Process of converting Coordinate Measurement Machine data of high accuracy components into meaningful assembly dimensions

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Process of converting Coordinate Measurement Machine data of high accuracy components into meaningful assembly dimensions.

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Abstract - Two novel designs have been generated for permanent magnet based quadrupoles for the Compact Linear Collider (CLIC). A first high strength permanent magnet quadrupole has been successfully assembled and tested[a]. The four yokes had been manufactured to close tolerance and in a controlled environment to meet the magnetic characteristic specification. For industrialization purposes a lower standard was chosen to simulate and gather experience for large production planning and assembly. Magnetic modeling indicates that the yoke nose pole shape and inscribed radius need to be tightly controlled in order to meet the stringent specification for magnetic field quality set down by CERN. A nominal figure of 10 micrometre as tolerance range will guarantee this. The process to convert Coordinate Measurement Machine data of high accuracy components into meaningful assembly dimensions is a complex and high manual input undertaking. A number of processes are required to use the data obtained, translate it between various formats and manipulate it in a number of different software to suit the goal of obtaining a physical assembly as close as possible to the nominal ideal model. Traditional CMM methods differ from this approach in terms of accuracy and do not utilize data beyond the comparison between manufactured and nominal component dimensions. The process of how to arrange the manufactured yokes to remain within this tolerance is described in this document.

Index Terms – **Accelerator magnets, permanent magnets, metrology, Coordinate Measurement Machines, CMM, high accuracy assembly**

I. EQUIPMENT:

The Daresbury Laboratory Coordinate Measurement Machine (CMM) is a DEA Gamma (now Hexagon Metrology) system using a standalone PC interface running the Aberlink 3D software. Computer Aided Design software packages are used, namely Autodesk's Mechanical Desktop 2013, Solid Edge ST4 and CREO Paramertric 2.0.

II. THE PROCESS:

A definition of the faces and locations to be probed has to be established. The component to be measured is then placed on the table on a set of parallels sufficiently high to permit access of the probe head to all locations. For the CLIC PMQ T2[b] yoke these have been defined as faces A to T as depicted in Figures 1 & 2:
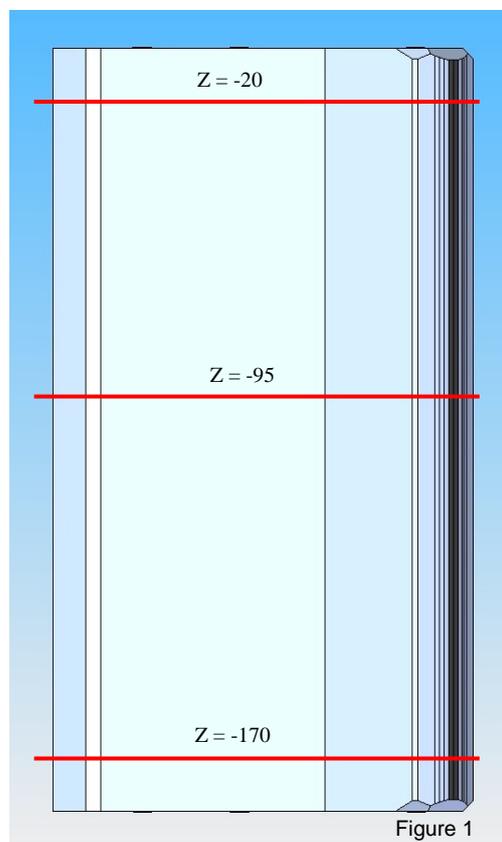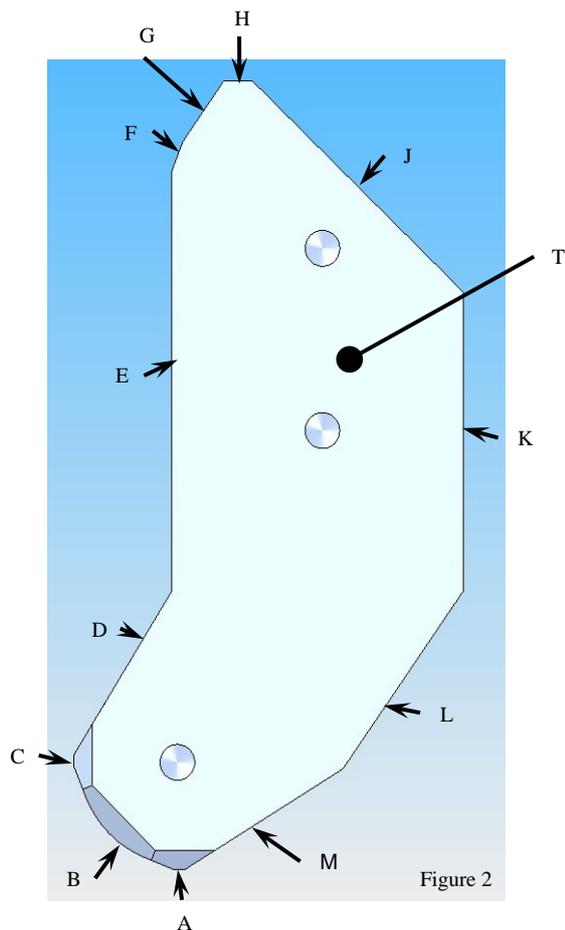

