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Three Dimensional Calculation on Toroidal Magnetic Field for RHIC Polarimeter

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Spin Note

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Takeo Kawaguchi, RIKEN
1996-2-6

1. Abstract

I and Dr. Okamura have calculated the magnetic field of the toroidal magnet for RHIC polarimeter. A location of the polarimeters is shown on Fig. 1.
Here, I write the calculated results, and also write some problems on the calculation which I experienced, as one of the instruction manual for using TOSCA code.

2. Dimensions of Toroidal Magnet

Dimensions of the toroidal magnet which I got from Okamura, are as follows.

Iron pole: inner dia. 15 cm, outer dia. 80 cm, length 150 cm.
Pole gaps: 4 gaps, each gap angle 7 degree
Toroidal coils: 12 pcs, total AT= 0.36 MA
cross section of one coil is 2.0 X 1.5 cm^2
current density 10000 A/cm^2

My opinion to the above geometry is that the inner diameter of the pole should be increased to get more space in inner region for coil arrangement.

3. Roughly Estimation of Magnetic Field

Magnetic field strength can be estimated using one dimensional method as follows.

$$Lg = \pi \cdot r \cdot 4\theta_g / 360 = 0.244 r \quad (m)$$

$$Li = \pi \cdot r \cdot 4\theta_i / 360 = 2.90 r \quad (m)$$

$$AT = HgLg + HiLi = B(Lg + Li/\mu r)/\mu 0 = (BLg/\mu 0)(1 + Li/(Lg\mu r)) = (0.194Br)(1 + 11.88/\mu r) X 10^6$$

Lg : total gap length (m)
Li : total iron length (m)
θ_g : one gap angle = 7 degree
θ_i : one pole angle=83 degree
r : radius of calculation point (m)
AT : total ampere turns (A)
B : magnetic field strength (T) average value in gap and iron.
$\mu 0$: permeability of air = $4\pi 10^{-7}$
μr : permeability ratio of iron

Figure 3-1 shows the B-H characteristics of iron pole, and the permeability ratio shown on Fig. 3-2. was calculated from Fig. 3-1.

We can roughly estimate the magnetic field strength of this toroidal magnet using the above equation and Fig. 3-2.

The result is shown on Fig. 3-3, and it shows that the magnetic fields at r=0.1 m and 0.35 m are 3.5 T and 2.3 T with the ampere turns of 0.36 MA.

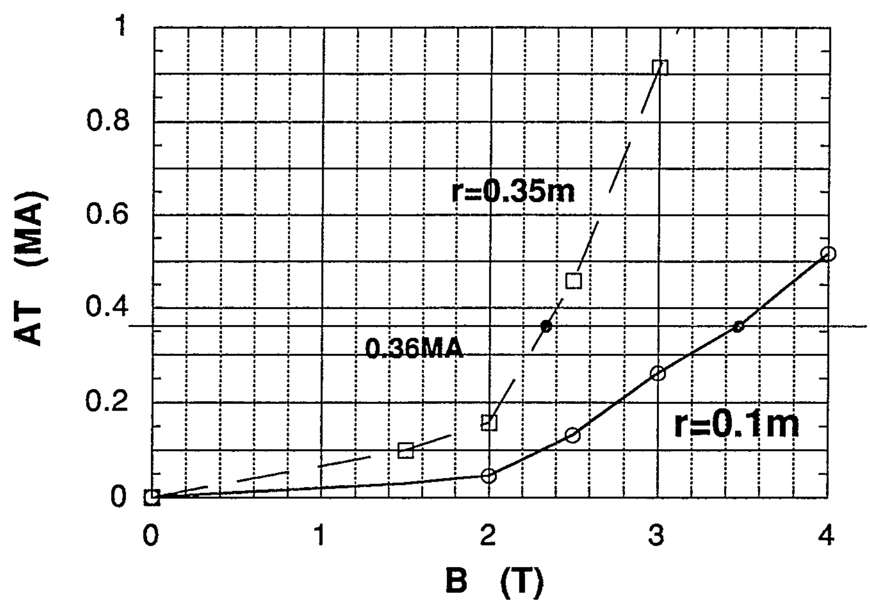


Fig.3-3. Estimated B-AT

4. Results of Three Dimensional Calculation

Results of the calculation are shown on following pictures.

Fig. 4-1 : TOSCA model

Here, full toroidal coils of 12 pcs. and a part of 1/8 of the iron poles are used for the calculation.

Fig. 4-2 : Magentic fields in Air gaps

Fields on x and y axises (in gap center) are shown. Maximum field is 2.8T.

Fig. 4-3 : Bmod along radii

Bmod (absolute value) on r=10 cm and r=35 cm are shown. Roughly estimated values are also compared.

Fig. 4-4 : Bmod vector on Pole face

Fig. 4-5 : Bmod vector in Inner area

Fig. 4-6 : Bmod vector in Outer area

5. Some Problems on the Calculation

I'd like to write some problems which I experienced on this calculation, as one of TOSCA manual.

(1) Error field and mesh size

Figure 5-1 shows a typical error field on this calculation. We can point out two problems on the figure ; one is a some big fields and another is an opposite vector.
The opposite vector is described in next paragraph (2).
A reason of the big fields was the big mesh size, and we can find the following message in OPERA [.res] file after TOSCA calculation.
This error would be occurred with large mesh size on the boundary between Total potential area and Reduced potential one. This problem was improved by increasing the mesh number from 10,000 to 80,000 total elements.

