10/13/2020 ver.2

Base Plate and its coordinate system

The fixture for glue deposition and module mounting of rings has two components. First is an eight-sided irregularly shaped Base Plate that sits in a fixed location on the Glue Robot. The second is a square plate that can rotate relative to the Base Plate, and supports the handling frame, which has the same dimensions. The square plate is locked into one of three well-defined orientations during use. Fig. 1 shows the square plate aligned to the middle alignment mark.

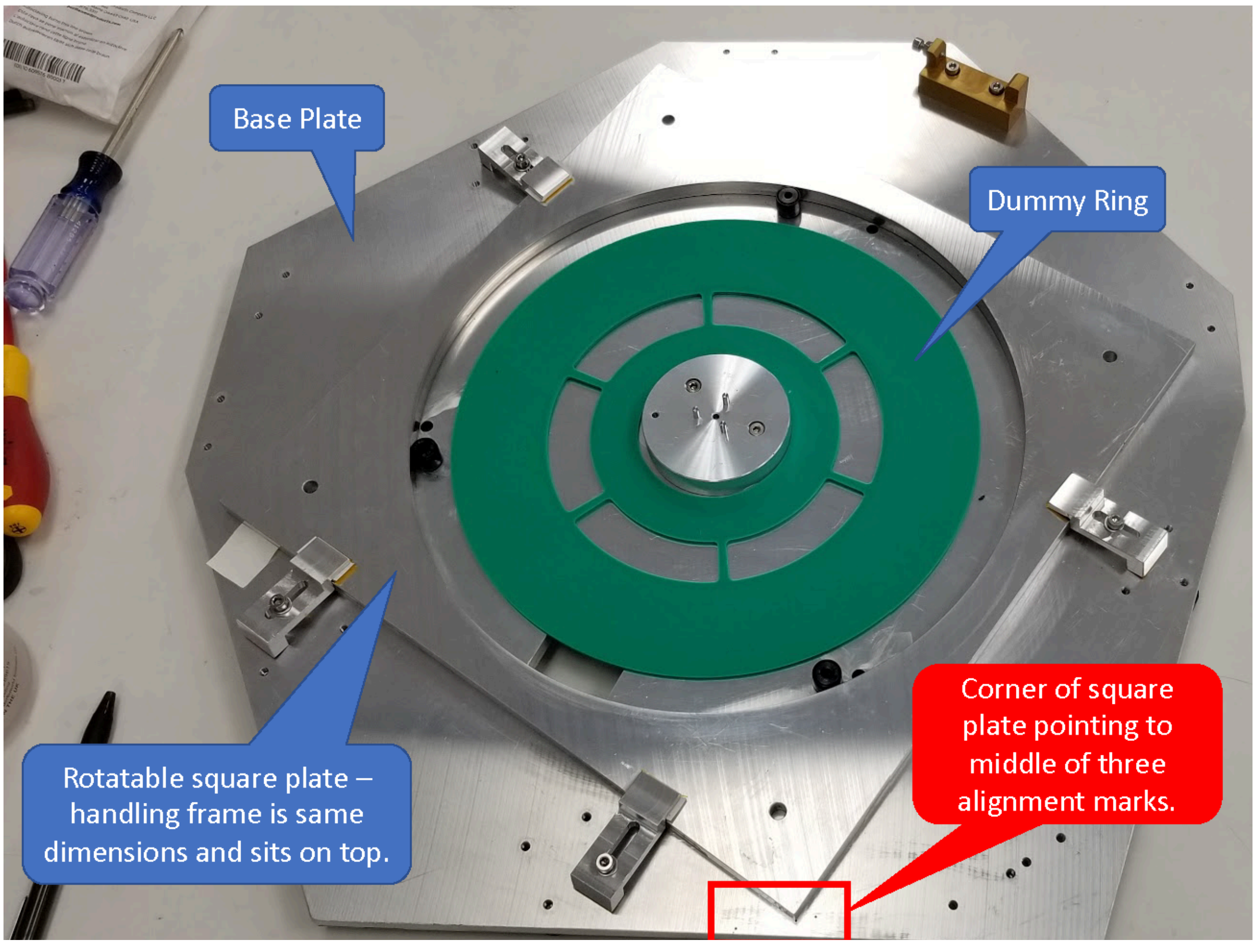


Figure 1: Supports for ring during glue deposition.