Figure 1

Figure 2

The point number on the specified faces has been chosen to enable fast yet sufficiently accurate data taking. In this case, six points on all large faces and three on all small faces with the exception of face B where 15 points are required due to the small faceted geometry in each of the three planes.

The operator has to create a local coordinate system (Frame) by taking a number of points in a line along Face E (approx. 10mm from top face with the vertical (Z) axis locked) and Face H. A third datum is created by taking points on Face T with the coordinate system datum now at the intersection of the three readings.

It was found that these readings are not perpendicular to each other due to the machining process and the created datum frame created an unacceptable offset between the recorded data and the overlaid CAD information. Subsequently a different approach was required leading to the following process.

The point collection[c] was exported as a comma separated value (CSV) file for further data manipulation and analysis.

The first step was to import the data into a spreadsheet and convert the information into numbers the CAD system can 'understand'. At this point it is essential to decide on the CAD system to be used and it was found that Autodesk's Mechanical Desktop is the most efficient. To this effect the data was broken down into features and the nondescript Aberlink point naming convention changed. The result is as shown in the Table below:

Point Name	X-Position (mm)	Y-Position (mm)	Z-Position (mm)
D1_01	165.73	-106.407	66.438
D1_02	164.126	-157.079	66.442
D1_03	149.903	-186.536	66.442
D1_04	170.128	-187.264	66.439
D1_05	189.231	-163.676	66.416
D1_06	189.231	-123.831	66.413

Table 1 illustrating the point feature naming convention for the Top Face (T) point collection.

The data is then imported into Autodesk's Mechanical Desktop CAD application using an IMPORTXYZ lisp[d] programme. The features are placed in individual layers and coloured accordingly as depicted in Figure 3:
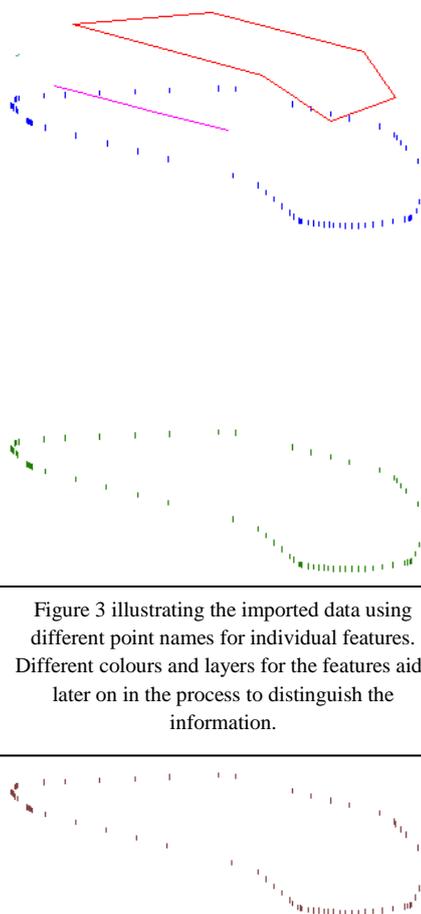

Figure 3 illustrating the imported data using different point names for individual features. Different colours and layers for the features aids later on in the process to distinguish the information.

