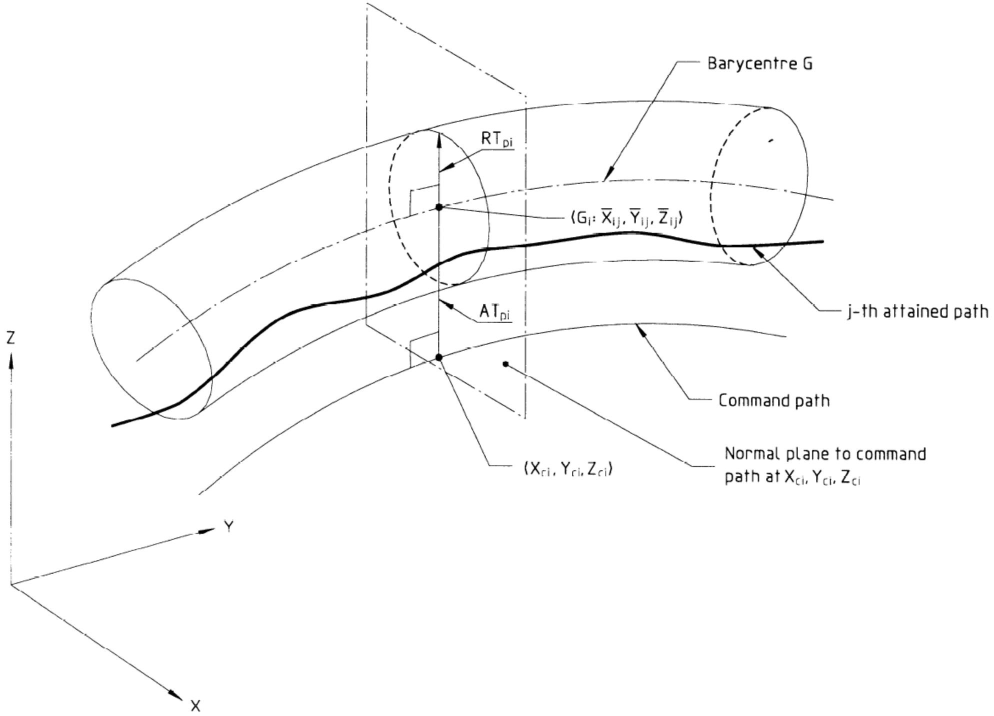
Path Accuracy (AT)

Path Accuracy (Rect Path E1-E4, Two Circ Paths → 10 cycles)

The path accuracy is the maximum deviation along the path in positioning and orientation. The evaluation is done by selecting m normal planes along the command path. For each cycle the intersection of the attained path with the selected normal plane represents a measured point p_j of plane i.

$$AT_p = max\sqrt{(\bar{x}_i - x_{ci})^2 + (\bar{y}_i - y_{ci})^2 + (\bar{z}_i - z_{ci})^2} \qquad i = 1 \ldots m$$