The +x and +y axes of the Base Plate are defined by datum B and datum A respectively in drawing REF-000115259. See Fig. 2. The three alignment marks are near the bottom corner of the square plate in this view. Module center positions are provided initially in this coordinate system, and have to be transformed to Glue Robot coordinates for programming.

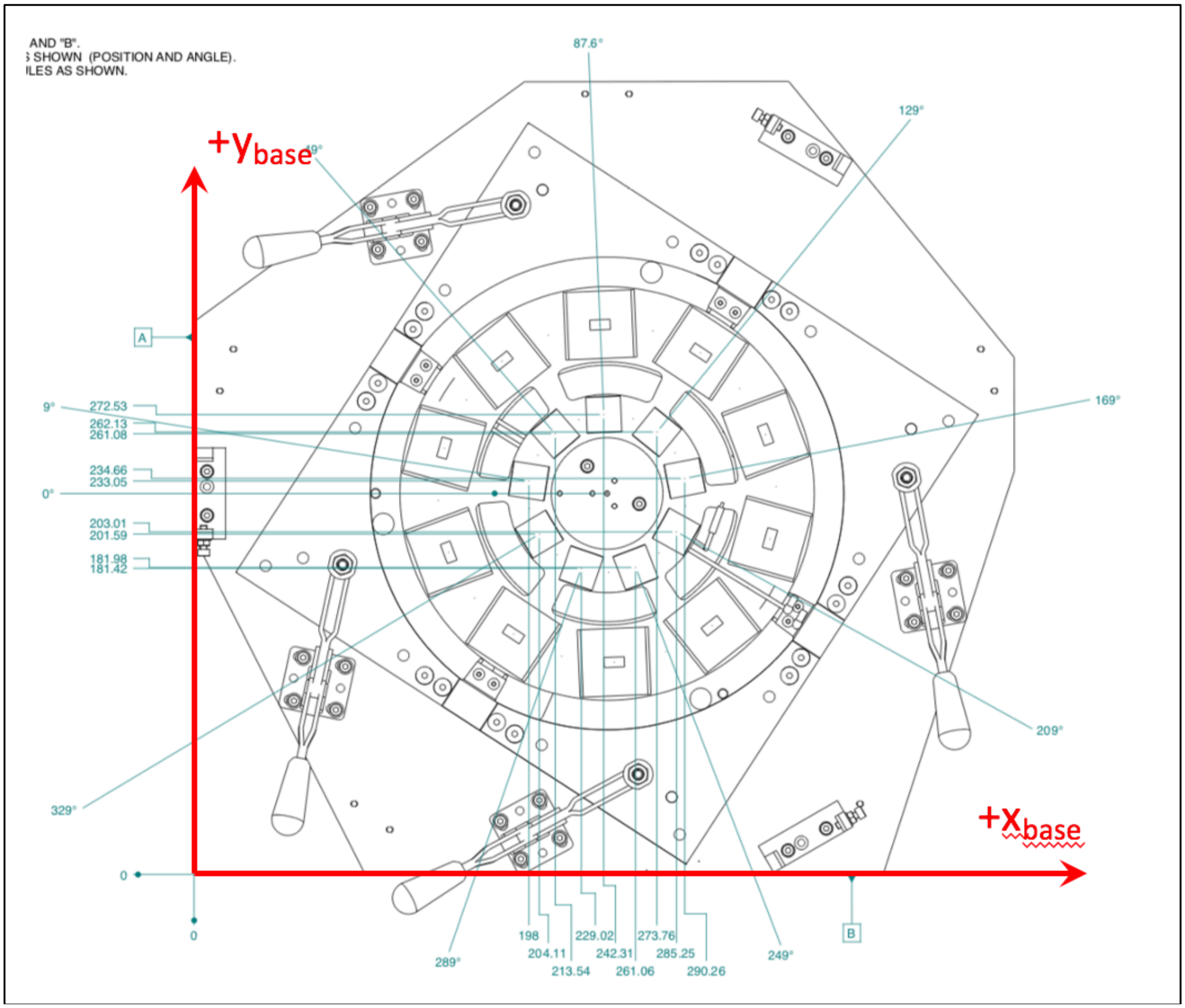


Figure 2: Base Plate coordinates

Note that the details in Fig. 2 are for Prototype 19-0. They do not apply to 19-1: cooling pipes have been modified and module positions have changed. However, the Base Plate is unchanged, in particular x_{base}, y_{base} and the three alignment marks.