The second step is to convert the Autodesk dwg file into a neutral CAD format such as IGES[e], STEP[e] or SAT[e] and import this data into the SpatialAnalyzer programme as illustrated in Figure 4.
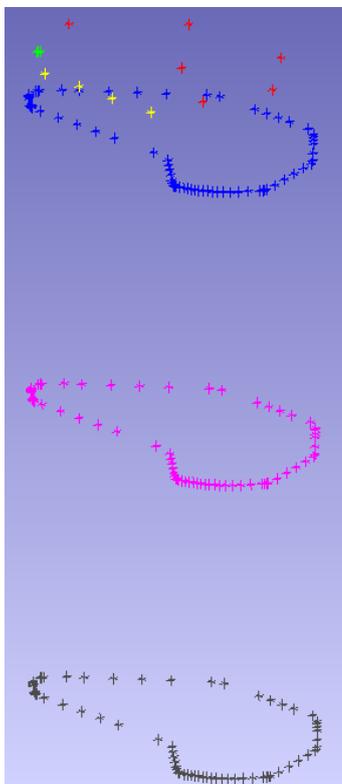

Figure 4 illustrating the imported data into the Spatial Analyzer programme. Note the colour information is retained to aid in further information dissemination.

This data set contains all the dimensional information as well as the metadata. The points have a probe radius offset and the faces contain the probe approach direction information.

The next step is to group the points into faces in accordance with the established convention (see Figure 2).

Following this is the construction of a plane through the points of the individual faces (except Face B) using the root mean squared (rms) fit function to achieve the best fit. At the same time the probe offset is applied and the vector direction changed to point towards the physical face of the component. The origin of this vector is marked also with point information on the centre of gravity marker on the plane. Figure 5 shows the overall component face and vector distribution in an ISO view. Figure 6 depicts a more detailed top view

clearly displaying the probe offset and vector direction of the cardinal points.

Face B planes are created using vertically adjacent points (15 points across the face at three Z-Positions = 14 planes created from 6 points each).

The information is then exported in a CAD neutral format as before (IGES preferred) ready to be imported into a 3D CAD programme.

The cardinal point data is also exported in ASCII format (as TXT file) for further assimilation into the CAD model at a later stage.
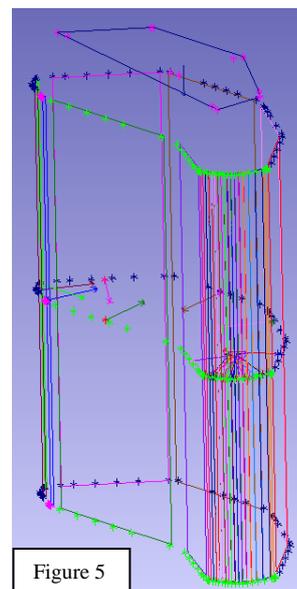