Error Message on TOSCA[.res] file

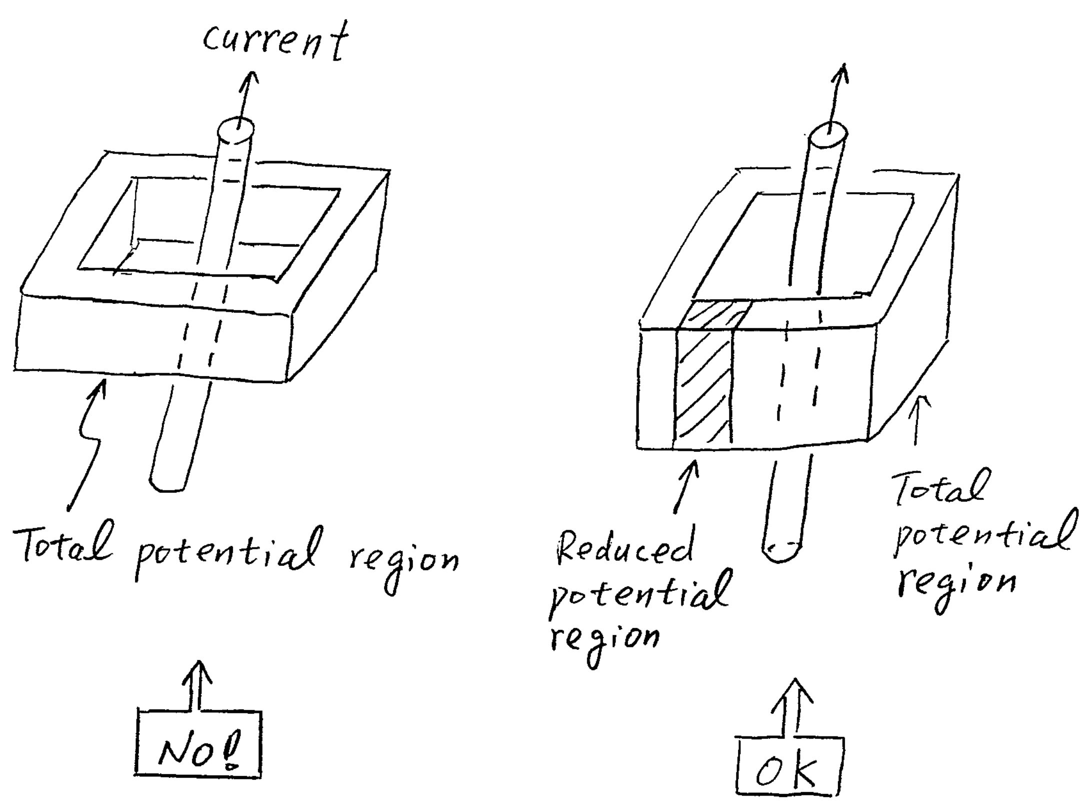
```
NUMBER OF TOTAL/REDUCED INTERFACE NODES= 2584

Discretisation inadequate to model coil fields at:
(  19.0    ,   38.9    ,  -75.0     ) (cm), error=   1.651% ******
(  38.9    ,   19.0    ,  -60.0     ) (cm), error=   1.279% *****
(  38.9    ,   19.0    ,  -52.5     ) (cm), error=   1.399% *****
(  38.9    ,   19.0    ,  -45.0     ) (cm), error=   1.429% *****
(  38.9    ,   19.0    ,  -37.5     ) (cm), error=   1.415% *****
(  38.9    ,   19.0    ,  -30.0     ) (cm), error=   1.388% *****
(  38.9    ,   19.0    ,  -22.5     ) (cm), error=   1.369% *****
(  38.9    ,   19.0    ,  -7.50     ) (cm), error=   1.349% *****
(  38.9    ,   19.0    ,  5.588E-07) (cm), error=   1.343% *****
(  38.9    ,   19.0    ,   7.50     ) (cm), error=   1.349% *****
(  38.9    ,   19.0    ,   15.0     ) (cm), error=   1.355% *****
(  38.9    ,   19.0    ,   22.5     ) (cm), error=   1.369% *****
(  38.9    ,   19.0    ,   30.0     ) (cm), error=   1.391% *****

(  38.9    ,   19.0    ,   45.0     ) (cm), error=   1.431% *****
(  38.9    ,   19.0    ,   52.5     ) (cm), error=   1.403% *****
(  38.9    ,   19.0    ,   60.0     ) (cm), error=   1.276% *****
(  38.9    ,   19.0    ,   67.5     ) (cm), error=   1.091% *****
(  38.9    ,   19.0    ,   75.0     ) (cm), error=   1.652% ******
(  32.2    ,   15.7    ,  -75.0     ) (cm), error=   1.246% *****
(  35.8    ,   17.5    ,  -75.0     ) (cm), error=   1.908% ******
(  32.2    ,   15.7    ,   75.0     ) (cm), error=   1.246% *****
(  35.8    ,   17.5    ,   75.0     ) (cm), error=   1.908% ******
(  26.3    ,   30.0    ,  -75.0     ) (cm), error=   2.221% ******
(  26.3    ,   30.0    ,   75.0     ) (cm), error=   2.220% ******
AVERAGE NUMBER OF CALLS TO SOURCE PER LINE INTEGRAL =   5.55
3:                                 Coil calculations:  1309.37     cp secs., elapsed
:  63.3833     mins.
```

(2) One turn Total potential problem

The TOSCA code has two kinds of potential areas. One is Total potential area and another one is Reduced potential one. Total potential area must not include any current region. So, in Total potential area $\oint H\,dl = 0$

If Total potential area surrounds a current, above Ampere's law does not consist.------ This is [one turn Total potential problem]. We must cut this one turn circuit with Reduced potential area, to get a correct TOSCA solution.

The opposite field vectors on Fig. 5-1 and 5-2 were occurred with above one turn Total potential problem. I got collect solutions described in chapter 2 with a change of potential region shown on Fig. 5-3.



[One turn Total potential problem]

(3) Error Field on Boundary Face

Both faces on x-axis and y-axis are set as Normal magnetic boundary condition for TOSCA calculation.

On the face of Normal boundary a tangential component must be zero. But on the Normal boundary face in Reduced potential region, the tangential component would be not-zero on TOSCA calculation. (In case of Normal boundary in Total potential region, the tangential component would be zero strictly.)

Figures 5-4 and 5-5 shows the not-zero tangential components on x-axis and y-axis with quarter coils (3 coils).

So, we should use full coils (12 coils) for TOSCA calculation as shown Fig. 4-1.

Polarized Proton Collisions at BNL

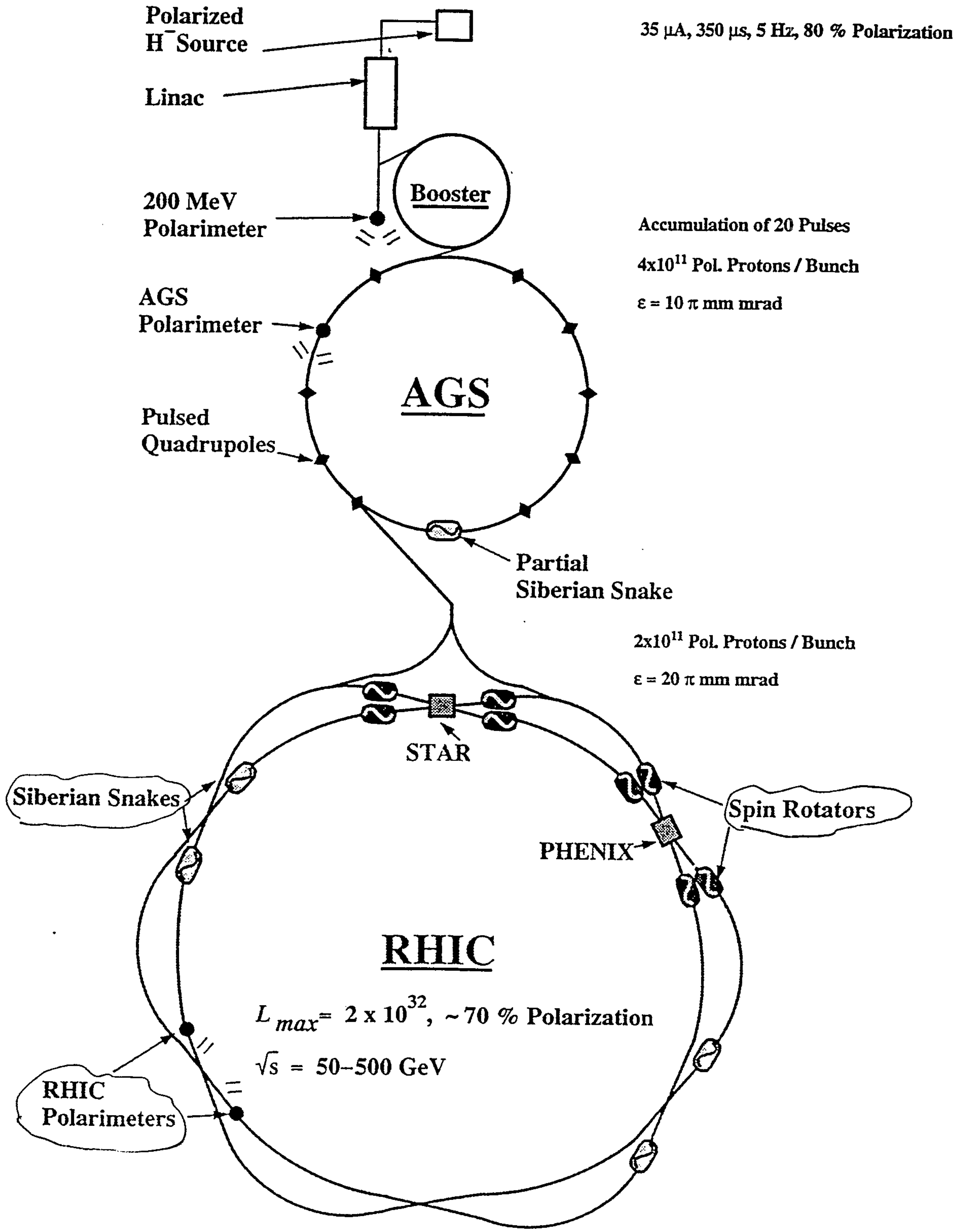


Figure 1

(8)