Glue Robot coordinate system

The Glue Robot operates in its own coordinate system. When standing in front of it and looking down, axes orientation is as illustrated in Fig. 3:

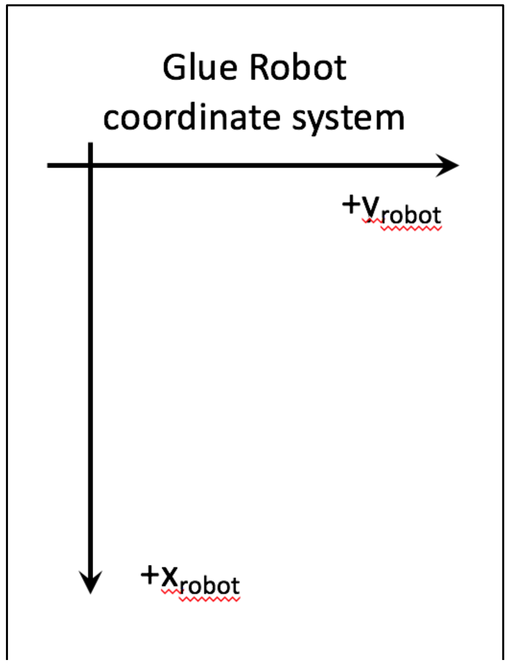


Figure 3: Robot coordinate system seen when standing in front and looking down.

Base Plate on Glue Robot

When installed on the Glue Robot, the Base Plate is oriented approximately as shown in Fig. 4. The $+x_{base}$ direction points to the $(-x_{robot}, -y_{robot})$ quadrant, and the $+y_{base}$ direction points to the $(+x_{robot}, -y_{robot})$ quadrant. The three alignment marks are now near the upper corner of the handling frame.