$$AT_a = \max|\bar{a}_i - a_{ci}| \qquad i = 1 \ldots m$$



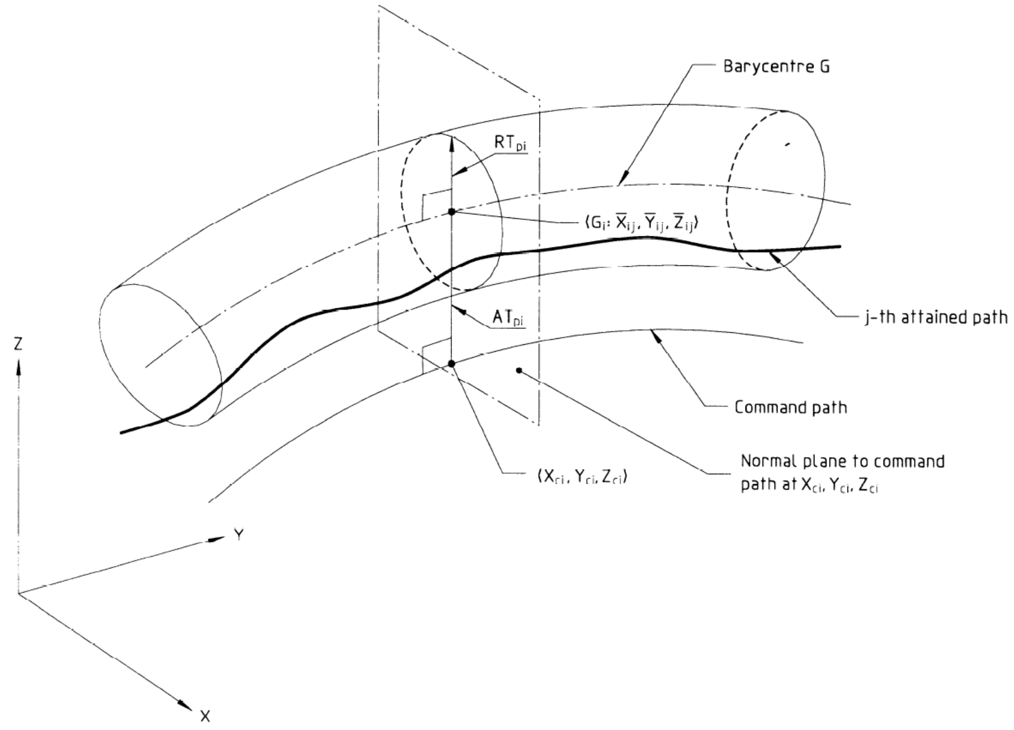
Path Repeatability (RT)

Path Repeatability (Rect Path E1-E4, Two Circ Paths → 10 cycles)

The path repeatability is equal to the maximum radius of a circle in the normal plane with its center on the barycenter line, including all measured points in this normal plane.

$$RT_p = \max\left[\bar{l}_i + 3\sqrt{\frac{\sum_{j=1}^{n}\left(l_{ji} - \bar{l}_i\right)^2}{n-1}}\right] \quad i = 1 \dots m$$

$$RT_a = \max\left[3\sqrt{\frac{\sum_{j=1}^{n}\left(a_{ji} - \bar{a}_i\right)^2}{n-1}}\right] \quad i = 1 \dots m$$



Path Accuracy on Reorientation

Path Accuracy with Alternation around Y_n (P6-P9 →10 cycles)

Evaluation of the path accuracy is the same as before, but the orientation of the TCP has to be changed as follows

- B_n at P6 +30º
- B_n from P6 to P1 -30º
- B_n from P1 to P9 +30º

Path Accuracy with Alternation around X_n and Z_n (P6-P9 →10 cycles)

Evaluation of the path accuracy is the same as before, but the orientation of the TCP has to be changed as follows