Figure 5
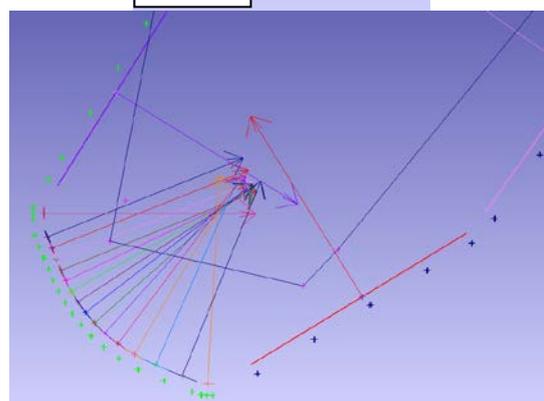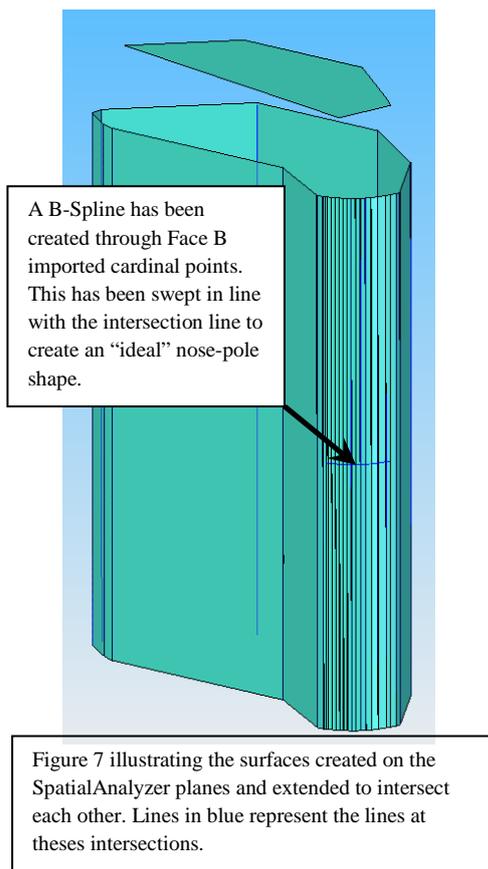

Following on from this, the data is now imported into a 3D CAD programme. Solid Edge ST4 was used in this instance to create a native surface model from the SpatialAnalyzer neutral file information.

Using the 3D CAD programme, the planes created in SpatialAnalyzer need to be converted into surfaces and extended to intersect each other. On these intersections thus created a curve needs to be

fitted to establish a closed loop profile in all three dimensions. These 'lines' will further serve later on as guides for further swept profiles and more importantly to constrain the model to the desired position. The orientation of these surfaces relative to the local coordinate system is at this stage ignored. On checking the models, the same discrepancies have been observed between these models and the virgin CMM data which subsequently is of no use for assembly purposes.

Figure 7 illustrating the surfaces created on the SpatialAnalyzer planes and extended to intersect each other. Lines in blue represent the lines at theses intersections.

The aim of the above is to get the data to a state fit for CAD assembly. One further task is the import of the SpatialAnalyzer cardinal point data. This is carried out by importing the data from the TXT format into a spreadsheet and keeping the relative positions unaltered to ensure precise overlay.

Coordinate Name	X-Position	Y-Position	Z-Position
Centroid_01	156.309356	-198.593020	-29.540012
Centroid_02	153.948914	-197.606309	-29.538046
Centroid_03	152.051379	-196.657815	-29.541115
Centroid_04	150.603864	-195.714381	-29.542311
Centroid_05	149.437526	-194.771573	-29.545675
Centroid_06	148.514110	-193.853952	-29.544212
Centroid_07	147.723644	-192.905233	-29.536921
Centroid_08	147.051042	-191.968270	-29.540784
Centroid_09	146.473534	-191.027232	-29.545820
Centroid_10	145.981027	-190.087965	-29.543002
Centroid_11	145.560028	-189.145228	-29.541029

Centroid_12	145.157895	-188.153266	-29.541052
Centroid_13	144.756000	-187.150531	-29.541222
Centroid_14	144.350459	-186.146288	-29.539221

Table 2 listing the Face B cardinal point coordinate data in a spreadsheet prior to CAD importing

Solid Edge has a function to generate best fit B-Spline curves to spreadsheet point data. As highlighted in Figure 7 above, this "Curve by Table" can then be 'swept' to create a surface along a specified path. The chosen path is one of the face intersection lines closest to the original apex of the nose-pole profile and as perpendicular to the curve profile as possible. A visual check has been carried out to ensure this surface is not 'running out' along the length of the component.

The above process is carried out for all four yokes in preparation for the next step; assemble yokes in CAD.

