PHOTOGRAMMETRIC APPROACH TO INSTALLATION PROBLEMS

K. Endo

National Laboratory for High Energy Physics
l-l Oho, Tsukuba-shi, Ibaraki-ken 305, Japan

Abstract After the completion of the TRISTAN accelerator, new components are going to be installed close to the detector solenoids. They are the superconducting quadrupole magnets to establish the mini-beta optics at every interaction point. Prior to their installation it must be required to check the obstacles which are obstructive to the alignment. The detector is complicated with its signal cabling, cryogenic piping for its superconducting solenoid and supports in addition to the geometrical complexity of detector itself. To detect these obstacles with an accuracy of few mm, the photogrammetric survey is adopted. The stereoscopic photographs make the three dimensional measurements possible with the help of a precise scanning stereocomparator. The 3-D coordinates are delivered to a CAD program and merged with the picture files of another well-defined components.

Introduction

The superconducting quadrupoles (QCS) are installed close to the interaction points at both sides of the detectors. Two QCS's are connected with a transfer tube in which the liquid helium is transferred to the cryostats to hold the superconducting coils at the liquid helium temperature. The structures of the cryostats and transfer tubes are different at every interaction point reflecting the geometrical shape of the detectors. Fig.1 shows an example of the QCS system at the Tsukuba experimental hall where the TOPAZ detector is located.

To attain the lowest possible β_y * (vertical beta function at interaction point), a nose of the cryostat, which contains most part of the superconducting coil, must be inserted in a pole tip of the detector. There are 6 mm clearance between the cryostat surface and the pole tip inner bore and 2.5 mm between the cryostat warm bore and the vacuum chamber. These are the design values and if the magnetic center of QCS is different from the mechanical center due to the welding deformation of the cryostat, the clearance becomes small at one side. The magnetic centers of the quadrupoles near the detector shall be on a straight beam line to avoid the background noise. The marks on the cryostat surface which reflect the magnetic center are used for the precise alignment. An accurate magnetic center is transferred on the cryostat surface using the scattering pattern of the plane-polarized light through the colloidal solution of Fe_3O_4 crystallites in the magnetic field of QCS [1].

Fig.2 shows the one side of the TOPAZ detector. A forehand device is a maintenance tool of the detector and is removed. The pole tip is at the center of the photo and has concentric circular hollow steps. The QCS is placed on the movable girder which can be set back by 4 m and is put into the inner bore of the pole tip smoothly. If there are obstacles around the space where QCS locates, they can be detected in the photos and their 3-D locations can be identified.

Photogrammetry

Photogrammetry used to be an important measures in the high energy experiments using the bubble chamber. Its technology is applicable in the field of the precise survey. An accuracy of the present technology is better than 1 part in 250,000 of the size of the measured object [2,3]. Photogrammetric survey consists of the data acquisition with camera, the digitization of film image with a stereocomparator, the photogrammetric triangulation and the implantation into the CAD environment.

For the acquisition of data, a camera, Hasselblad MK70 with 60 mm focal length, was used. Retrotargets which are used to establish a common coordinate system were affixed at several points on the object surface. Their coordinates are surveyed with three dimensional survey system ECDS2 of Kern & Co. in reference to the beam coordinate of the accelerator and they were photographed in one frame. The 3-D coordinates given by ECDS2 were used as a general coordinates of the photos. A color film of 60 x 60 mm^2 was used instead of the monochrome film because it can identify the fringes and contours easily. Its absolute resolution is 10 μm but the rms value of errors of the coordinates relates the scale of photo, 1/115. The resultant resolution of the object coordinates is 1.2 mm. If the object is photographed in a larger film such as 230 x 230 mm^2 or smaller sections are taken individually, the resolution will be 0.3 mm or less. For the present purpose it is enough by 1 mm resolution. The image deformation of the lense is corrected by the software using analytical formula with an aid of 25 fiducial points simultaneously taken in the image. Errors by film unflatness can be minimized with a flattening mechanism in the camera against the flat glass plate.

The coordinates of the image points were digitized with the help of the stereocomparator, MPS2 of ADAM Technology, under which the stereoscopic image was observed. The digitized coordinates were transferred real-time to the 80386 based personal computer via RS-232C. Thus the digitized data are displayed under the control of the CAD software. The stereocomparator has a resolution of 1 μm and a rate of measuring image points is about 1 in a second. Merits of using the 3-D CAD software are that the well-defined geometries - such as line, circle, ellipse and polygon - can be determined by scanning few points, the 3-D surface can be expressed by mesh and the digitizing error can be fined on the screen.

