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NOMINAL VALUES OF Q_H AND Q_V FOR THE BOOSTER AND THEIR RANGE OF TUNING

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1. The technical problem

One of the reasons for the selection of a separated function design is the possibility of continuous, independent Q-tuning in the two planes. From this point of view three separate power supplies (for bending magnets, F and D lenses, respectively) give the greatest freedom. However, as realized from an early date, this solution also entails the most stringent tolerances and the highest cost.

An intermediate solution, discussed in the beige book[1] is to power the two lens-circuits in series, thereby saving some money, and, more importantly, reducing the tolerances required. However, as C. Bovet[2], B. Godenzi and R. Mosig[3] found out, the tolerances are still rather unpleasant (for $|\Delta Q| < 0.02$).

The proposal is therefore to give up some flexibility and to power the entire magnet system in series from one supply. The problem is then where to put the nominal working point, viz. in the region of point A, B or C in Fig. 1.

B. Godenzi and R. Mosig prefer a solution which does not require a reversal of the correcting (tuning) current during a proton accelerating cycle, with the lens lengths and number of turns calculated to suit some chosen nominal working point. (Smaller correcting supplies, one for each set of lenses, would then provide the continuous independent tuning over a sufficient region.) This is because with thyristor supplies the current is badly controllable during an interval of about 5 ms while crossing the point $I_{corr.} = 0$. (This would not be so with transistor supplies; however the voltage is probably too high for such supplies.)

This consideration then favours points A (+ currents only) or C (- currents only, i.e. shunts in the limit). On the other hand point B is more interesting because the tuning current range is smaller and one my even choose a point where the Booster would work with $I_{corr.} = 0$.

2. Theoretical considerations

These considerations were discussed at a meeting between W. Hardt, H.G. Hereward, P. Lapostolle and the writers.

a) A working point at injection between B and C is favoured for the following reasons.

i) When the (transverse) space charge detuning has lowered the effective Q to a half-integer or integer value, resonance occurs and the beam is blown up and probably lost. However, at $Q = 4$ we also have systematic 4th order resonances which makes one feels that the $Q = 4.5$ stop band is basically less dangerous and easier to narrow down. For the detailed position of the working point one can let oneself be guided by W. Hardt's paper[4]. The graph of his Figure 1 gives the optimum ratio $\lambda = \Delta Q_y/\Delta Q_x$ for various beam diameter ratios α = average beam width/average beam height, where the ΔQ_i are the shifts induced by the space charge forces (Fig. 2).

ii) In this region ionic resonances are prohibited[5].

b) A working point between point A and B has some advantages from the point of view of throbbing beam transverse resistive instabilities[6]. These instabilities have several modes, which have different stability conditions. Neglecting the practically stable monopole mode (symmetric oscillations of the beam envelope), one has the following conditions[6].

Type of oscillations	Approximate frequency of oscillations (βtron frequency = ω_0)	Stable conditions for bunched beams
Dipole	ω_0	$n < Q_0 < n + 1/2$
Quadrupole	$2\omega_0$	$n < 2Q_0 < n + 1/2$
Sextupole	ω_0 $3\omega_0$	$n < Q_0 < n + 1/2$ $n' < 3Q_0 < n' + 1/2$
Octupole	$2\omega_0$ $4\omega_0$	$n < 2Q_0 < n + 1/2$ $n' < 4Q_0 < n' + 1/2$

where Q_0 is the low-intensity Q and n and n' are integers (Fig. 3). From this it is seen that the stable region moves more and more towards point A the higher the mode. As this is however contrary to desideratum a) above one would in practice not consider taking this into account. Anyway, these instabilities are expected to occur at higher intensities than the resonances of type a).

c) At higher energies these considerations apply to a lesser degree. At transfer energy it would be nice to be sufficiently close to $Q_R = 4.5$ to be able to eject in two-turns (bunch splitting).

d) Obviously, at all energies one wants to stay away sufficiently from the stop bands for half integer, integer, sum and difference resonances (see Fig. 4).

6. Tentative solution proposed

As a consequence of all the above considerations a nominal working point $Q_{Ho} = 4.60$, $Q_{Vo} = 4.65$ is tentatively proposed.

In Figure 5 the effect of a five per cent current change in the quadrupoles is shown for the four possible regimes : + currents in F and D lens circuits ((1)), + currents in F and - currents in D ((2)), = ((3)) and $\mp$ ((4)).

In Fig. 6 a practical situation is shown for a two per cent current change at transfer energy, which allows a ten per cent current change at injection. It is seen that in the region ‡ ((1)) the "machine Q's" may be set to any value in the first quadrant, and in particular in the triangle of interest. At transfer, the possibilities of adjustment look adequate.

On the other hand, injection studies with a working point in the third quadrant can be made in the regime = ((3)) up to about $p = 2\ p_{inj.}$, and if we were so unlucky as to find that only the third quadrant is free from serious instabilities, some additional shunts would make it available throughout the cycle.