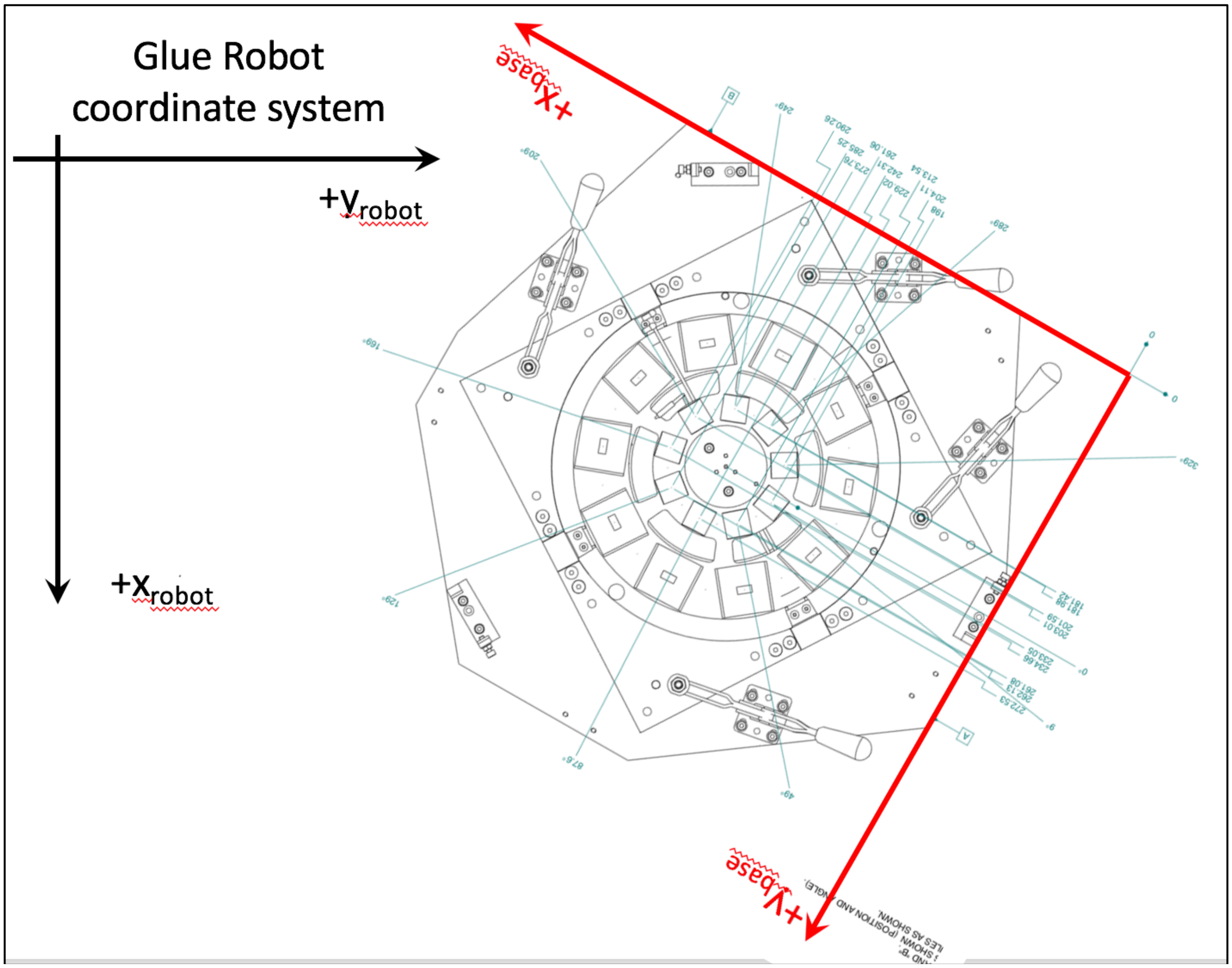


Figure 4: Base Plate and Glue Robot coordinate systems.

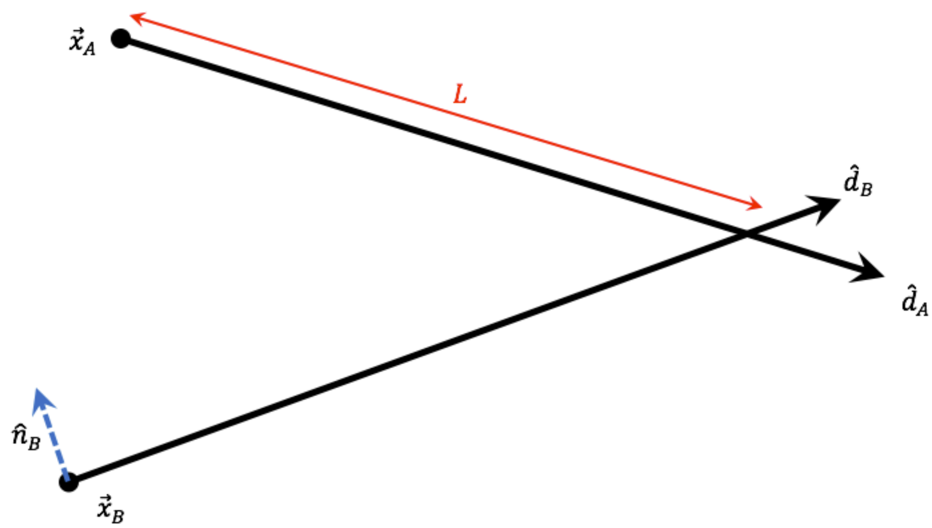
Determining Base Plate Axes in Glue Robot Coordinates

Gently run the edge sensor (see Scott's slides in 8/25 meeting https://indico.cern.ch/event/949175/contributions/3987909/attachments/2091451/3514331/Tooling_Update_25_Aug_2020.pdf) to touch the plate edge corresponding to x_{base}, i.e. datum B, and record its position in Glue Robot coordinates. Repeat for several points. A minimum of three point should be used to over-constrain the line. Space out the measurement points to cover the length of the edge for more precise determination of its direction.

Use sheet 'Datum B' in the spreadsheet to calculate the edge in Glue Robot coordinates. Replace numbers in cells with yellow background with actual measurements. We assume that each point has a measurement uncertainty of 0.50 mm. This is reverse engineered to give $\chi^2 \sim 1$; it is also compatible with what we know about the machinery. Update the formulas in cells with light blue background so they operate on the appropriate number of measurements. Check that fit quality is OK. The calculation accounts for an offset between the edge sensor and the physical edge of the Base Plate with the latter in the $(+x_{robot}, -y_{robot})$ direction relative to the sensor.

Repeat for y_{base}, using the sheet 'Datum A'. Note that the physical edge sensor position is in the $(-x_{robot}, -y_{robot})$ direction relative to the sensor.

