GEM TN-91-35

FRINGE FIELD DIPOLE-DIPOLE FORCE INTERACTION

November 5, 1991

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Abstract:

Initial estimates of the magnitudes and directions of the forces arising from an interaction of magnetizable material with the fringe fields of the magnet for the GEM detector.

MIT-GEM-EM-01

Fringe Field Dipole-dipole Force Interaction

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TO: R. J. Thome

FROM: R. D. Pillsbury, Jr.

DATE: October 31, 1991

SUBJECT: Fringe Field Dipole-dipole Force Interactions

INTRODUCTION AND SUMMARY

A force and possibly a torque are experienced by magnetizable material when placed in a magnetic field. Initial estimates of the magnitudes and directions of the forces arising from an interaction of such material with the fringe fields of the magnet for the GEM detector have been made and are described below.

Several magnet pole and return frame design options have been investigated. These are: (1) the thin pole with no flux return frame; (2) the thick pole with no return frame; and (3) the thick pole with a 1.8 m thick return frame.

The body force densities experienced by small volumes of magnetizable material vary from less than 1 kN/m**3 to a maximum of 20 kN/m**3 (except for a small region in the vicinity of the pole where the forces are higher). In terms of the acceleration of gravity for iron at 7800 kg/m**3 the range is from 0.1 to 2.5 g's. For installed structural components such as rock bolts and I-beams, these forces appear to be a small portion of the total load carrying requirements.

For the two designs without a return frame, the forces are very similar with differences only in the immediate vicinity of the pole. The iron return frame serves to shield the hall from the fields and, hence, the force distributions are reduced by a factor of approximately 20 over the other two cases.

ALGORITHMS

If the volume of material is small so that its influence on the local field is negligible, the body force density can be expressed as:

$$\vec{F} = (\vec{M} \cdot \vec{\nabla})\vec{B} \tag{1}$$

where $\vec{M}$ is the magnetization in the material (i.e. the dipole moment per unit volume) and

$\vec{B}$ is a magnetic flux density. If the material magnetization vector is unable to align with the local magnetic field direction, the volume of magnetizable material will also experience a torque that tends to align the magnetization direction and the ambient field directions. This torque is given by:

$$\vec{T} = \vec{M} \times \vec{B} \tag{2}$$

If the material is saturated then the magnetization can be written as:

$$\vec{M} = \vec{B}_{sat}/\mu_0 \tag{3}$$

where $\vec{B}_{sat}$ is the saturation flux density for the material and μ_0 is the permeability of free space. Typical values of the saturation flux density for iron range from 1.2 to 2.0 T.

On the basis of these equations, the body force density experienced by a small magnetized body which can rotate in order that its magnetization direction is aligned with the ambient magnetic field can be written as:

$$\vec{F} = \vec{B}_{sat}/\mu_0(\vec{B}/|\vec{B}| \cdot \vec{\nabla})\vec{B} \tag{4}$$

Estimates have been made of the magnitude and direction of the force density at various points in the experimental hall using equation (4) assuming a saturation magnitude of 1.5 T. These estimates are presented below.

FORCE ESTIMATES

A two-dimensional, axisymmetric, non-linear, finite element code, MITMAP, was used to generate the magnetic field distribution for the baseline magnet concept. Equation (4) was used to calculate a distribution of the force densities in the hall assuming a 1.5 T saturation field level.

Figure 1 shows an elevation view of one half of the experimental hall with the magnet and pole piece of the thin pole design shown. Also shown is the position of the crane rail. Contours of constant body force density in kN/m**3 are shown. A small body of magnetizable material aligned with the local field line on one of these contours will experience that body force density shown. Figure 2 shows vectors of this force density for the thin pole design. The length of the vector shank is proportional to the magnitude of the force. As can be seen, regions near the end of the pole experience the largest magnitude of the force and the direction is toward the pole. The crane rail above the pole cuts the

line labeled 10 kN/m**3 in the plane of the pole which in terms of the acceleration of gravity is approximately 1.2 g.

Figure 3 shows an end view of the magnet and hall at an axial or z-directed location that is at the center of the pole piece. Shown are the crane rails and the I-beams along the walls of the hall. In this view all forces are directed radially inward toward the axis of the magnet represented by the circle. The I-beams that support the crane rails see a maximum loading of approximately 30 kN/m**3 and the load falls off as a function of vertical position to 5 kN/m**3. Rock bolts, if required, will see the same level of force densities.

