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Quadrupole Design

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QUADRUPOLE DESIGN

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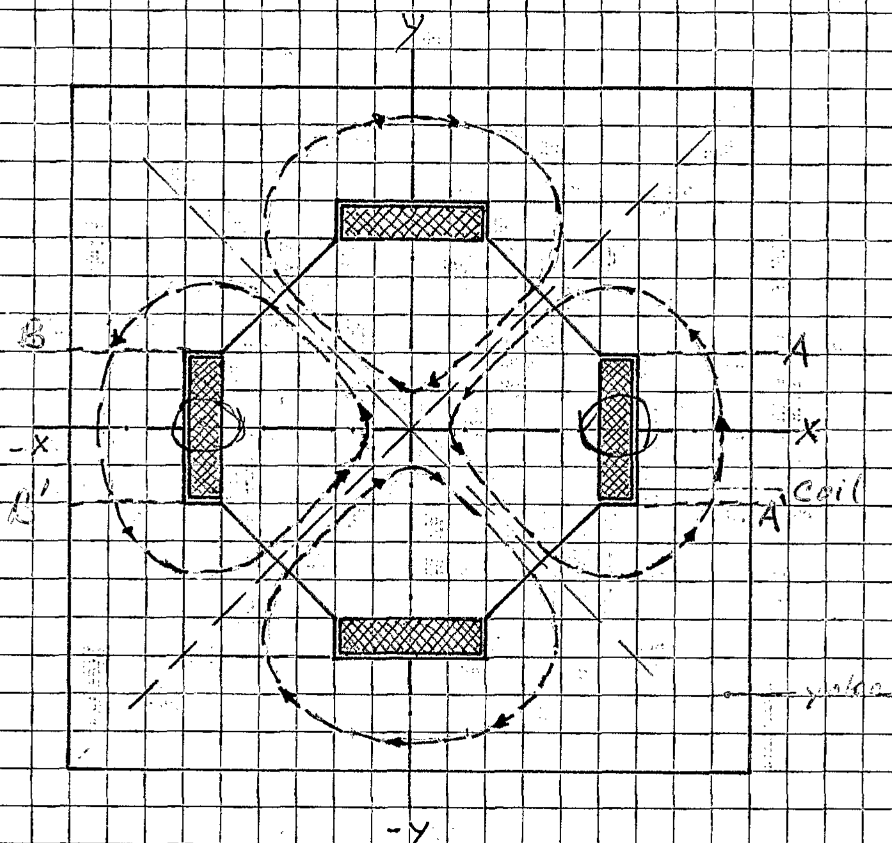
On Quadrupole design

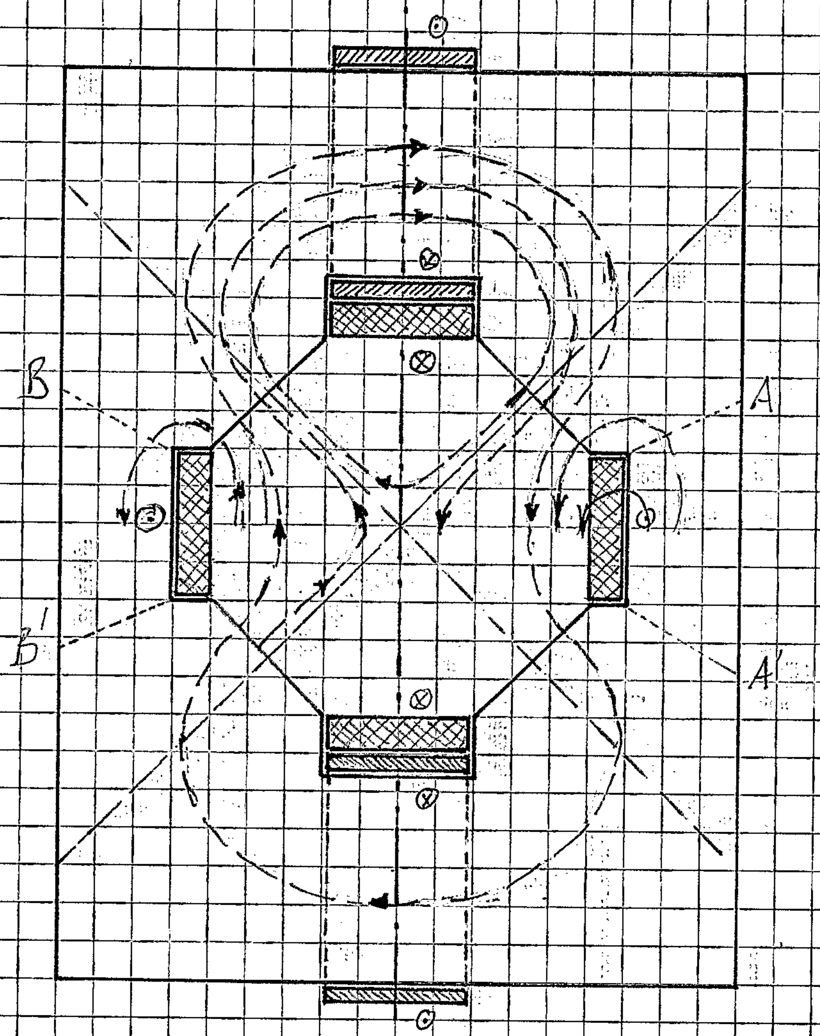
Consider basic quadrupole as sketched below



There is both magnetic and mechanical quadrupole symmetry, a few flux lines have been sketched in. It is evident that the flux through the yoke iron is largest in the horizontal and vertical symmetry planes -XOX, -YOY. If the iron has sufficiently high μ this is of little consequence, only a few amp-turns are required to push the flux through and H is very low. If the μ drops, due to iron saturation, the H increases and a non negligible $H_{\parallel}$ develops on the outer surfaces of the yoke's legs.

In the cross section shown this will happen first and primarily in the vicinity of the horizontal and vertical planes of symmetry.
There will be a leakage flux outside the yoke in these regions. This flux tends to go through nearby, less saturated iron, e.g. through the vertical leg of a companion quadrupole.

The effect can be prevented, or at least reduced by removing the flux through the vertical legs. This can be done by forcing the magnetic potential difference $\int H\,dl$ between the planes A-A', B-B' to zero, a) by increasing the widths of the horizontal legs, b) by installing additional excitation around these legs. The net result is shown below.
It is clear that some flux can be tolerated in the vertical legs, e.g. $B \leq 1T$ perhaps, because up to that B value μ is so high that H_t on the leg surface is negligibly low.
This is obviously necessary in a quadrupole, since the flux in the vertical legs must change proportionally with the distance to the planes of symmetry.
It is also obvious that the extra coils can be very small. Their function is to make the magnetic potential difference between A and B, as well as



Must be driven A' and B' to approximately zero, making the upper and lower "U"s of the yoke into semi perfect magnetic shorts.

This must be done while flux is flowing, thus creating a MMF. This MMF can be very small because it is mostly controlled by the thickness of the horizontal legs, which are not restricted in any way. The function of the two extra coils is mainly to compensate for this MMF.