The intersection of these two edges is calculated in the sheet 'Intersection'. Each edge or line is defined by a point $\vec{x}$ and a unit vector $\hat{d}$, and $\hat{n}$ is a unit vector normal to the line. The intersection point is a distance L from the point x_A in the direction $\hat{d}_A$. This point is also on line B, which is by definition orthogonal to $\hat{n}_B$: $\hat{n}_B \cdot \left(\vec{x}_A + L\hat{d}_A - \vec{x}_B\right) = 0$. Therefore, the intersection point of the two edges is given by $\vec{x}_A + \frac{(\vec{x}_B - \vec{x}_A)\cdot\hat{n}_B}{\hat{d}_A\cdot\hat{n}_B}\hat{d}_A$. In the limit where the two lines A and B are orthogonal, the denominator is one and the factor in front of $\hat{d}_A$ is simply the perpendicular distance from point A to line B.



The transformation from the Base Plate coordinate system to the Glue Robot coordinate system involves a rotation and a translation. The rotation is computed based entirely on the direction of datum B, i.e. the x_{base} axis, because it is longer than datum A and should therefore be better determined.

Cross Check

Please see comments added to the end of this section. The coordinates of several features, the center of the ring and the four corners of the square, given in Base Plate coordinates (Fig. 5) are transformed to Glue Robot coordinates. See Table 1. [Two module positions were also provided in Base Plate coordinates. However, these were not used in this cross check because there are no features on the plate to compare with.] The glue dispenser was then moved to the calculated Glue Robot coordinates for the first point. It was confirmed by eye that the tip was directly above the center. The accuracy of this statement is roughly 1 mm or better. Since the square plate has rotational freedom, one of the corners was used to set this rotation. The other three corners were then checked by moving the glue dispenser to the computed corner positions and it was confirmed that the tip was above each corner.

While these cross checks are not very precise, they indicate there are no logical errors such as errors in compensating for edge sensor size, a wrong sign or similar logical errors.