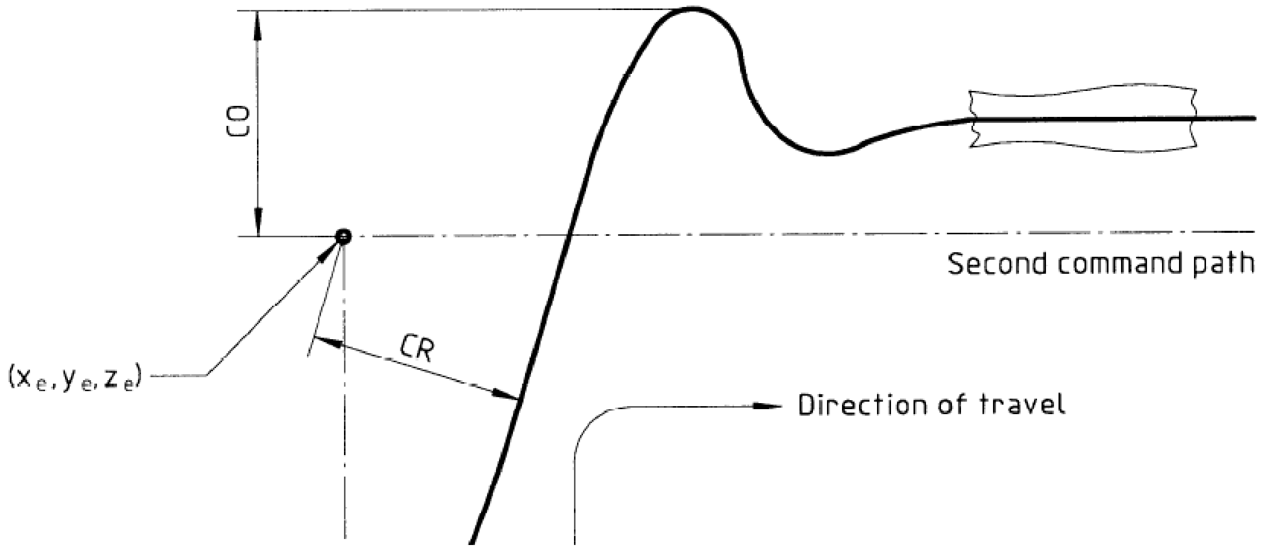
- A_n at P6 +30º
- A_n from P6 to P7 0º
- C_n from P7 to P1 -30º
- C_n from P1 to P8 0º
- A_n from P8 to P9 -30º

Corner Round Off Error (CR)

Corner Round Off Error (E1-E2-E3-E4 → 3 cycles)

Is the maximum radius of three consecutive cycles, where the circle is defined as a circle around the edge point where the attained path is tangential.

$$CR = \max\left[min_j\sqrt{(x_i - x_e)^2 + (y_i - y_e)^2 + (z_i - z_e)^2}\right] \quad \mathrm{j} = 1,2,3$$



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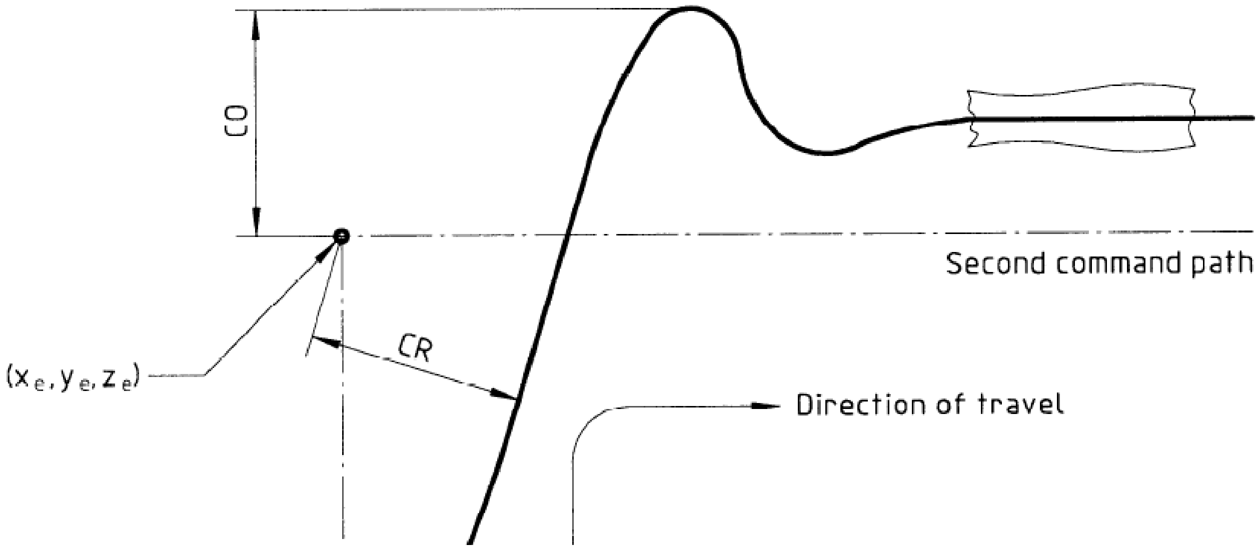
Cornering Overshoot (CO)