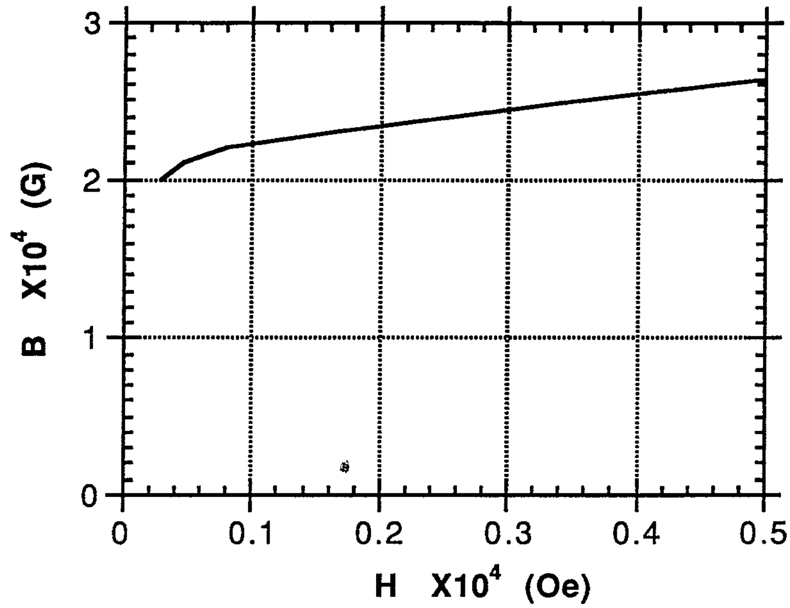


Fig. 3-1. B-H curve of iron pole

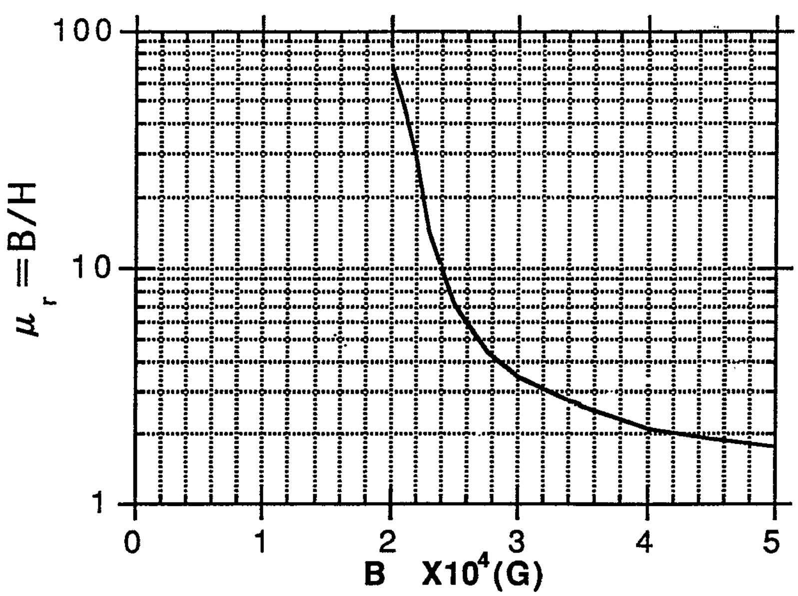


Fig. 3-2. B-(mu)r curve

RHIC Polarimeter 用 トロイダル電磁石 96-1-22.

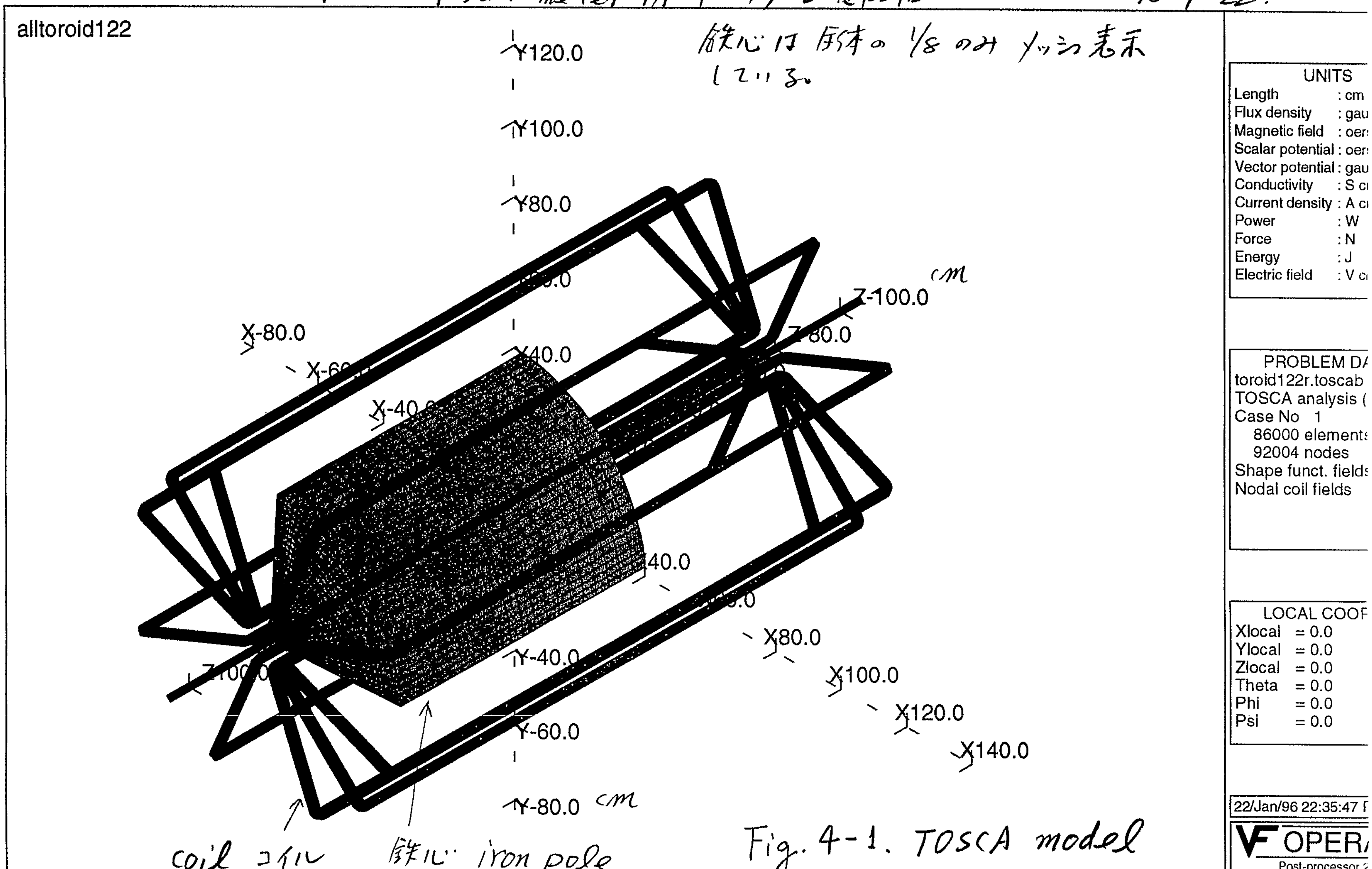


Fig. 4-1. TOSCA model

(101)