Assembly Specification:

1. Aperture to have an inscribed radius of 13.8mm.
2. Yoke apex to 'touch' along entire length of aperture.
3. Line of contact to be in the 45 degree position.
4. Large inside faces (E) to be as vertical and parallel as possible.
5. Faces A and C also as horizontal/vertical as possible (lower importance though).
6. Optimise assembly by 'swapping' yokes from one position to a different location to reduce nominated spacer errors.
7. Define and establish dimensions from point minima to datum planes of the ideal beam centre vertically and horizontally.

Assembly naming convention:

To retain consistency, a naming convention needs to be established for assembly and measurement purposes. Figure 8 illustrates the reference points and associated spacer distances.
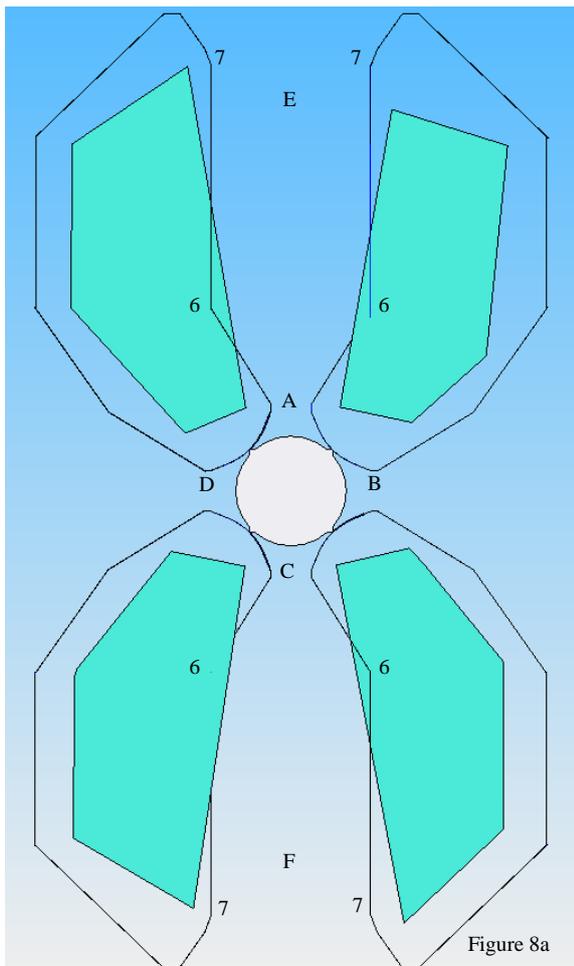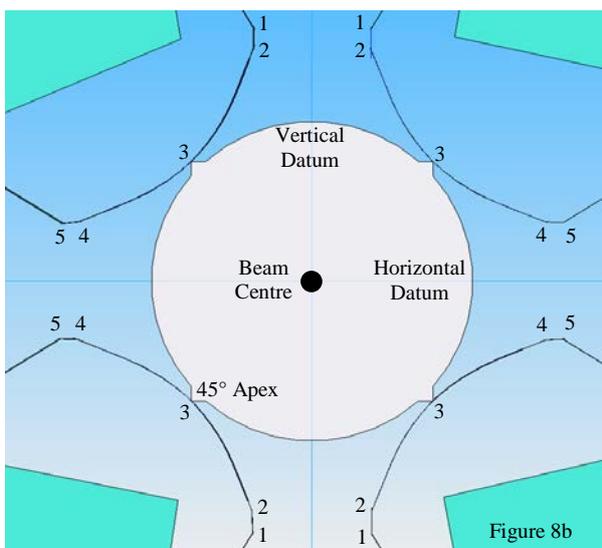
Figure 8a illustrating the naming convention for the spacer distances denoted in letters "A to F". Measurement points are numbered "1 to 7" and are located at the nearest point. Each point has a front (out of the page) measurement and rear (into the page) measurement. Figure 8b is a more detailed view of the centre arrangement.

Assembly methodology:

For a consistent process and to achieve the best results the following methodology has been established.