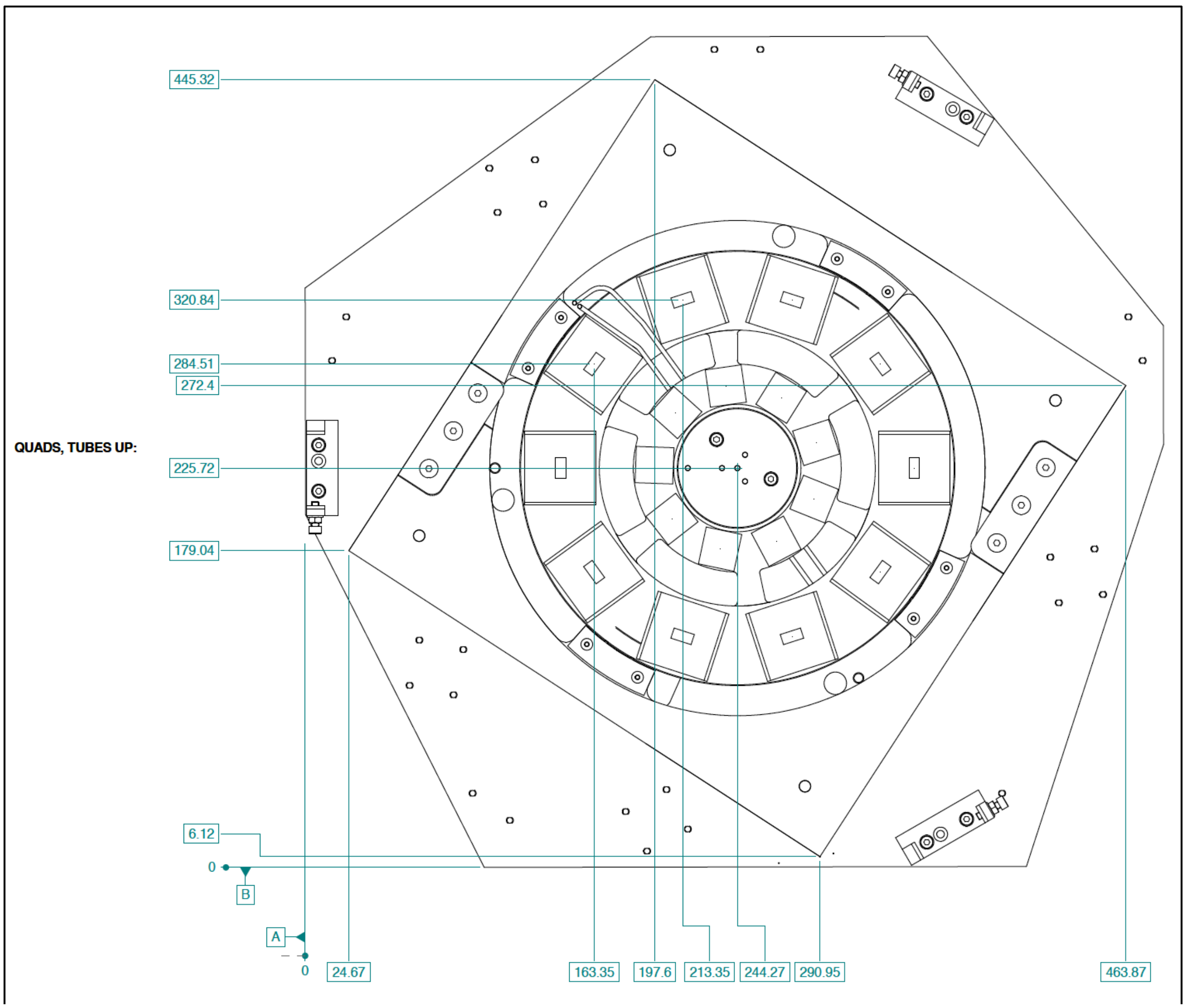


Figure 5: Coordinates in Base Plate frame.

		Base Plate Coordinate (mm)		Robot Coordinate (mm)	
		x	y	x	y
REF-000115259	Center	244.270	225.720	239.259	276.749
	Corners	290.950	6.120	39.119	378.471
		24.670	179.040	340.981	476.888
		197.600	445.320	439.392	175.019
		463.870	272.400	137.537	76.609
	Modules	163.350	284.510	335.846	302.734
		213.350	320.840	332.675	241.010

Table 1: Transforming from Base Plate to Glue Robot coordinate system.

Comment added for Version 2: After performing this cross check, a mistake has been found with the input values in Base Plate coordinates. It does not impact the conclusion because the error is much smaller than the accuracy of visual cross check. Nevertheless, none of the numerical values in Fig. 5 or Table 1 should be used for quantitative applications.

Module Locations for Glue Robot Programming

We plan to dispense the same pattern of glue, sometimes referred to as a snowflake pattern, for each frontend (FE) chip: one snowflake for each of the three modules in an R0 triplet and one snowflake for each of the four FE in a quad module. This section provides the center position of each module's sensor in Glue Robot coordinates. It is left to Glue Robot programming to relate this center position to the location and orientation of snowflakes.

There are three ways to align the ring in the Base Plate, correspond to (1) quads with cooling tubes up, (2) triplets with cooling tubes up, and (3) both quads and triplets with cooling tubes down. These three configurations are achieved by aligning the corner of the square plate with (1) the middle, (2) right, and (3) left alignment marks respectively. Fig. 6 shows the third case of aligning with the left mark for when cooling tubes point down, with the other two alignment marks rotated by 6^o and 8^o respectively.

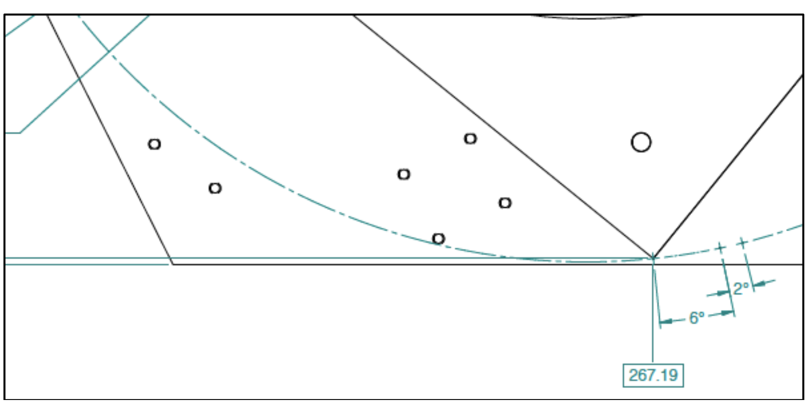


Figure 6: Alignment of square plate when cooling tubes are pointing down.

Note that the Base Plate is unchanged from one alignment configuration to another. Therefore, the coordinate transformation from Base Plate coordinates to Glue Robot coordinates discussed earlier is also unchanged.