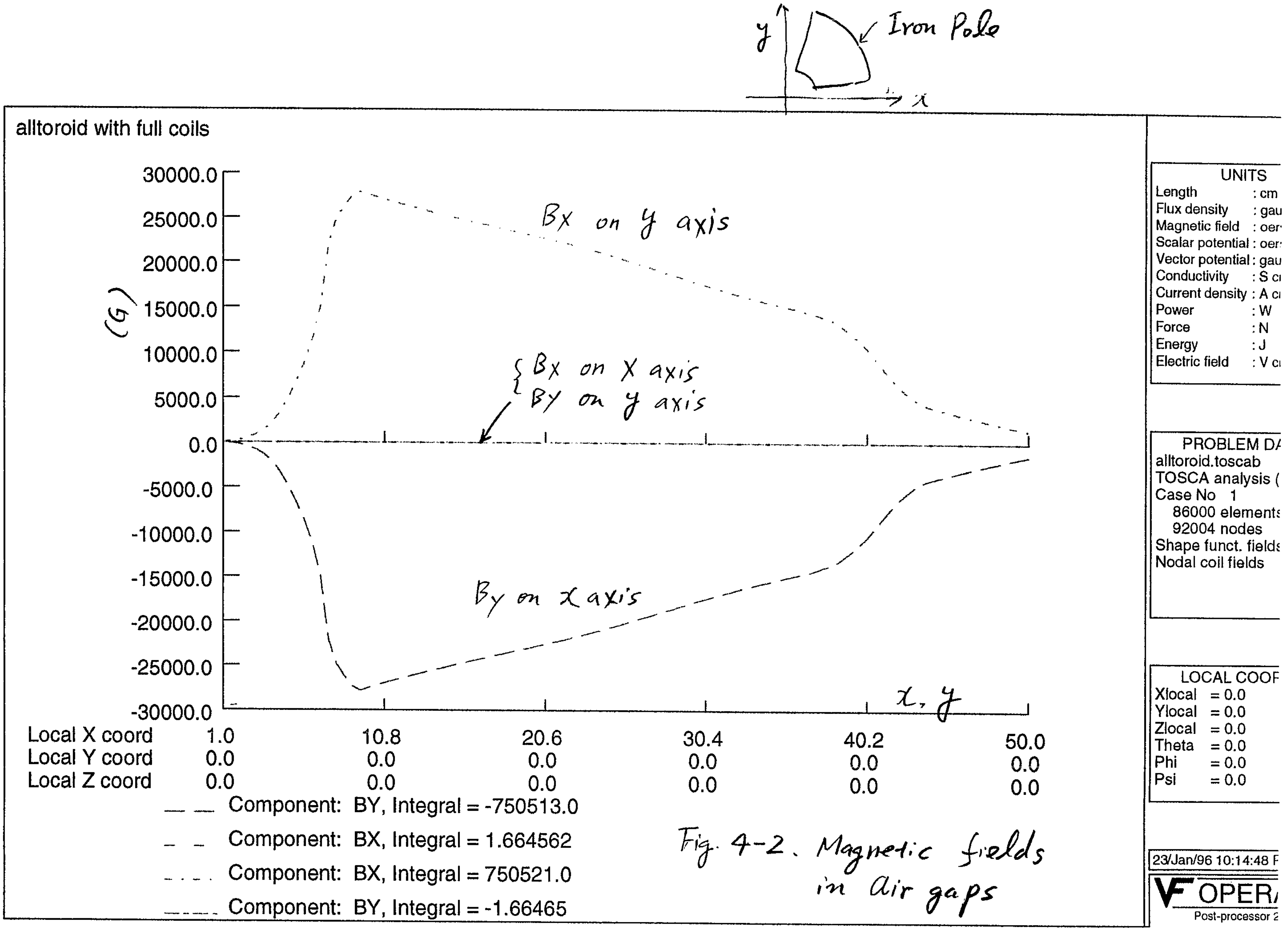


Fig. 4-2. Magnetic fields in air gaps

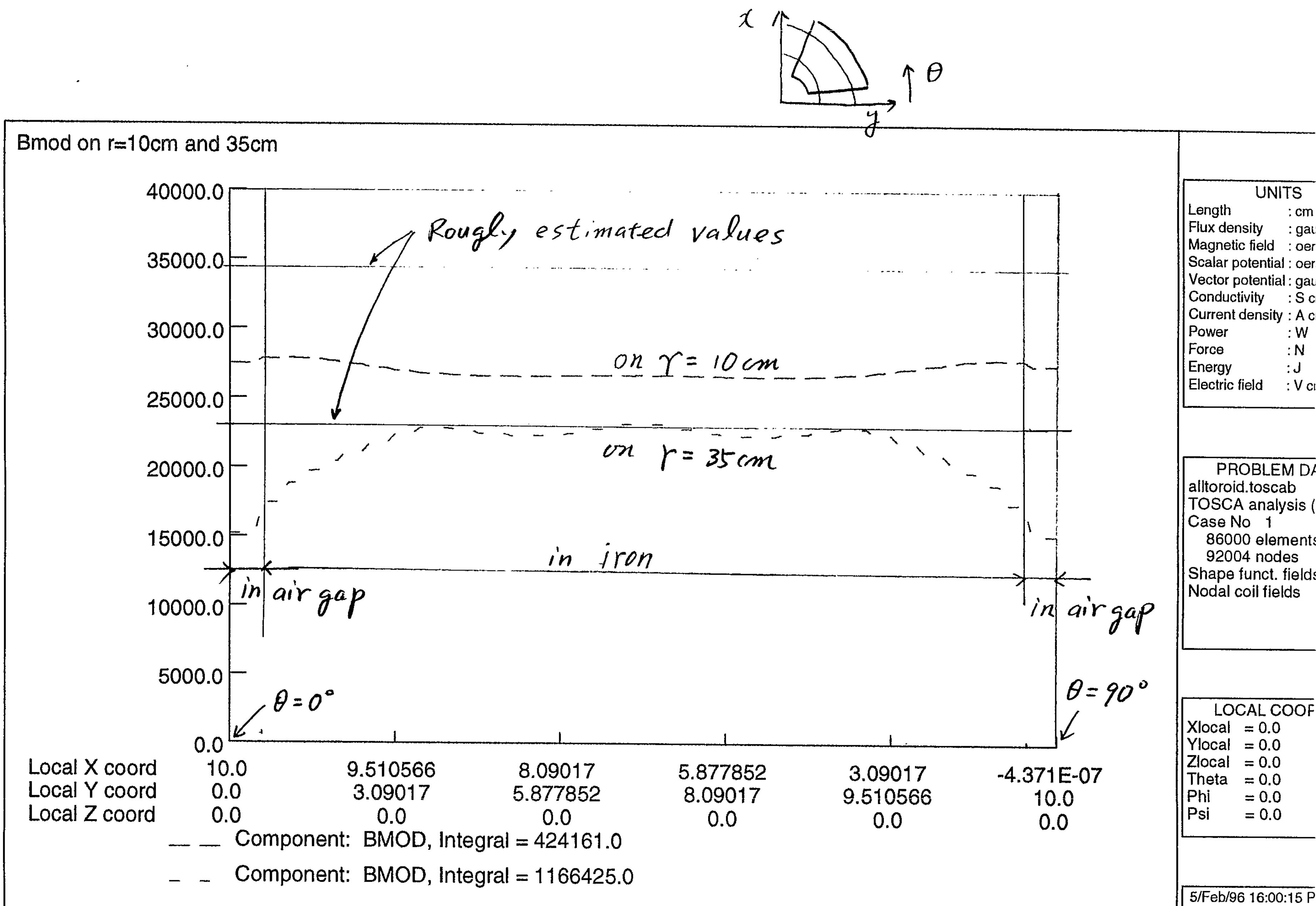


Fig.4-3. Bmod along radii