Figure 4 shows a plot of the axial component of the body force density (directed along the side crane rails) versus axial position measured from the center of the magnet. As can be seen, the force is zero at $z = 0$, but an object would be in unstable equilibrium at this point – any perturbation in position will put a force on the object that will tend to move it away from the $z = 0$ position. At an axial position of approximately 15 m, the axial force is again zero. It can be seen that a perturbation about this point is stable, since an object in a position on either side of 15 m will experience a force attracting it to the 15 m point (i.e. the plane of pole piece). Figure 5 shows a similar plot for the radial component of the body force density which also reaches a maximum in the plane of the pole.

Similar analyses were made for the cases of the thick pole and the iron return frame. Figure 6 shows the elevation view of the magnet and hall with the contours of constant body force density superposed for the thick pole case. Comparison of Figures 1 and 6 show that the body force density distribution in most of the hall is essentially the same. Differences only appear very near the pole.

Figure 7 shows the force density contours in the hall for the case of a thick pole plus 1.8 m thick iron flux return frame. As can be seen the force densities are reduced by a factor of approximately 20 from those of the thin or thick pole cases.

Additional analyses are under way to assess the distribution of loads on larger components such as the I-beams, crane rails, and crane cross-rails. These components may not have a local magnetization direction that aligns with the ambient field as is assumed in the preceeding analyses, but the loads found by integrating the values found using the method described in this memo should be conservative.