(1) Quads with cooling tubes up

The corner of the handling frame is aligned with the middle alignment mark as stated earlier. The quad module at 9 o'clock in the (x_{base}, y_{base}) view of Fig. 7 is rotated by 0.1° relative to the $-x_{base}$ direction. We arbitrarily designate this module #1, with the other modules numbered sequentially in clockwise direction. Results are in the Appendix.

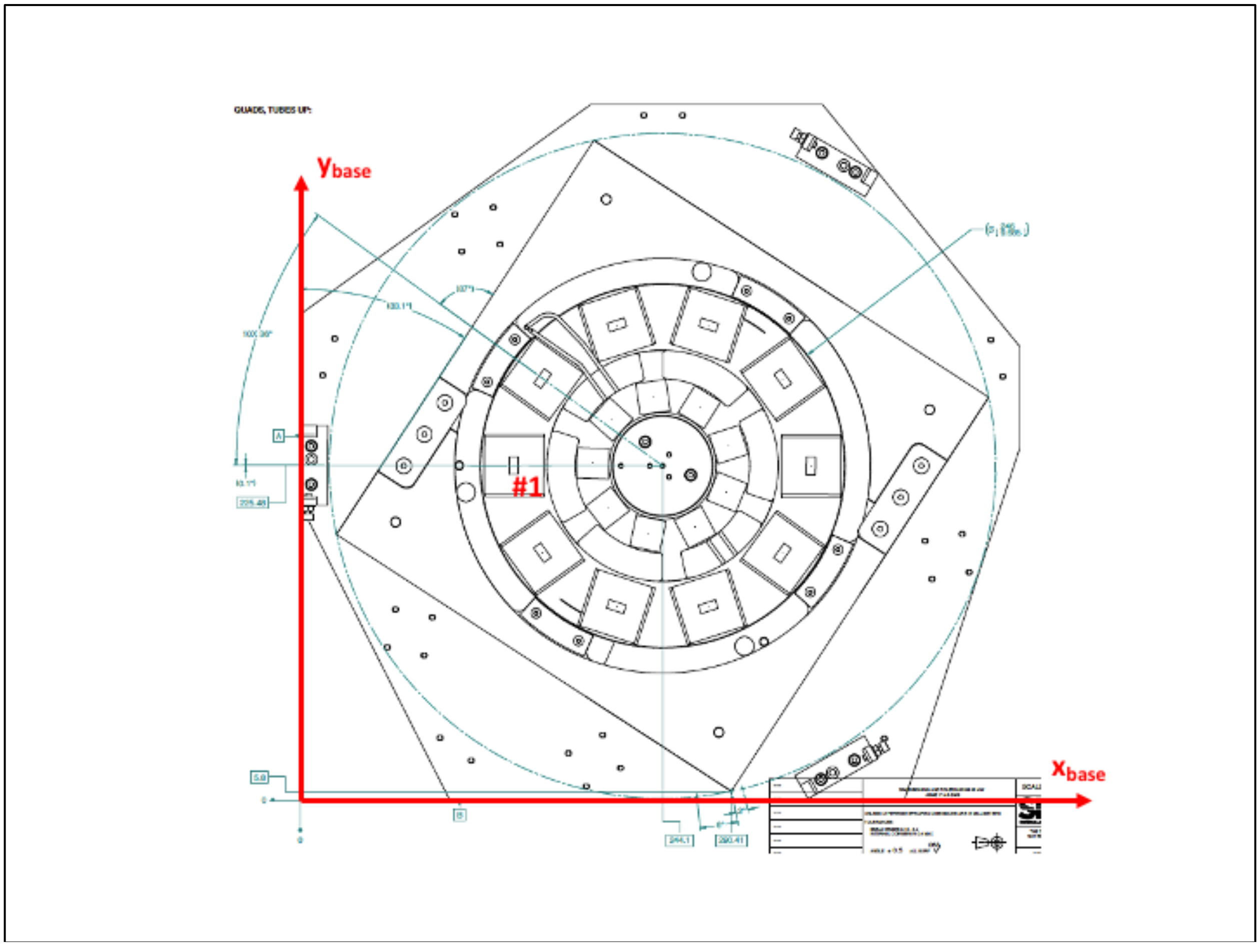


Figure 7: Quads with cooling tubes up.