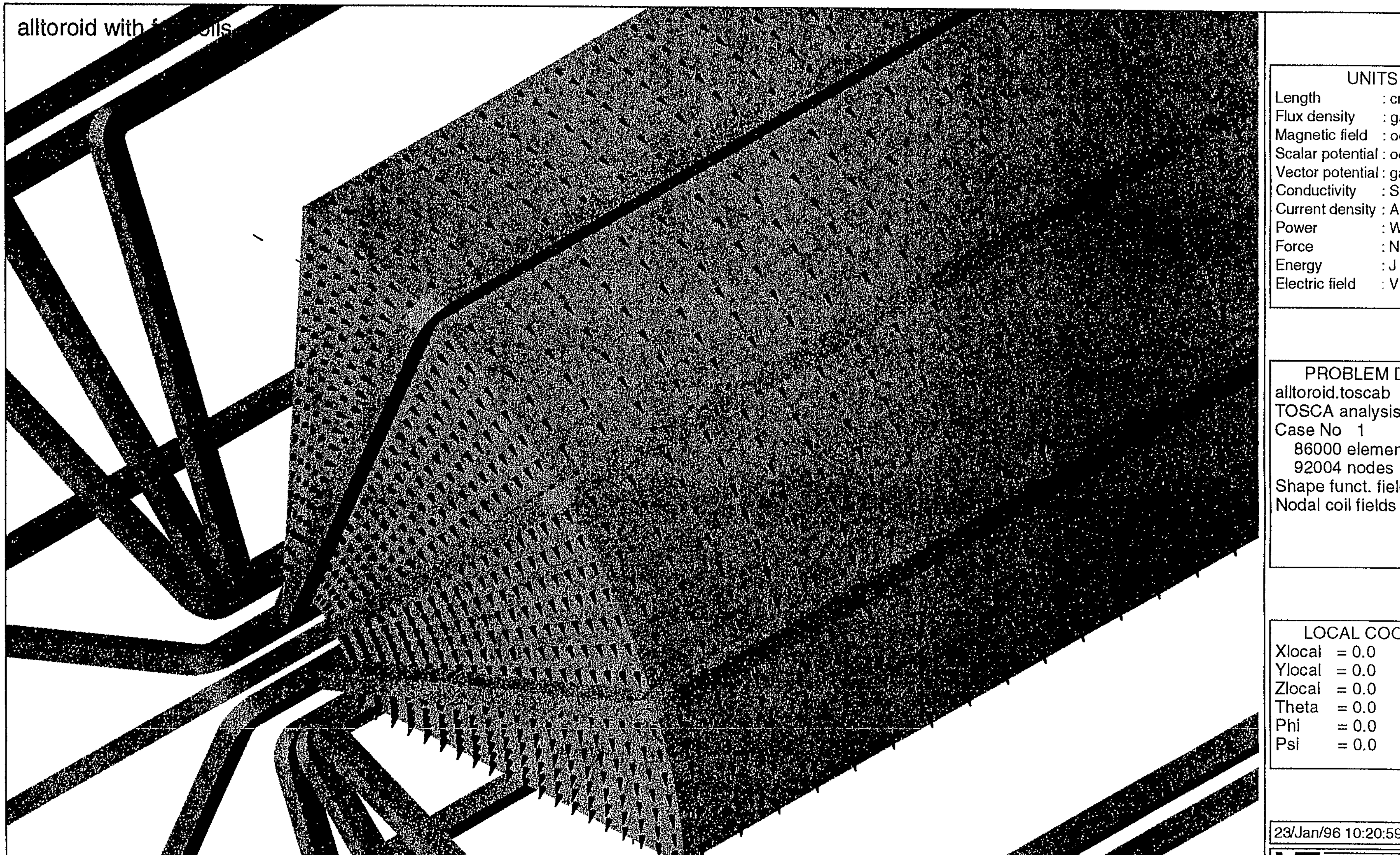


Fig. 4-4. Bmod vector on pole surface

内径部の磁界ベクトル図

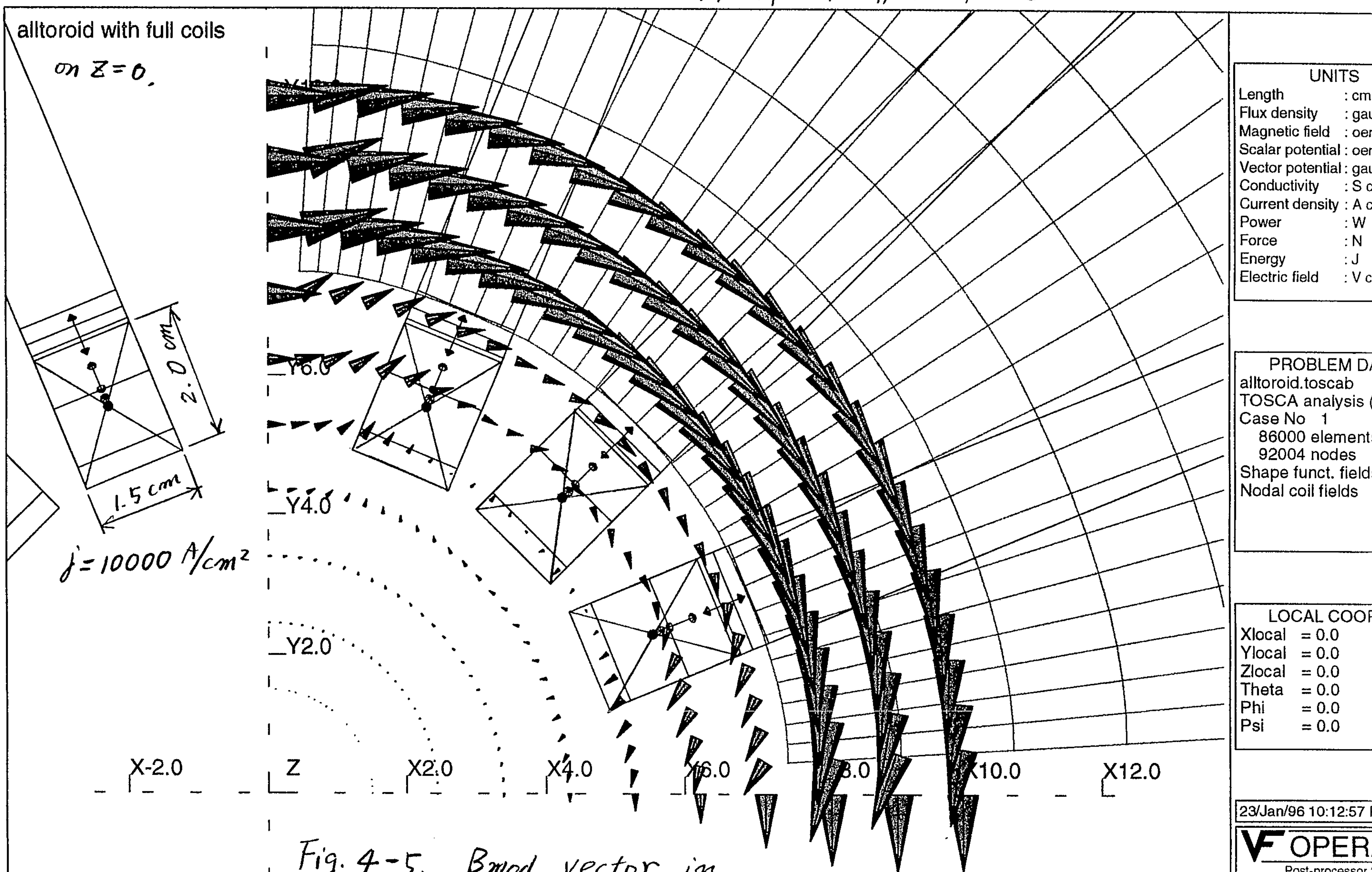


Fig. 4-5. Bmod vector in Inner area

(14)

(51)