1. Constraining of points are to the datum planes.
2. All six degrees of freedom need to be constraint.
3. Use a similar approach in CAD as in practice.
4. Face "E" points are chosen to act as a tripod like arrangement controlling the horizontal distances, rotation about the Y and Z-axis (right hand rule, Z pointing vertically up).
5. Points 4 at the front and rear controlling vertical distances and rotation about the X-axis.
6. The linear D. o. F. in the beam direction is constraint via the midpoint of the line connecting point 6 (front and rear) but still permit rotation in all 3 axis and horizontal offsets (floating).

As the assembly process to obtain the best fit is iterative, a table to list results is kept as a historic document and a scratchpad for calculations to reduce the number of iterations.

As a quick check the author has overlaid the nominal CAD assembly to visually illustrate if and where discrepancies are present. The centre of the unit has been used as datum for this to ensure a common reference frame. See Figure 9 for a representation of the overlay.
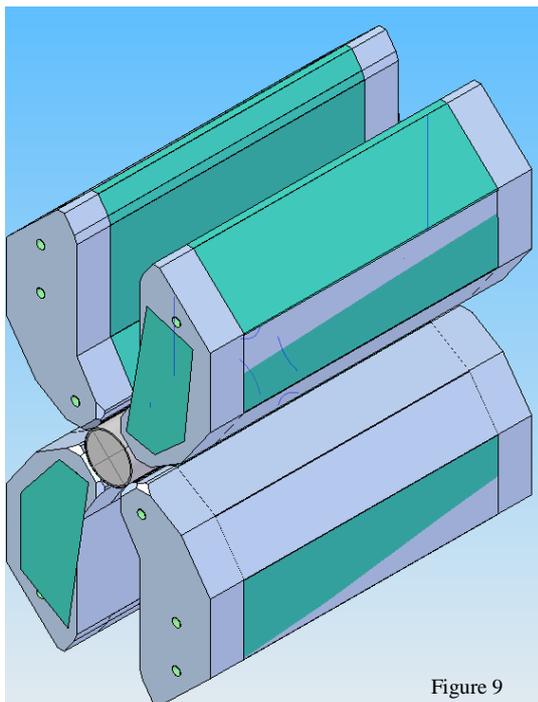
Figure 9

Figure 9 depicting the green Coordinate Measurement Machine data models assembled in CAD to 'optimum' positions. The grey yoke CAD models are positioned in the ideal nominal location. This visual check serves to illustrate the discrepancies between true and nominal. Green faces showing indicates larger than nominal and grey smaller.
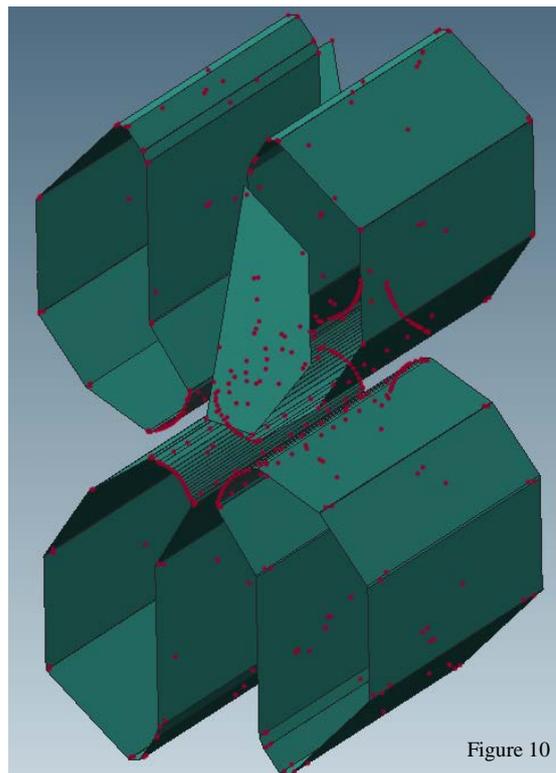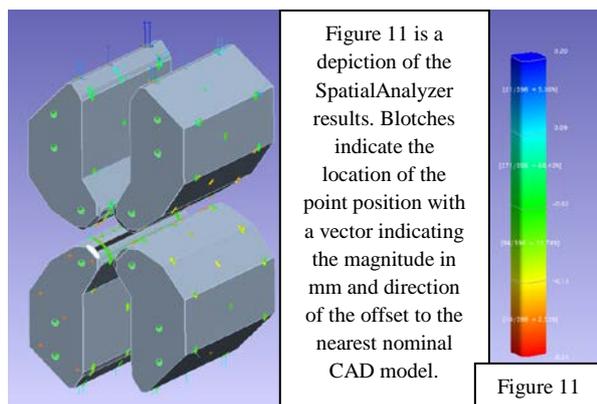