The photogrammetric triangulation is done outside the stereocomparator by the bundle adjustment software. The software generates the parameters of data transformation from both the digitized data and the input coordinates of retrotargets. The common coordinate system to satisfy the stereoscopic photos is thus established. The bundle adjustment dose not requires the accurate camera location and rays from different photos pointing the same target are mathematically oriented to intersect at the target point. The transformed digitized coordinates are given to the 3-D CAD system and displayed on the screen with the cursor lines.

Beam coordinate measurements

Retrotargets on the detector surface were measured with a three dimensional survey system, ECDS2. To determine the beam axis through the detector, a straight line connecting the magnetic centers at 20 m upstream and downstream from the interaction point was assumed as the beam line. Layout of magnets and detector is given in Fig.3. QC1-D, QC2-F and QC3-D are the quadrupoles, where D and F mean the defocusing and focusing quadrupole, respectively. When QCS's are installed between the QC1 and detector, QCS's act as the defocusing quadrupoles and QC1's are switched to the focusing quadrupoles. QC2's are not excited and QC3's remain defocusing. Every quadrupole remains at the same place even after QCS's are installed.

Setting of the theodolite coordinate was changed three times. Two measurements (#l and #2) were for each side (L-side and R-side) of the detector and the last measurement (#3) was for connecting coordinates of both sides. L- and R-side are shown in Fig.3. Measurement of either #l or #2 assumed the coordinate origin at one of the theodolites fixed near the QC1 quadrupole and was done for the spherical target of Rank Taylor Hobson Ltd. fixed precisely on the quadrupoles and for the sighting seals on the wall which could be sighted in the measurement #3.

With the help of the sighting seals, a common coordinate system could be established by giving the rotations and parallel shifts to the #l and #2 coordinates to merge in the #3 coordinate accurately. The merged coordinate #3 was finally rotated and shifted so that the beam axis became the z-axis having the origin at the center between two QC1's.

In the above measurements, the coordinates of retrotargets were also determined and were given as data of the bundle adjustment. Accuracies were estimated to be 22 mm to the z direction and ±0.5 mm to the x and y directions in the final coordinate system. However, the relative accuracy of either L- or R-side would be ±0.5 mm in all directions because the large error was introduced in merging the #l and #2 coordinates longitudinally. The relative locations of quadrupoles in the #l and #2 coordinates were reserved.

CAD as an alignment tool

Another components such as QC1 and QCS quadrupoles were not photographed, so their figures were constructed from the drawings by using the AutoCAD program of Autodesk Ltd. Every component has separate picture files (Fig.4 and Fig.5) and after completing the individual files, they were merged in a file (Fig.6) which gives an image what they look like when they are at their proper locations. When merging files, the magnetic centers of QC1 and QCS were assumed on the z-axis determined above. As QC1 and QCS quadrupoles are set on the common girder at 4 m behind their destined locations, they can be moved close to the detector with the electric motor. The movement is given by the command of CAD. When they are approaching the detector, their clearance to the detector is watched on the screen. An example of Fig. 7 is seen from the inside of the detector. If QCS is moved into the cylindrical hollow of the pole tip by dragging the picture along z-axis, the clearance can be measured on the screen. Arbitrary cross-sectional views can be obtained by the clip command. As CAD allows the change of the view point, the views from the different points can be obtained easily.

A problem treated here is rather simple one to the purpose of alignment but this method can be applied to more complicated problem. If the photogrammetry is also applied to QCS structure, more accurate inspection is possible. This method is also useful even at the design stage of the components. Modifications of detectors are not usually reflected in the drawings. If the photogrammetry is not used, the geometries of detectors must be recorded in a video tape and investigated frequently to reflect them to the design of the QCS cryostats and transfer tubes. Sometimes an actual exploration shall be required.

Author appreciates the contributions of Messrs H. Hasegawa and K. Uesugi of Pasco Co. on the measurements of stereocomparator and CAD manipulations. He would like to acknowledge to Dr. H. Kichimi for an information of TOPAZ geometry and giving a convenience to taking photos.