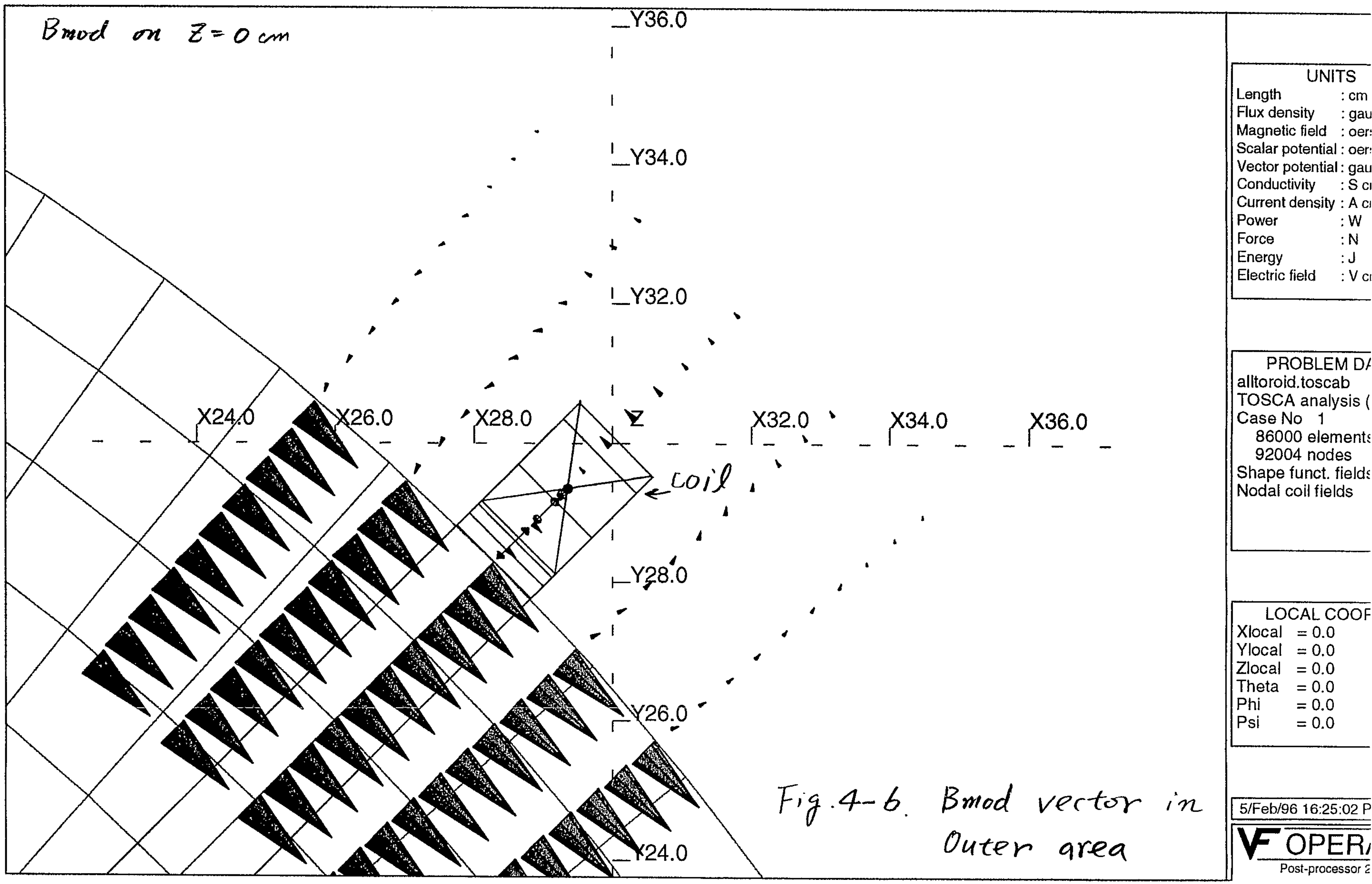


Fig.4-6. Bmod vector in Outer area

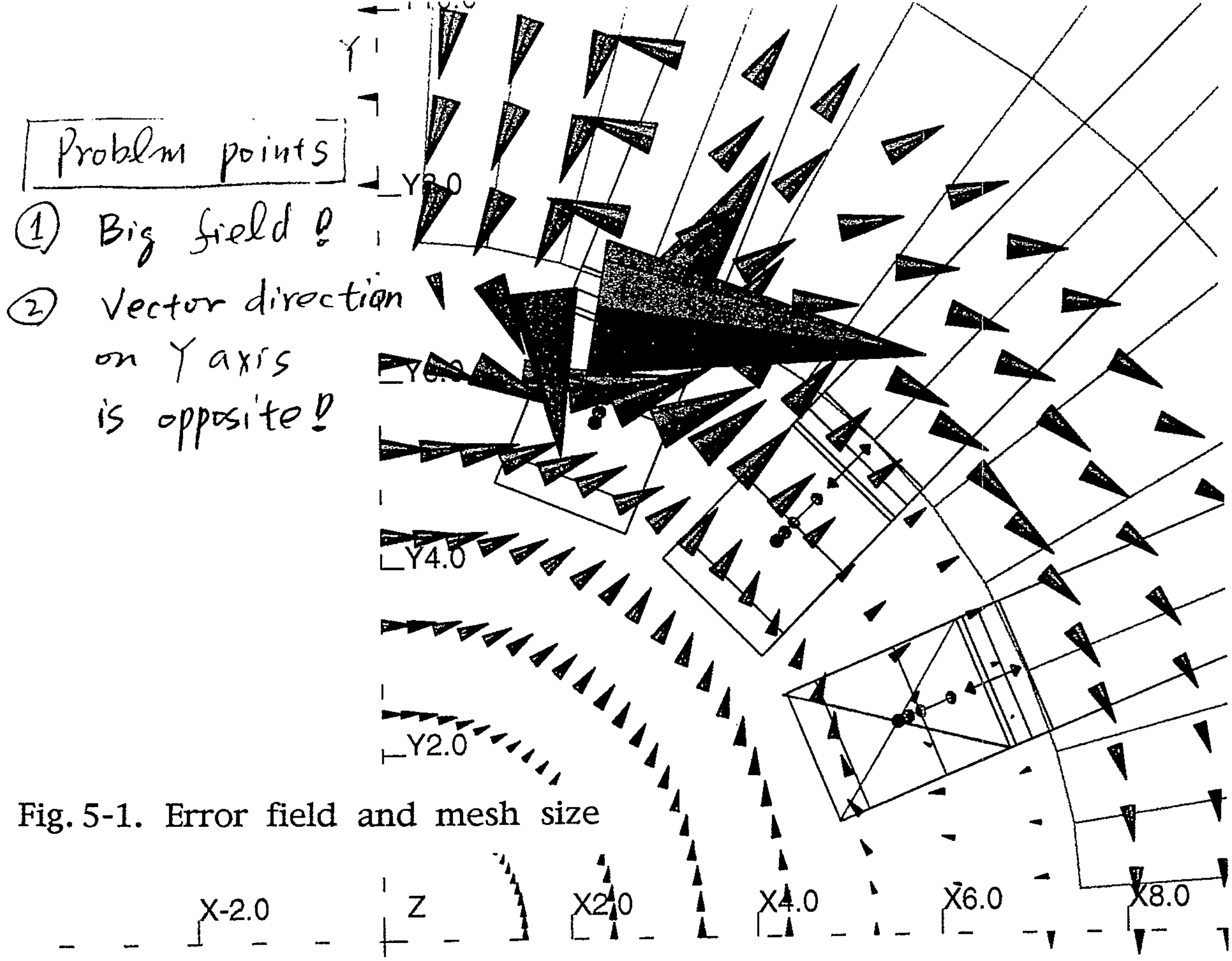


Fig. 5-1. Error field and mesh size