The calculations were checked as follows. The square plate was removed, and a full-size drawing was taped to the Base Plate in the appropriate orientation as shown in Fig. 8. The glue dispensing needle was positioned by eye to be directly above the center in the drawing. This position was compatible with the computed position to better than 1 mm. Similar tests were made for all ten quad modules.

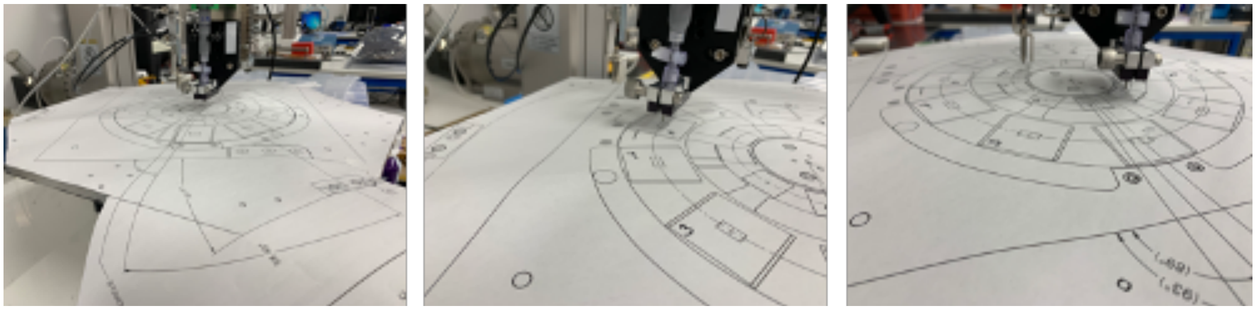


Figure 8: Using full-size drawing to confirm positions.

(2) Triplets with cooling tubes up

A similar procedure was followed to calculate module center positions using parameters for this case. And a similar check was performed with five out of nine modules.

(3) Quads and triplets with cooling tubes down

A common alignment is used for both quad and triplets when cooling tubes are pointing down. And the check was performed for five quad modules and five triplet modules.

Appendix: Module Center Positions

"Module center" refers here to the center of the sensor. Frontend chips (FE) extend beyond the sensor, and this orientation-dependent difference has to be taken into account when depositing glue.

All positions are given in Glue Robot coordinates and in units of mm. The center of the ring is at (244.100, 225.480). Angles refer to the angle between a line from the center of the ring to module center and the x-axis, and are given in $degrees$.

Results are given in three groups corresponding to the three alignments of the square plate in the Glue Robot. Module number is arbitrarily chosen to be 1 nearest the $-x$ axis of the Base Plate coordinates and increases in clockwise direction.

<u>Quad Modules and Cooling Tubes Up</u>

	Module Center Position		**Angle**
	x	**y**	
1	302.169	354.699	50.957
2	335.791	302.842	14.957
3	332.510	241.125	-21.043
4	293.580	193.124	-57.043
5	233.871	177.173	-93.043
6	176.189	199.364	-129.043
7	142.567	251.222	-165.043
8	145.848	312.939	158.957
9	184.778	360.940	122.957
10	244.487	376.891	86.957

<u>Triplet Modules and Cooling Tubes Up</u>

	Module Center Position		**Angle**
	x	**y**	
1	268.626	313.471	51.057
2	285.159	286.017	11.057
3	280.178	254.360	-28.943
4	256.012	233.310	-68.943
5	223.970	232.719	-108.943
6	199.045	252.862	-148.943

7	192.899	284.315	171.057
8	208.408	312.359	131.057
9	238.315	323.874	91.057

Cooling Tube Down

	Module Center Position		**Angle**
	x	**y**	
Quad 1	302.034	354.809	51.057
2	335.746	303.010	15.057
3	332.573	241.288	-20.943
4	293.727	193.219	-56.943
5	234.045	177.164	-92.943
6	176.325	199.255	-128.943
7	142.612	251.054	-164.943
8	145.785	312.776	159.057
9	184.632	360.845	123.057
10	244.313	376.900	87.057
Triplet 1	268.626	313.471	51.057
2	285.159	286.017	11.057
3	280.178	254.360	-28.943
4	256.012	233.310	-68.943
5	223.970	232.719	-108.943
6	199.045	252.862	-148.943
7	192.899	284.315	171.057
8	208.408	312.359	131.057
9	238.315	323.874	91.057