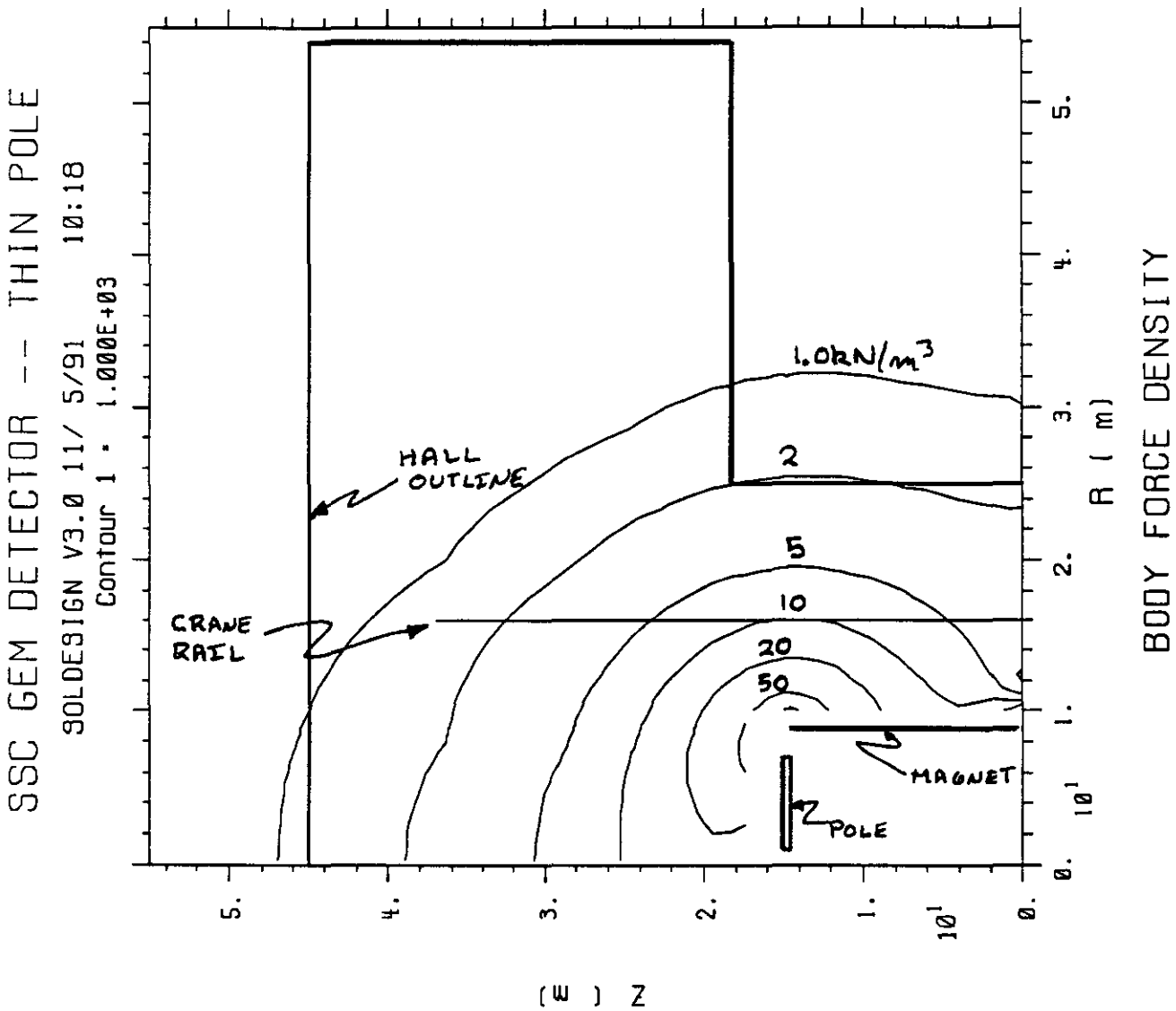


Fig. 1 – Contours of constant body force density for the thin pole baseline design for GEM. A small magnetizable body at any point along a contour will experience a body force density of the magnitude indicated. For iron at 7800 kg/m**3, 1 kN/m**3 of body force density translates to an acceleration 0.128 g's.