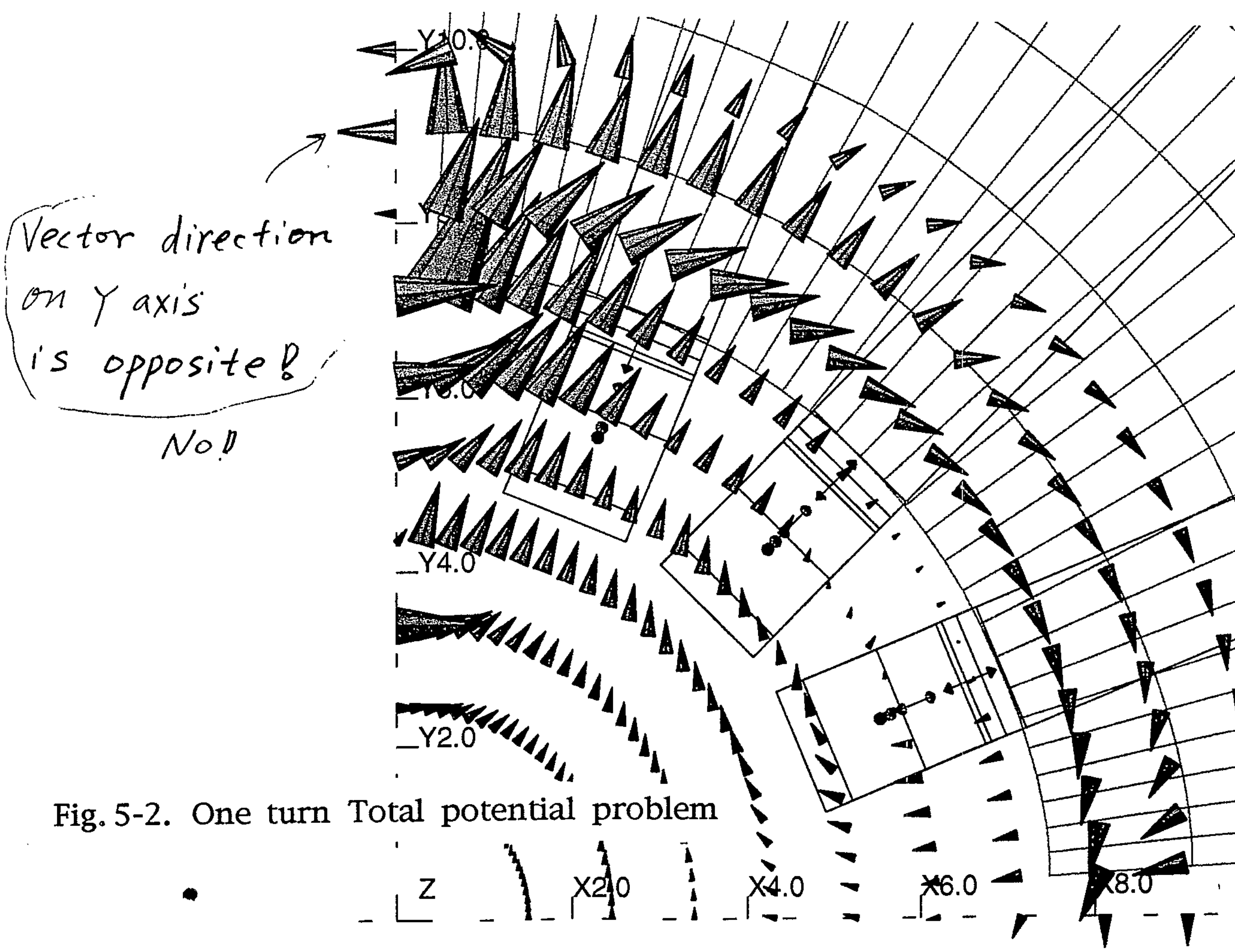
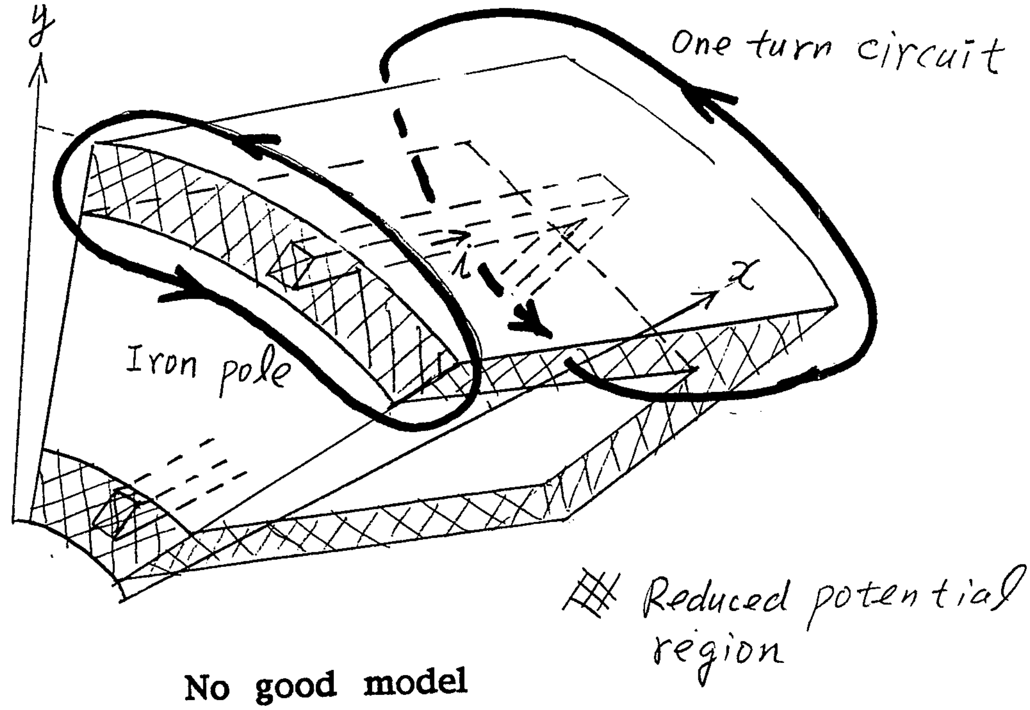
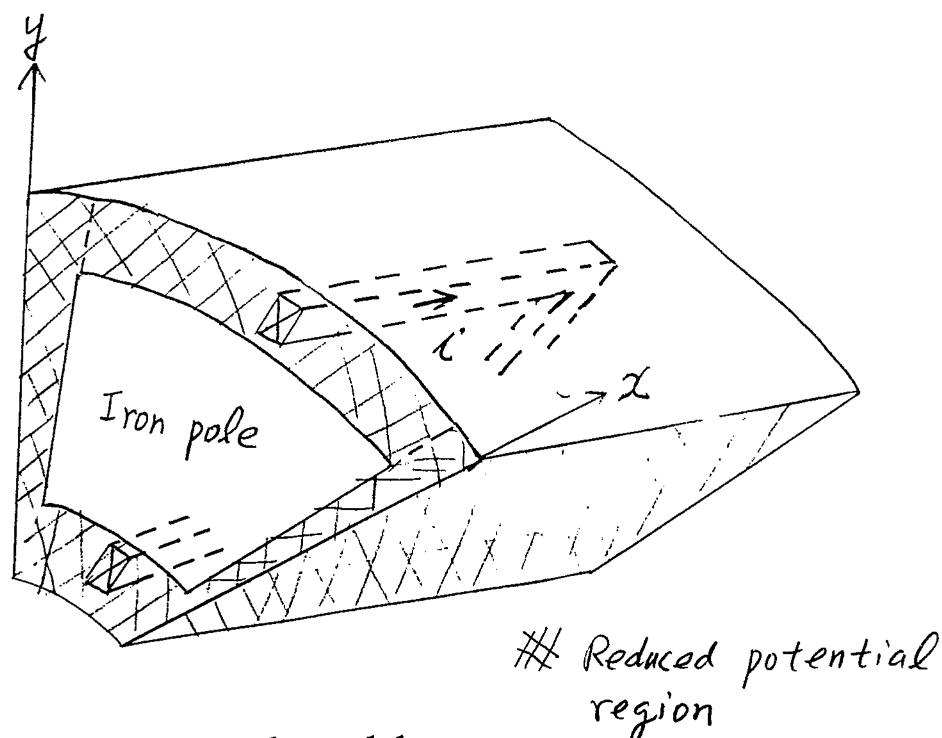