Cornering Overshoot (E1-E2-E3-E4 → 3 cycles)

The overshoot is the maximum deviation from the second command path, after the robot start to move along the second command path. If the second command path is defined as the z-axis the overshoot is calculated as follows.

$$CO = \max\left[max_j\sqrt{(x_i - x_{ci})^2 + (y_i - y_{ci})^2}\right] \quad j = 1,2,3$$



Path Velocity Characteristics

Path Velocity Accuracy (AV) (10 cycles)

Is defined as the error between the command velocity and the mean of the attained velocity

$$AV = \frac{\bar{v} - v_c}{v_c} x100$$

Path Velocity Repeatability (RV) (10 cycles)

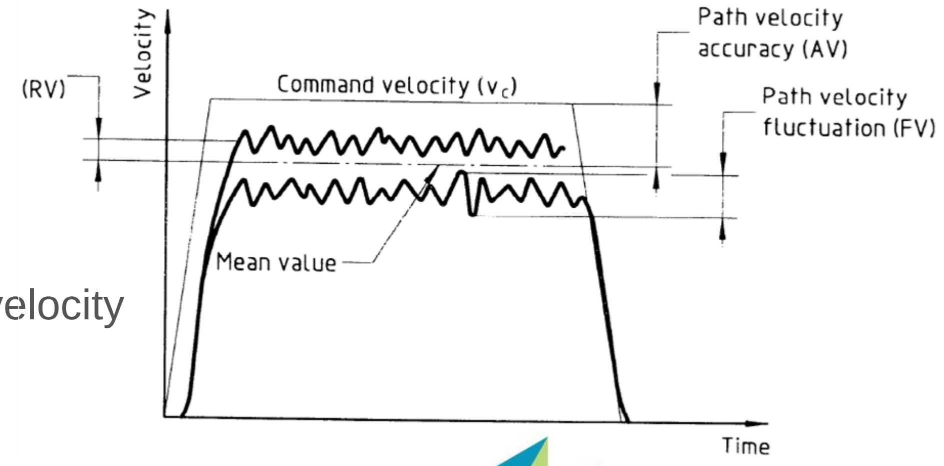
Is a measure of the closeness of agreement of the velocities attained for the same command velocities

$$RV = \pm\left(\frac{3}{v_c}\sqrt{\frac{\sum_{j=1}^{n}\left(\bar{v}_j - \bar{v}\right)^2}{n-1}}x100\right)$$

Path Velocity Fluctuation (FV) (10 cycles)

Is the maximum deviation in velocity during one replication with one command velocity

$$FV = \max\left[max_{i=1}^{m}\left(v_{ij}\right) - min_{i=1}^{m}\left(v_{ij}\right)\right] \quad \mathrm{j = 1 \dots n}$$



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Minimum Posing Time

Posing Time (P1 – P1+7 → 3 cycles)

The posing time is the time between departure from and arrival at a stationary state when traversing a predefined distance. The robot shall be moved at 100% velocity. The poses are programmed along a cube diagonal where P1 is the cube center

Point	P1	P1+1	P1+2	P1+3	P1+4	P1+5	P1+6	P1+7
Distance	0	-10	+20	-50	+100	-200	+500	-1000

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Static Compliance

Static Compliance (3 cycles per direction)

Is defined as the maximum displacement per unit of applied load. The test shall be done with the servos on and the brakes off while the robot is in P1. The loads shall be increased in 10% steps of rated max load and be applied in each direction of the base coordinate system (both negative and positive). The displacement shall be reported in mm/N applied load.