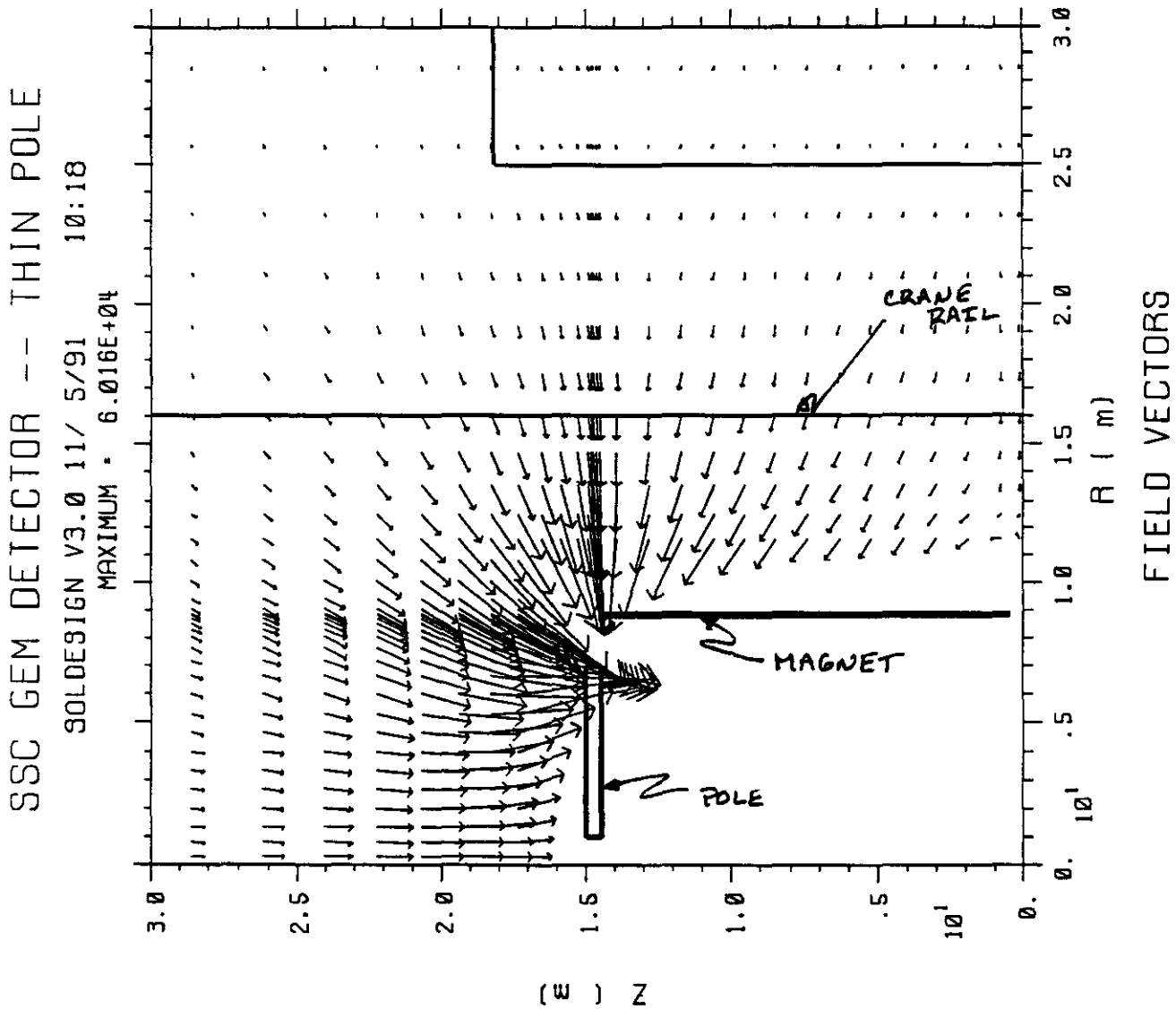
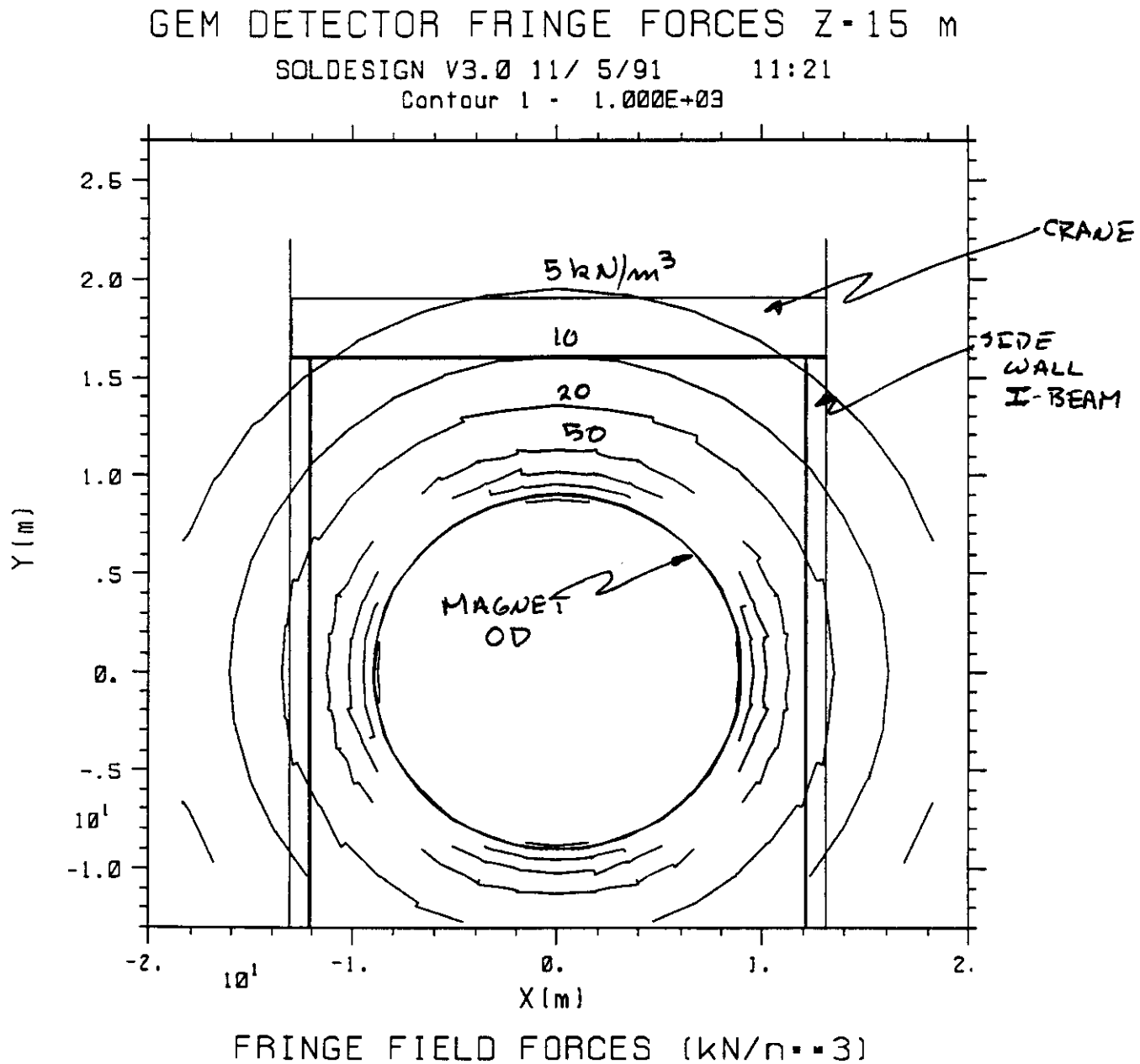