Fig. 5-2. One turn Total potential problem



No good model



Good model

Fig. 5-3. One turn Total potential problem

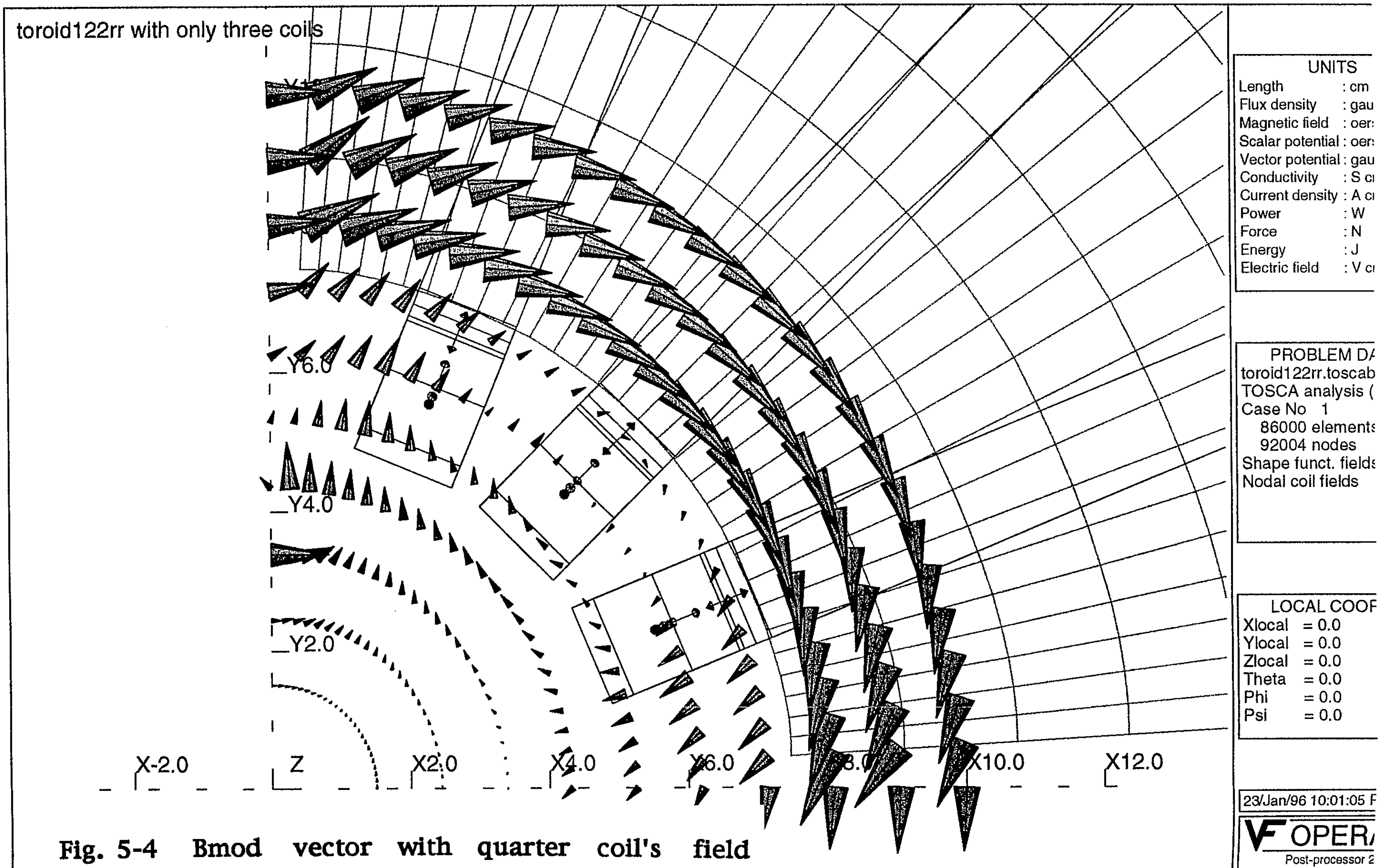


Fig. 5-4 Bmod vector with quarter coil's field

(18)

(19/19)

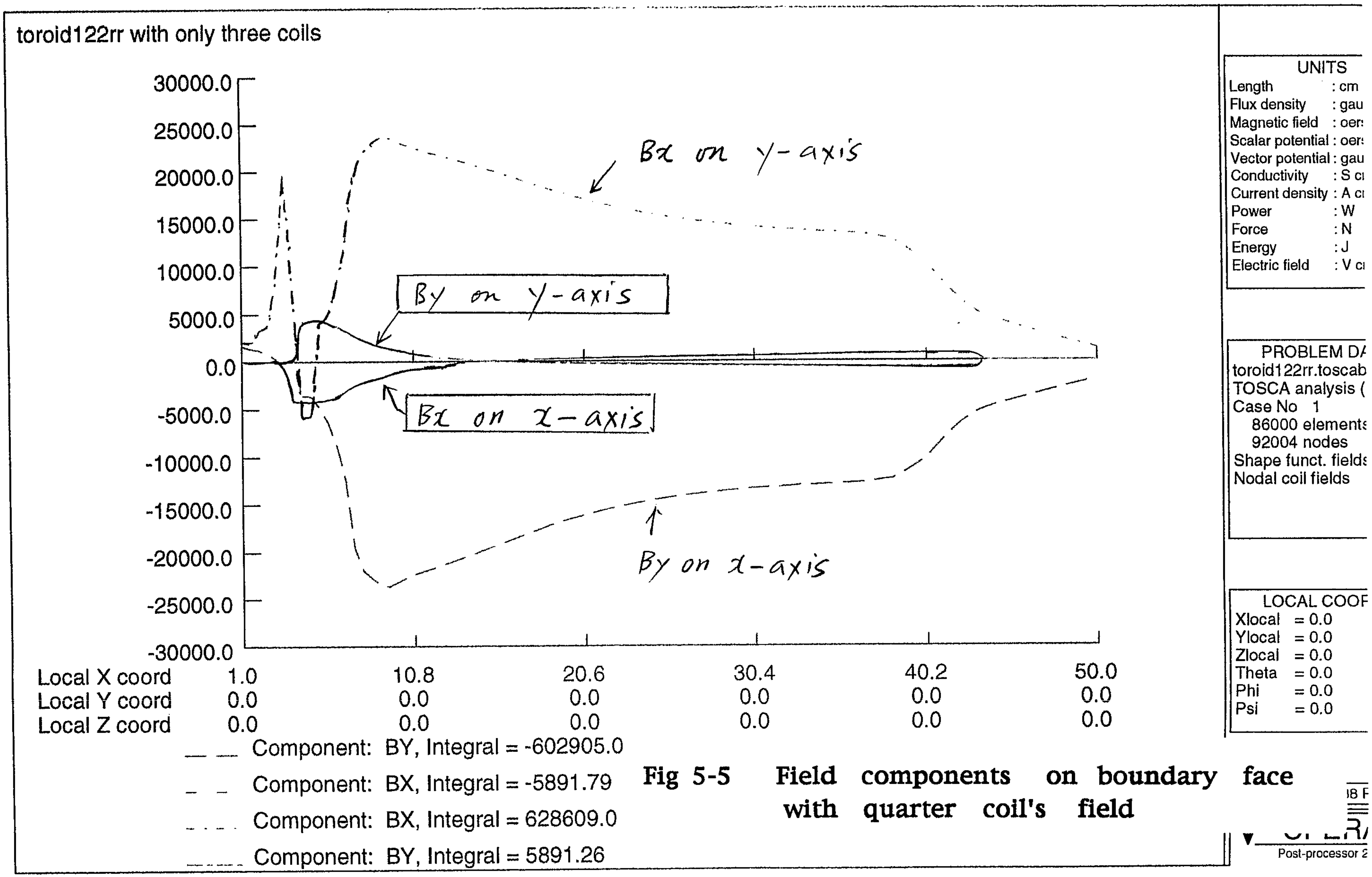


Fig 5-5 Field components on boundary face with quarter coil's field