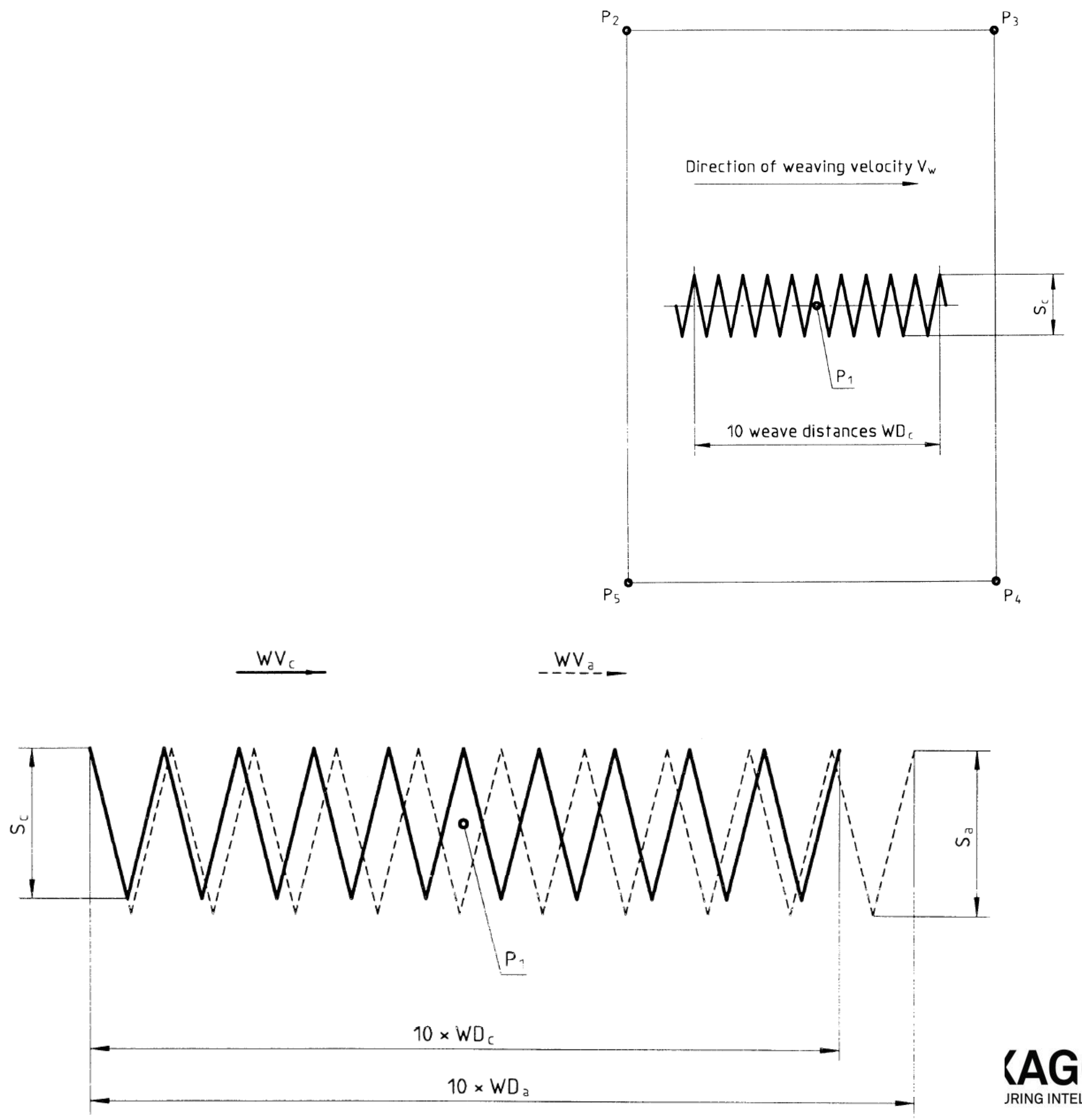
Weaving Deviations

- Weaving Stroke Error (WS) (At least 10)

$$WS = \frac{S_a - S_c}{S_c} x100$$

- Weaving Frequency Error (WF) (At least 10)

$$WF = \frac{F_a - F_c}{F_c} x100$$



Report

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What Needs To Be Stated

- Method of command pose entry (teaching, offline, numerical, etc.)
- Relationship between base coordinate system and selected testing coordinate system
- Measurement point position (TCP offset)
- Figure showing the test cube (with coordinates)
- Distance accuracy command pose input method
- Number of normal planes for trajectory analysis
- Corner smoothing method (if one was used for cornering deviations)
- Any reduction in velocity, while measuring cornering deviations
- All measurement results