Fig. 2 – Vectors of body force density for the thin pole baseline design for GEM. The length of the vector is proportional to the force density.



– Contours of constant body force density for the thin pole baseline design for GEM in an end view in the plane of the pole. Force direction is toward the axis of the magnet. A small magnetizable body at any point along a contour will experience a body force density of the magnitude indicated. For iron at 7800 kg/m**3, 1 kN/m**3 of body force density translates to an acceleration 0.128 g's.

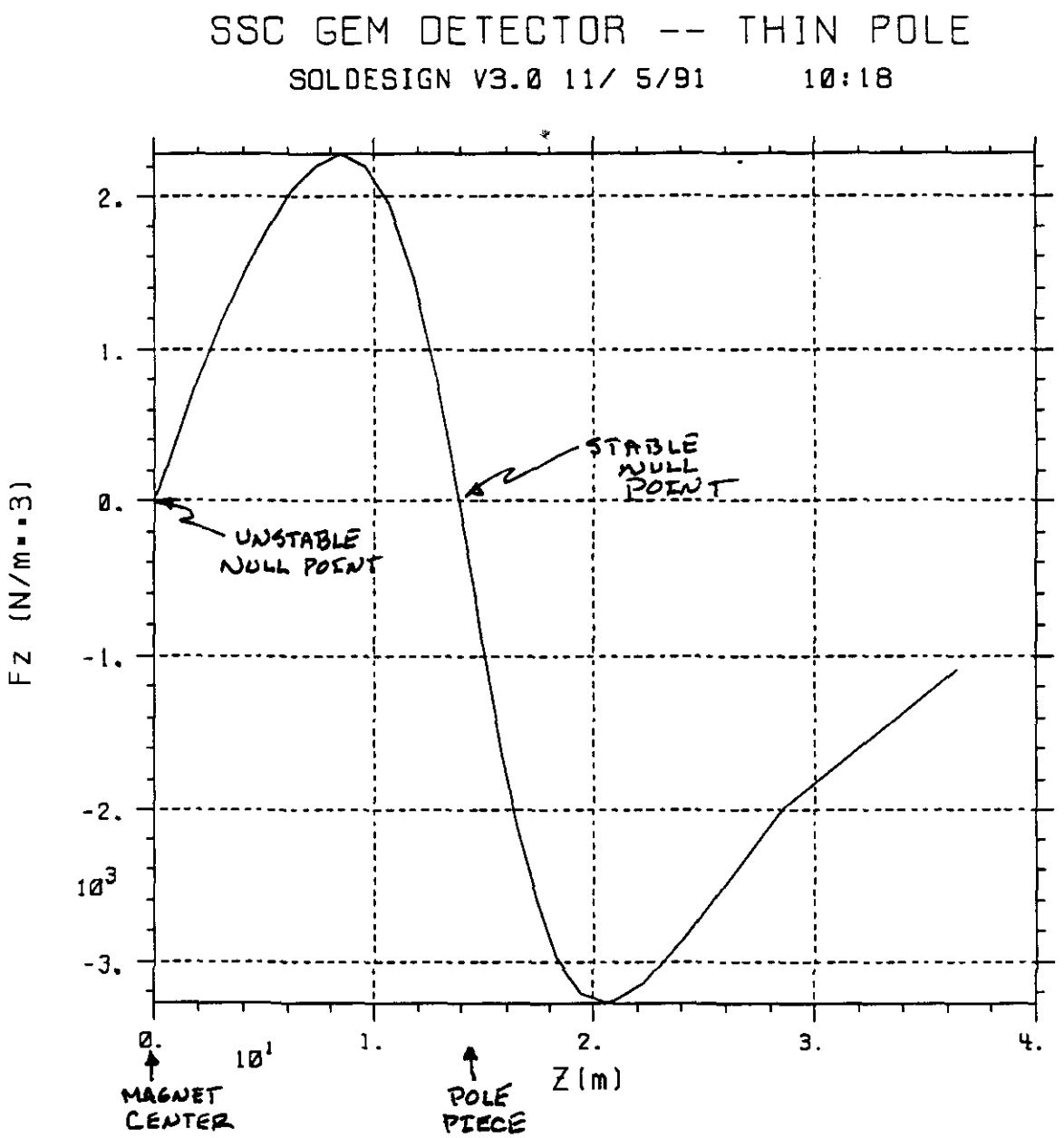


Fig. 4 – The axial component of body force density versus position along the crane rail for the thin pole baseline design for GEM.

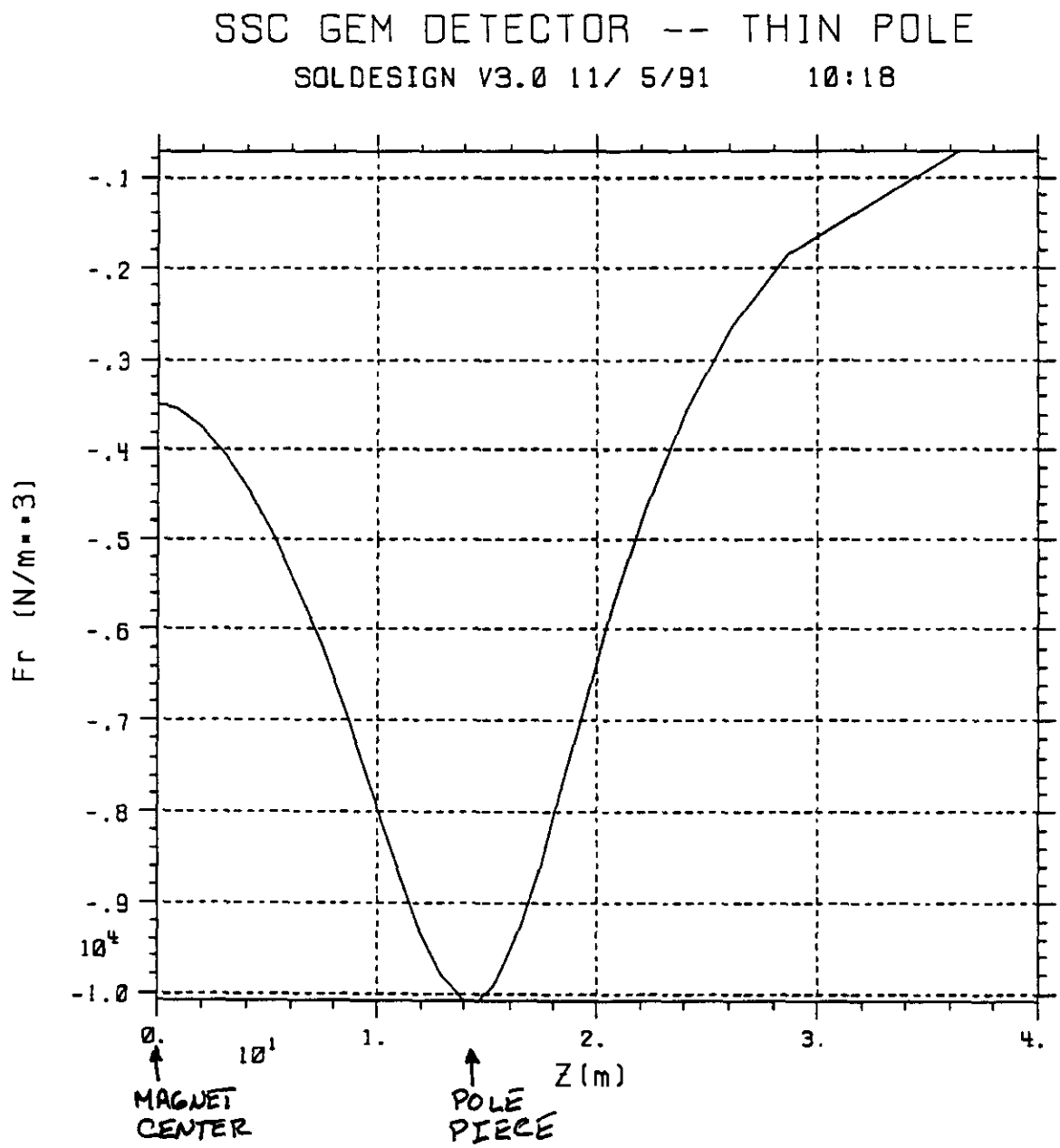


Fig. 5 – The radial component of body force density versus position along the crane rail for the thin pole baseline design for GEM.