References

[l] R. Sugahara, T. Kubo and Y. Ohsawa, "A Colloidal Solution of Fe_3O_4 Crystallites to Optically Locate the Magnetic Center of Multipole Magnets", Proc. 7-th Symposium on Act. Science and Technology, Osaka, 1989, p158-9.

[2] C. S. Fraser and D. C. Brown, "Industrial Photogrammetry: New Developments and Recent Applications", Photogrammetric Record, 12(1968)197-217.

[3] C. S. Fraser, "State of the Art in Industrial Photogrammetry", 16th Cong. Int. Sot. of Photogrammetry & Remote Sensing, Kyoto, 1988.

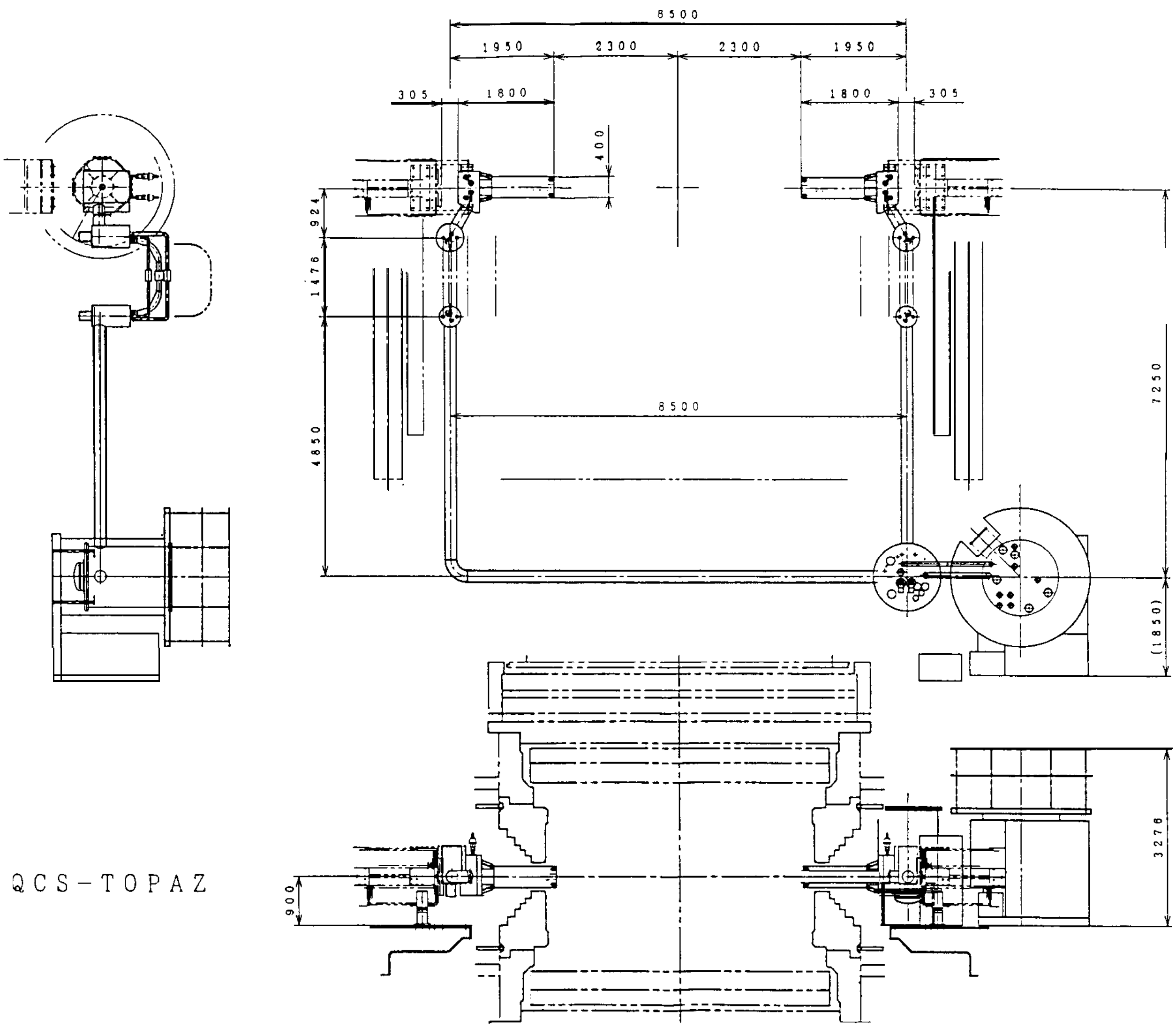

Fig. 1 Cryogenic system of the superconducting quadrupoles (QCS) and its layout at Tsukuba experimental hall. A part of the TOPAZ detector is shown in the bottom figure.