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Characteristics	Possible Solution	Remarks
Pose accuracy and pose repeatability	SA Ultimate + AIC (Poses natively programmed and exported), or SA Machine (Poses already inside SA)	Both T-MAC or 3 reflectors would work for orientation acquisition
Multi-directional pose accuracy variation	SA Ultimate + AIC (Poses natively programmed and exported), or SA Machine (Poses already inside SA)	Both T-MAC or 3 reflectors would work for orientation acquisition
Distance accuracy and distance repeatability	SA Ultimate + AIC (Poses natively programmed and exported), or SA Machine (Poses already inside SA)	Both T-MAC or 3 reflectors would work for orientation acquisition
Position stabilization time	SA Ultimate + AIC (Poses natively programmed and exported), or SA Machine (Poses already inside SA). Measure continuously and export points, plot behavior and read out manually. Timestamps are stored along with measured points → calculate time	Both T-Mac or reflector possible, as orientation is not demanded. The main challenge is the unknown nyquist frequency to avoid aliasing.
Position overshoot	SA Ultimate + AIC (Poses natively programmed and exported), or SA Machine (Poses already inside SA). Measure continuously and export points, plot behavior and read out manually	Both T-Mac or reflector possible, as orientation is not demanded. The main challenge is the unknown nyquist frequency to avoid aliasing.
Drift of pose characteristics	SA Ultimate + AIC (Poses natively programmed and exported), or SA Machine (Poses already inside SA)	Both T-MAC or reflector would work

SA and the ISO 9283

Characteristics	Possible Solution	Remarks
Exchangeability	SA Ultimate + AIC (Poses natively programmed and exported), or SA Machine (Poses already inside SA)	Both T-MAC or reflector would work
Path accuracy and path repeatability	SA Ultimate + AIC (Poses natively programmed and exported), or SA Machine (Poses already inside SA)	T-MAC is necessary as dynamic orientation measurements are demanded. Measuring device with high resolution and measuring frequency necessary
Path accuracy on reorientation	SA Ultimate + AIC (Poses natively programmed and exported), or SA Machine (Poses already inside SA)	T-MAC is necessary as dynamic orientation measurements are demanded. Measuring device with high resolution and measuring frequency necessary
Cornering deviations	SA Ultimate + AIC (Poses natively programmed and exported), or SA Machine (Poses already inside SA)	Both T-MAC or reflector would work. The main challenge is the unknown nyquist frequency to avoid aliasing.
Path velocity characteristics	SA Ultimate + AIC (Poses natively programmed and exported), or SA Machine (Poses already inside SA)	Both T-MAC or reflector would work. Measuring device with high resolution and measuring frequency necessary. Can be measured, however, some manual work is necessary, as velocity must be calculated form timestamps and position.
Minimum posing time	Should be done natively, because of communication delays. Also SA is designed to measure 6D positions and not time.	

SA and the ISO 9283 Evaluation

- Almost every characteristic can be measured and evaluated using SA Ultimate & MP programming
- Both AIC and SA Machine are possible solution, whereas SA Machine would be the cleaner and more maintainable solution
- For some characteristics plotting and manual evaluation is probably necessary
- For velocity evaluations, etc. the measuring frequency could lead to difficulties as the robot has always to move at max velocity. For velocities of 2 m/s this would mean a resolution of only 2 mm for a Leica system and even less for other systems. Also the nyquist frequency is unknown and we can’t therefore guarantee an accurate signal.
- Posing time should best be measured on the robot side, as the communication delays would distort the measurement results

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Questions?

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THANK YOU!