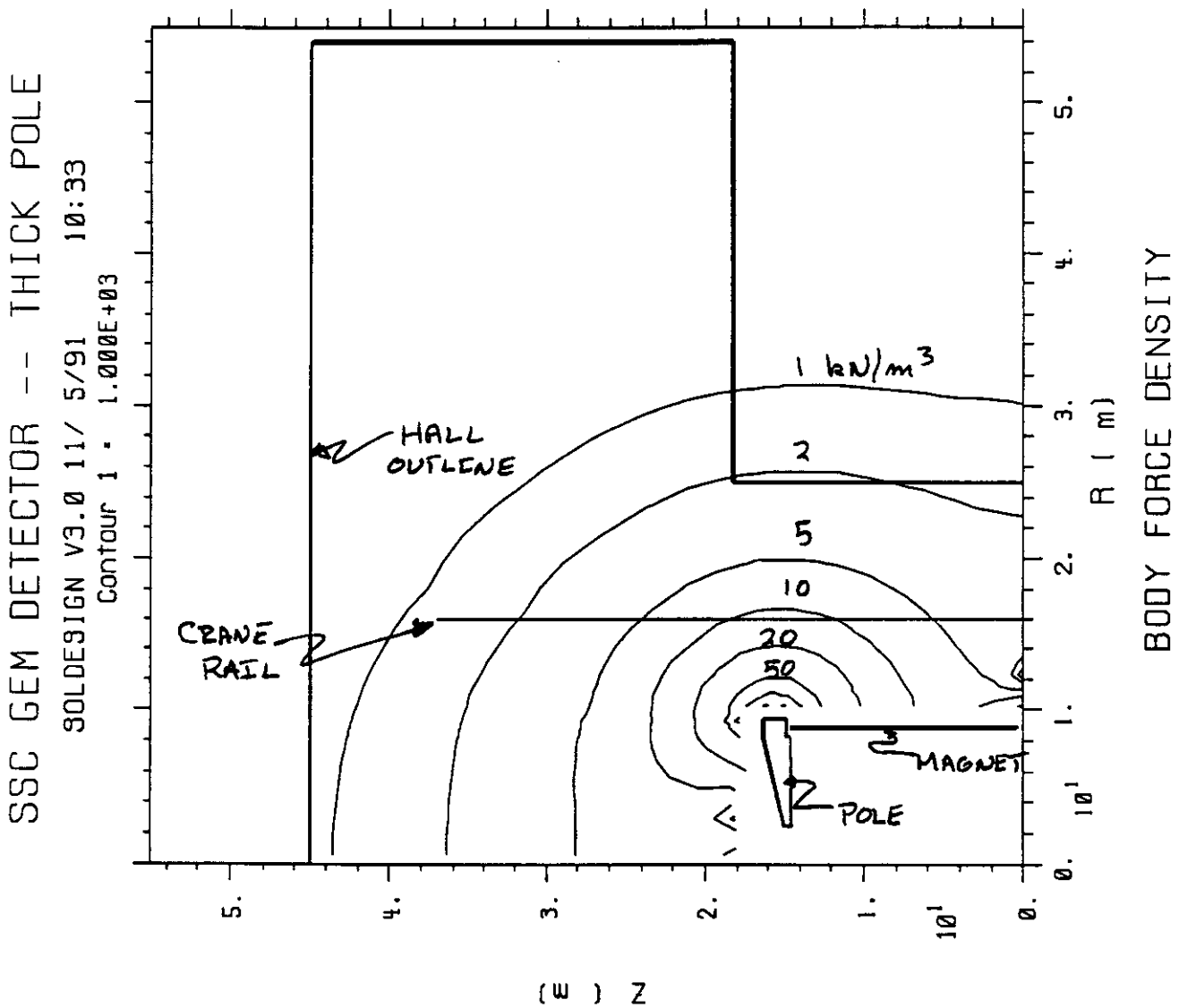


Fig. 6 – Contours of constant body force density for the thick pole design option for GEM. Note only slight differences in contours from the thin pole case.