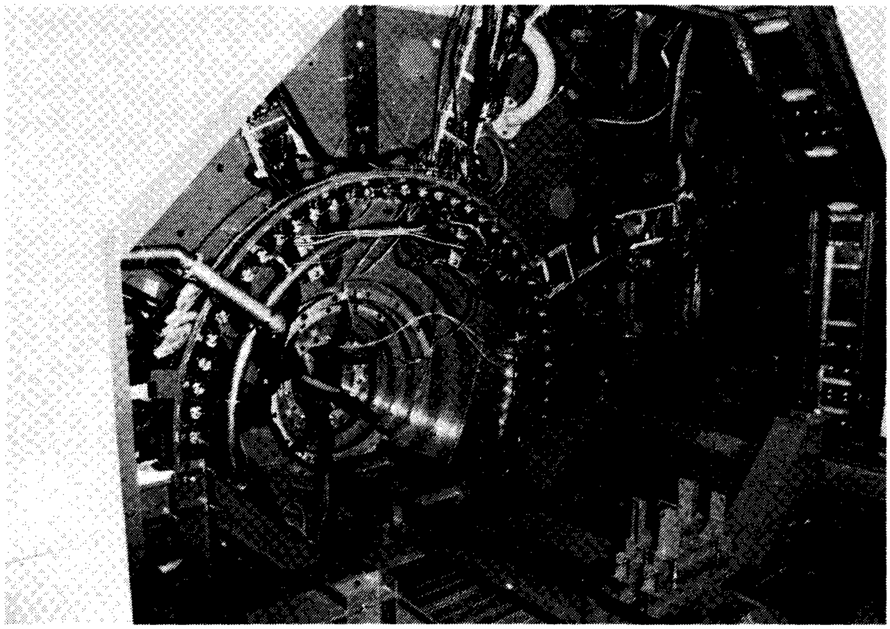

Fig.2 A view of pole tip of TOPAZ detector. The QCS magnet is inserted in the central hollow of the pole tip.

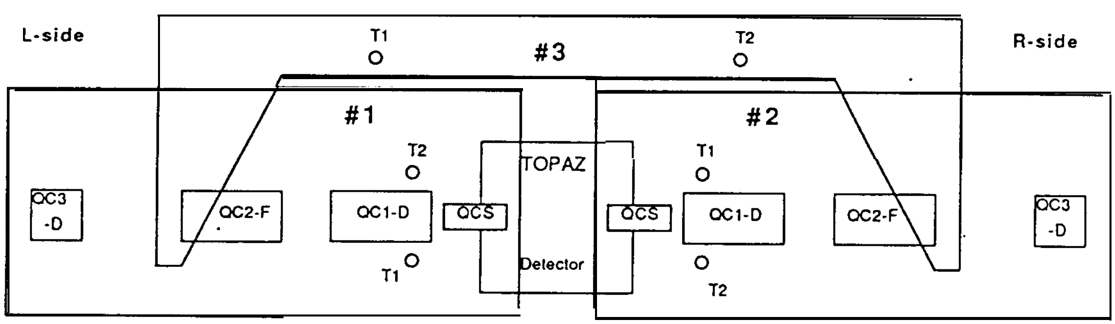

Fig.3 Independent coordinates for three measurements (#l, #2 and #3). T1 and T2 are locations of theodolites for each coordinate.