Figure 10

Figure 10 depicting the CMM data CAD assembly with the arbitrarily placed points; one in each of the 4 corners and 1 in the approximate centre of each surface.

Note the nose-pole profile has a large point cloud density and the B-Spline extruded face was used rather than the facetted individual CMM faces.

A more detailed analysis has to be carried out to quantify these differences. For this purpose the CMM data assembly is exported from Solid Edge, in this case in IGES format, and imported into another CAD programme, namely Creo Parametric. Only surfaces and the reference datum have been included in the data set. This CAD programme permits the creation of point data required for further analysis. To this extend points have been placed onto the surfaces in a random position towards the four corners and one in the centre. It is deemed that these 5 points are sufficient for an adequately accurate analysis. Figure 10 shows the CMM data CAD assembly with the point data.

Having created the point data, the information is exported as a neutral CAD format file, IGES in this case, after stripping the surface data information out of the set. This point information only is subsequently imported into the Spatial Analyzer software. The nominal CAD model assembly is also imported and overlaid. The need to maintain the reference datum is now clear as the analysis must relate both respectively to this 'common' frame. In Spatial Analyzer a query is created to 'compare' the nominal CAD information with the 'manufactured' CMM data. A graphical representation summary of this is illustrated in Figure 11 below. A detailed report is generated permitting the investigation of individual point off-sets if required or export the data for further rms error analysis.

Figure 11 is a depiction of the SpatialAnalyzer results. Blotches indicate the location of the point position with a vector indicating the magnitude in mm and direction of the offset to the nearest nominal CAD model.

Figure 11

III. Summary

There will always be a dimensional difference between manufactured and CAD generated components. In assemblies like the CLIC PMQ T2 these discrepancies have a direct impact on the systems performance when unchecked. To minimise this potentially detrimental effect, it is essential to know exactly (to three decimal places) the dimensions of the individual parts in order to assemble these in such a way that the effect is nullified or very near it. Coordinate Measurement Machines permit us to obtain the true shape and dimensions quantitatively and subsequently arrange and position components accordingly. Comparing this data with the ideal shape and optimising it permits the physical system to perform very near to or as predicted by CAD and Magnetic modelling software.

IV. Conclusion:

The process described above is extremely labour intensive and one would think that some sort of software is available to automate. Extensive searches and discussion with experts has proven that this is not the case, mainly due to the human judgment and decision requirement at various stages. On any need to 'compare' ideal (nominal) geometry with real component information gathered via a CMM, measurement arms or even Laser Tracker scenario this process needs to be carried out. This particular case was called for due to the accuracies required; better than 10 µm. A further notice is that certain CAD programmes have certain required capabilities, which others haven't, leading to seemingly continuous data translation. The use of 'non CAD' software, i.e. spread-sheets provided some automation in terms of data manipulation and the import into a CAD programme via the use of specific macros or LISP programmes. The goal of having a visual and quantitative comparison has been achieved and it proved that the rearrangement of the manufactured components is now such that it matches very closely the ideal design where it matters most.

References

[a] B.J.A. Shepherd *et al*, "Permanent magnet quadrupoles for the CLIC Drive Beam decelerator", CLIC Note 940.

[b] Compact Linear Collider Permanent Magnet Quadrupole Low Strength version

[c] Point data from the Aberlink 3D software exported via Hexagon specific macro

[d] Jeffrey Saunders AutoLISP point import script

[e] CAD Data exchange, Wikipedia, http://en.wikipedia.org/wiki/CAD_data_exchange