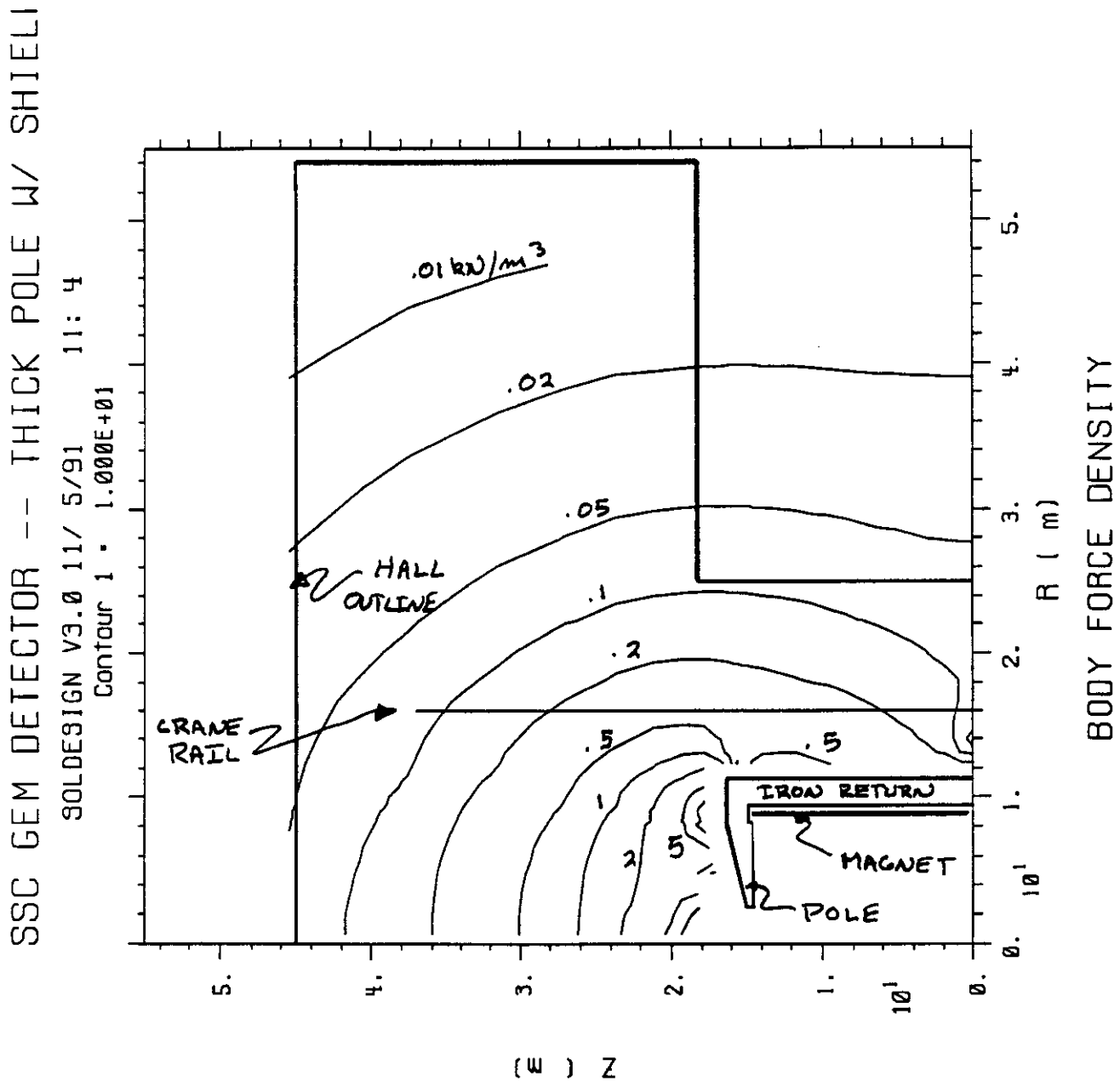


Fig. 7 – Contours of constant body force density for the iron return frame design option for GEM. Note only contours values are reduced by a factor of approximately 20 from the thin pole baseline option.