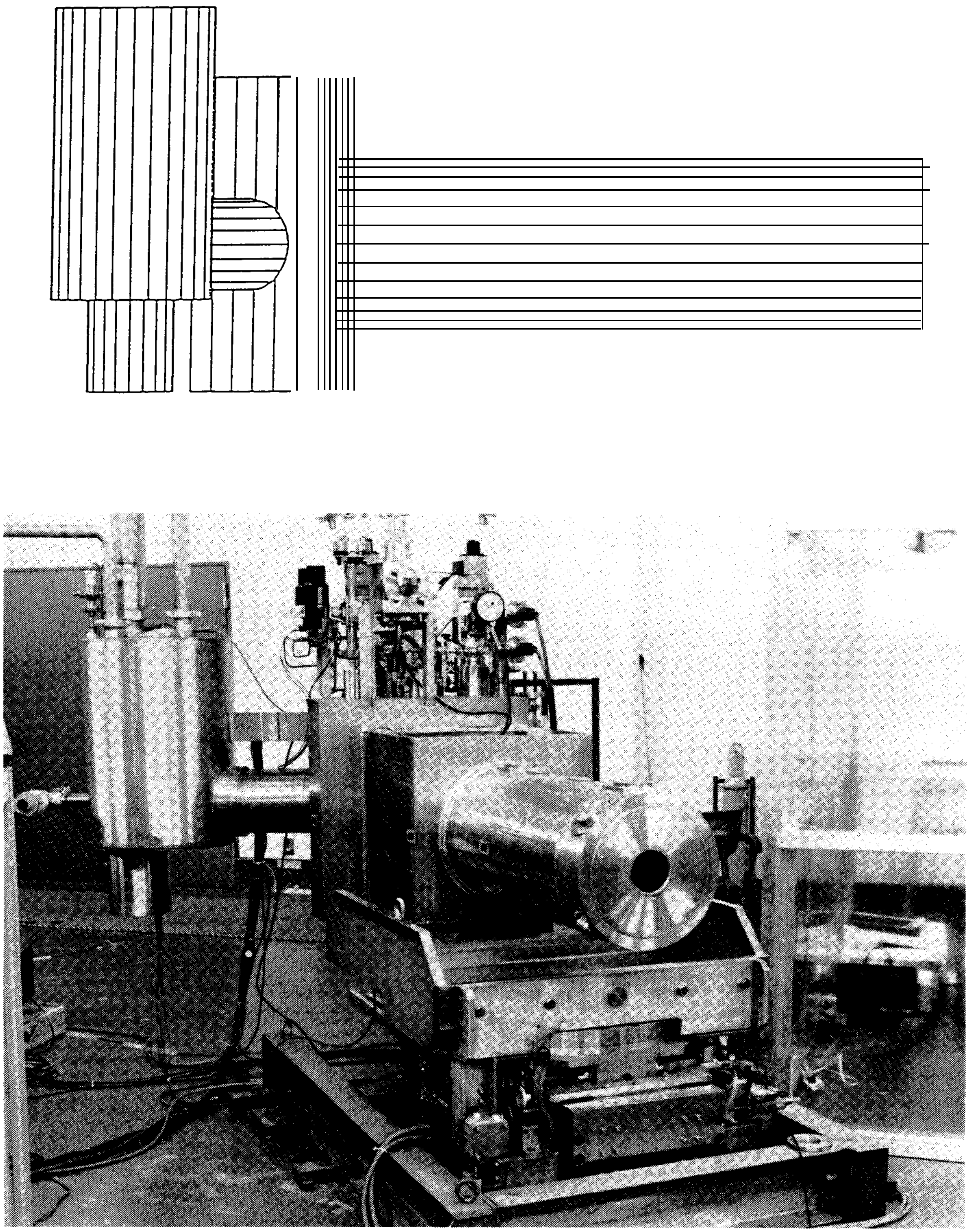

Fig.4 Geometrical shape of the cryostat of QCS in CAD and its photo.

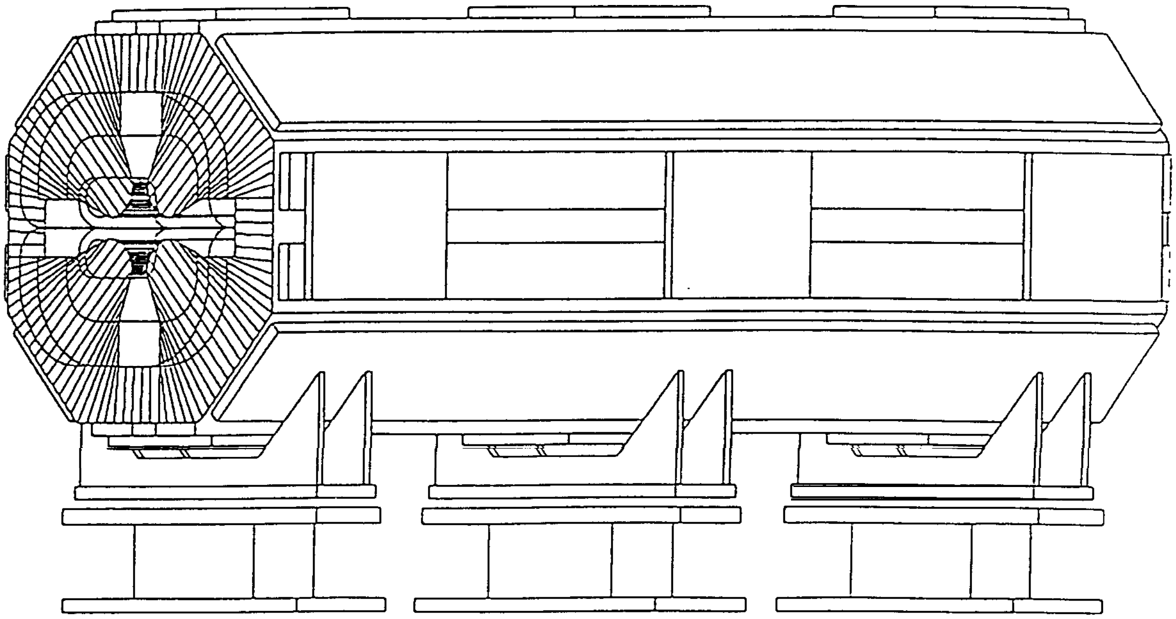

Fig.5 Geometrical shape of QC1 quadrupole in CAD.

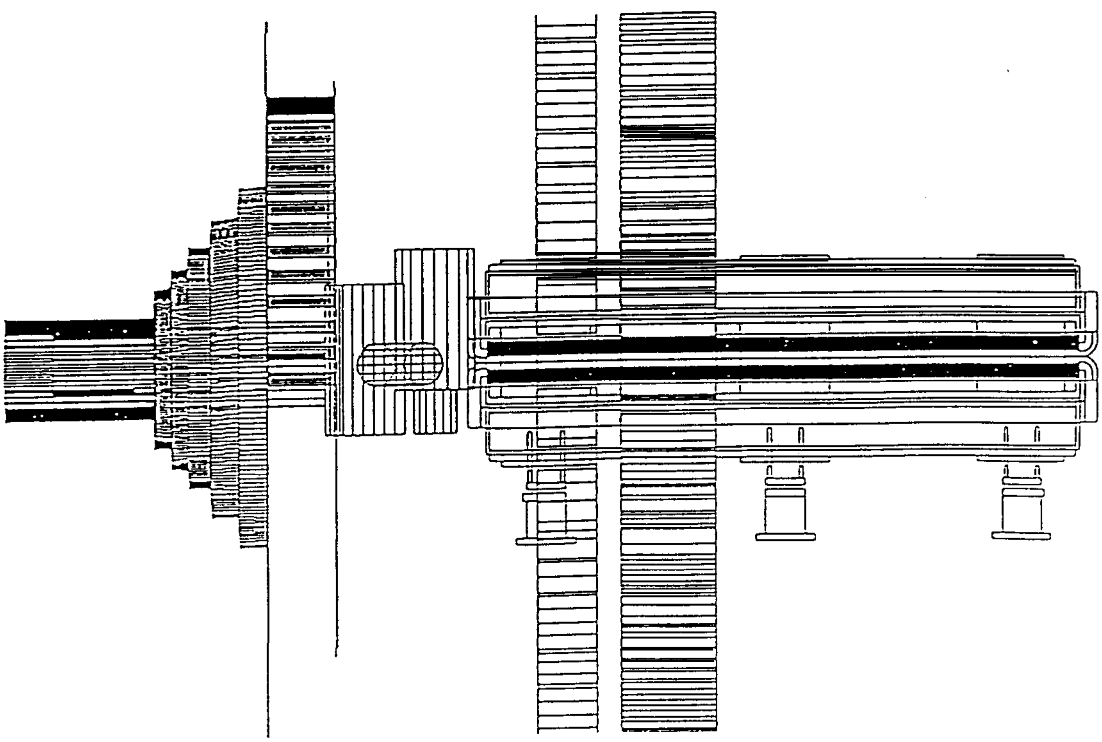

Fig.6 Clipped picture at the vertical plane containing beam axis after merging three graphic files. All components are at the right places.

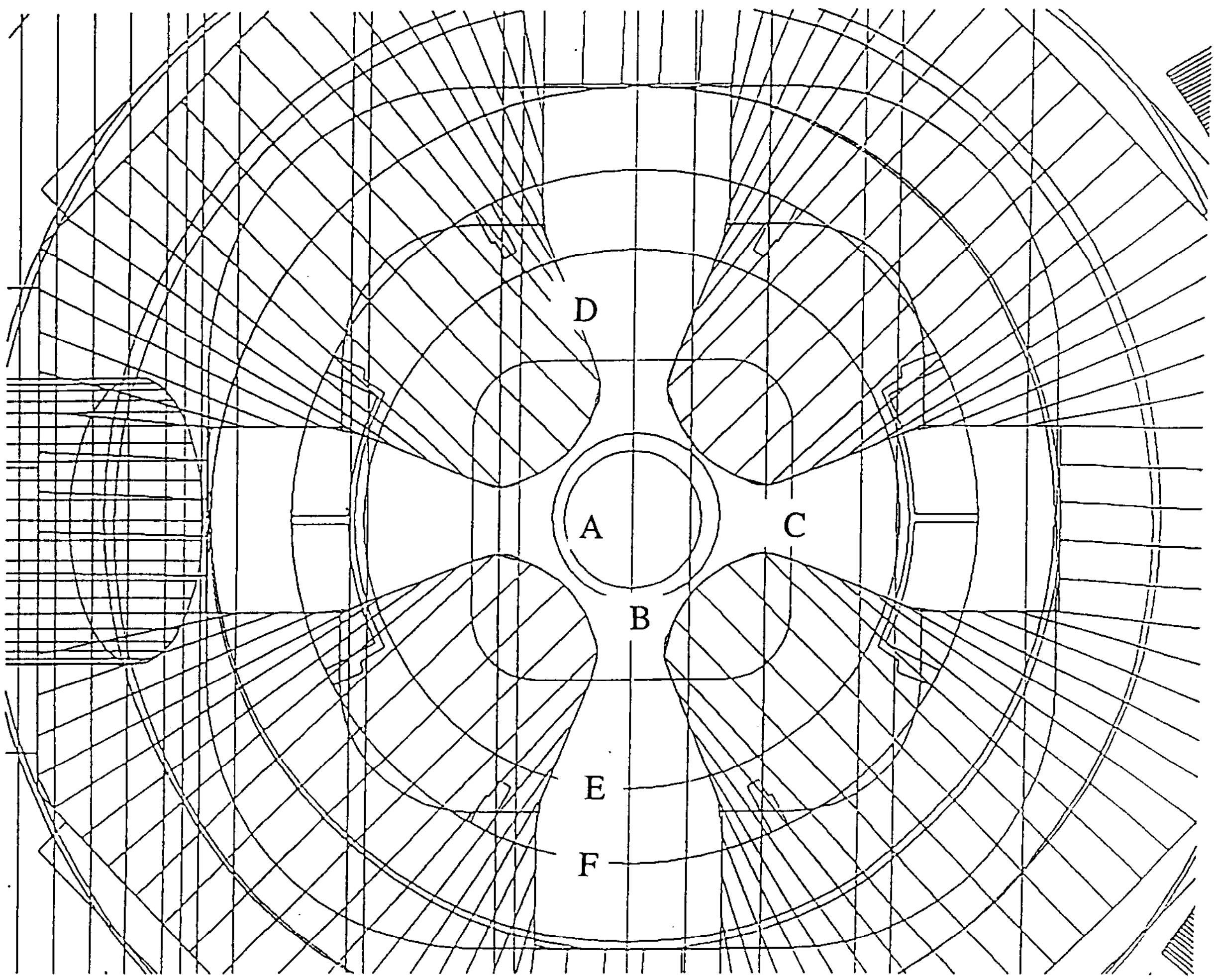

Fig.7 Enlarged picture around the beam axis seen from the inside of detector. A= vacuum pipe in the detector, B= inner bore of QCS, C= inner coil edge of QC1, D= pole of QC1, E= outer fringe of QCS, and F= inner hollow fringe of the detector pole tip.