<u>Distribution</u> (open)

List MPS/SI 1

References

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2) C. Bovet, Nouvel Injecteur du CPS : variations et tolérances du courant d'alimentation des triplets, MPS/DL - B/Note 67-12, 23.10.1967.

3) B. Godenzi and R. Mosig, Private Communication.

4) W. Hardt, On the Incoherent Space Charge Limit for Elliptic Beams, ISR/Int. 300 GS/66.2, 14.1.1966.

5) H.G. Hereward, The Instability of Radial Betatron Oscillations in the CPS, MPS/Int. DL 64-8, 20.3.1964.

6) For instance, M.J. Lee, F.E. Mills and P.L. Morton, Throbbing Beam Transverse Resistive Instabilities in Circular Accelerators and Storage Rings, SLAC-76, August 1967.

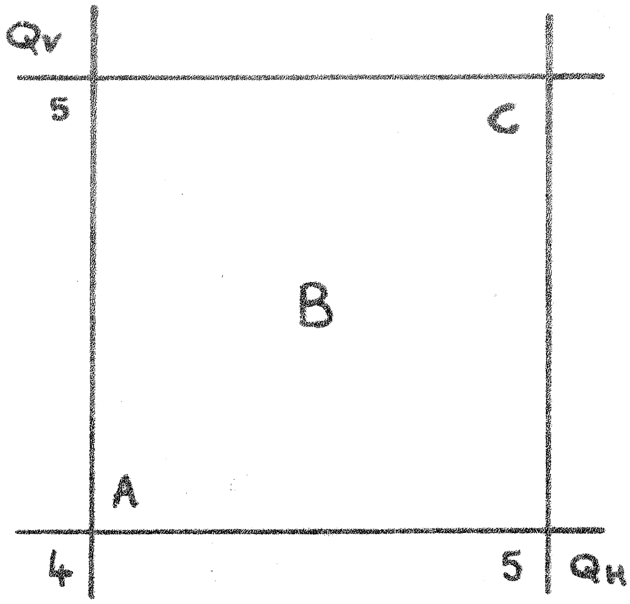

Fig. 1. Q values

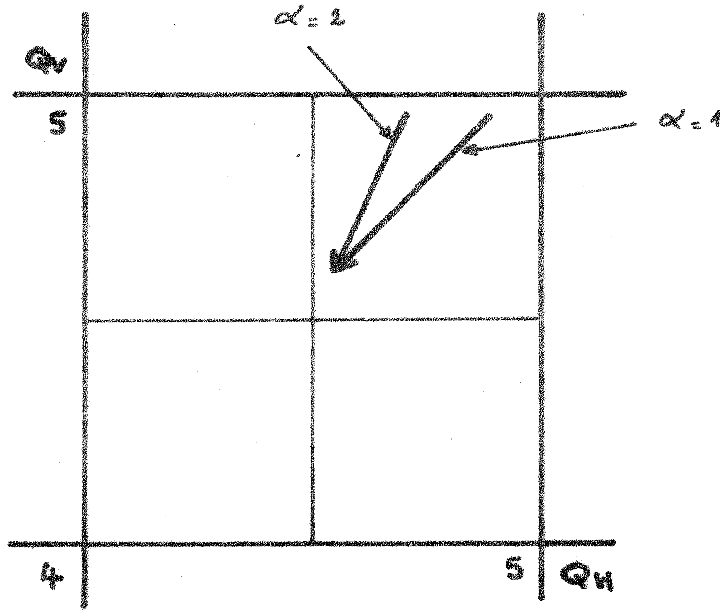

Fig. 2. Depression of Q values due to space charge

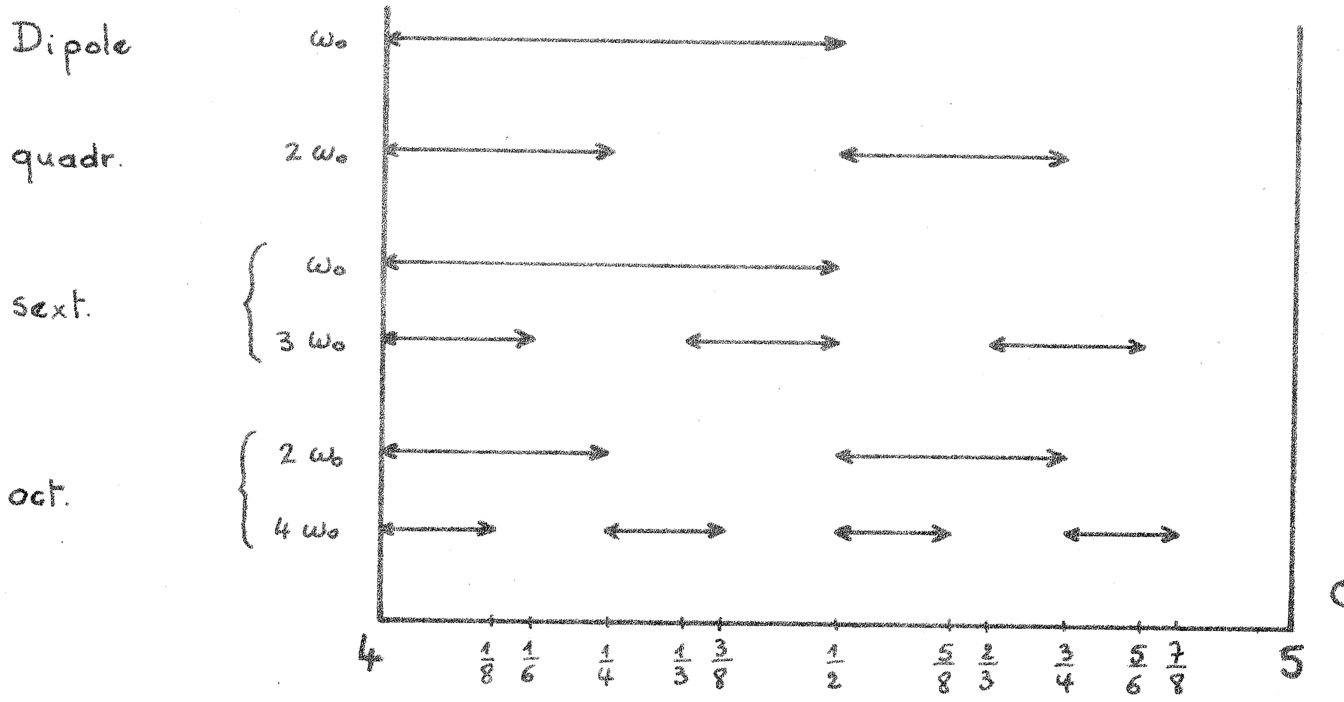

Fig. 3. Stable regions for throbbing beam instabilities of different orders

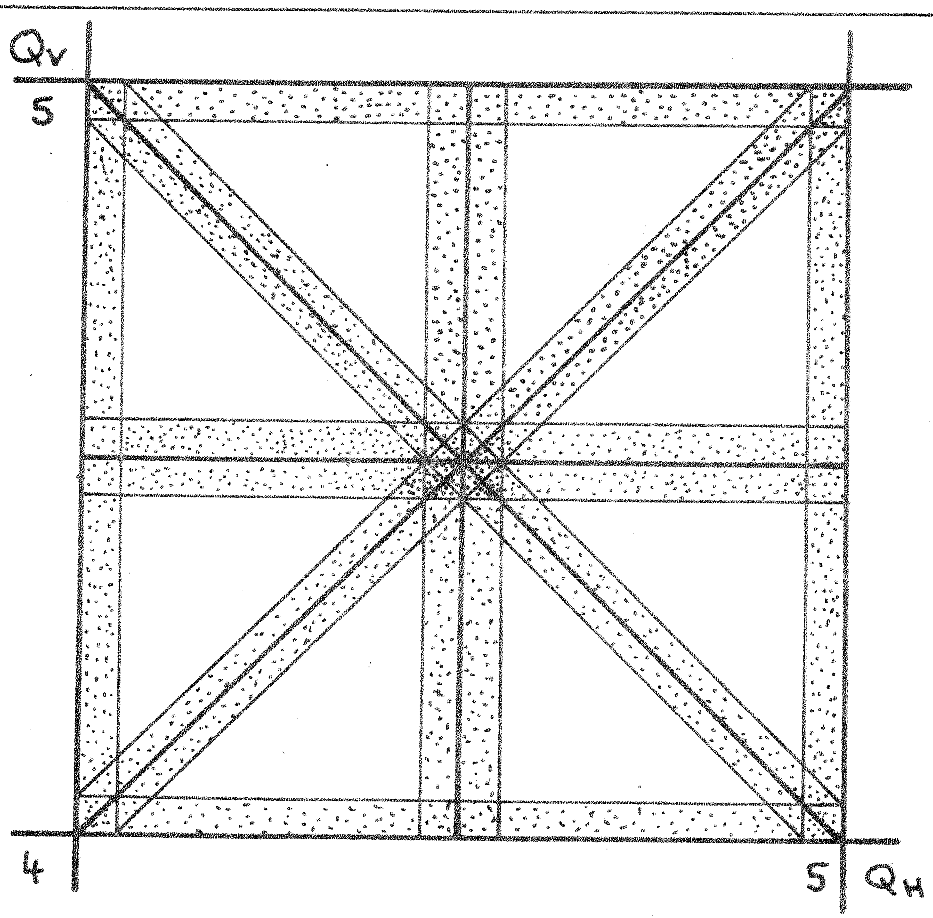

Fig. 4. Forbidden regions

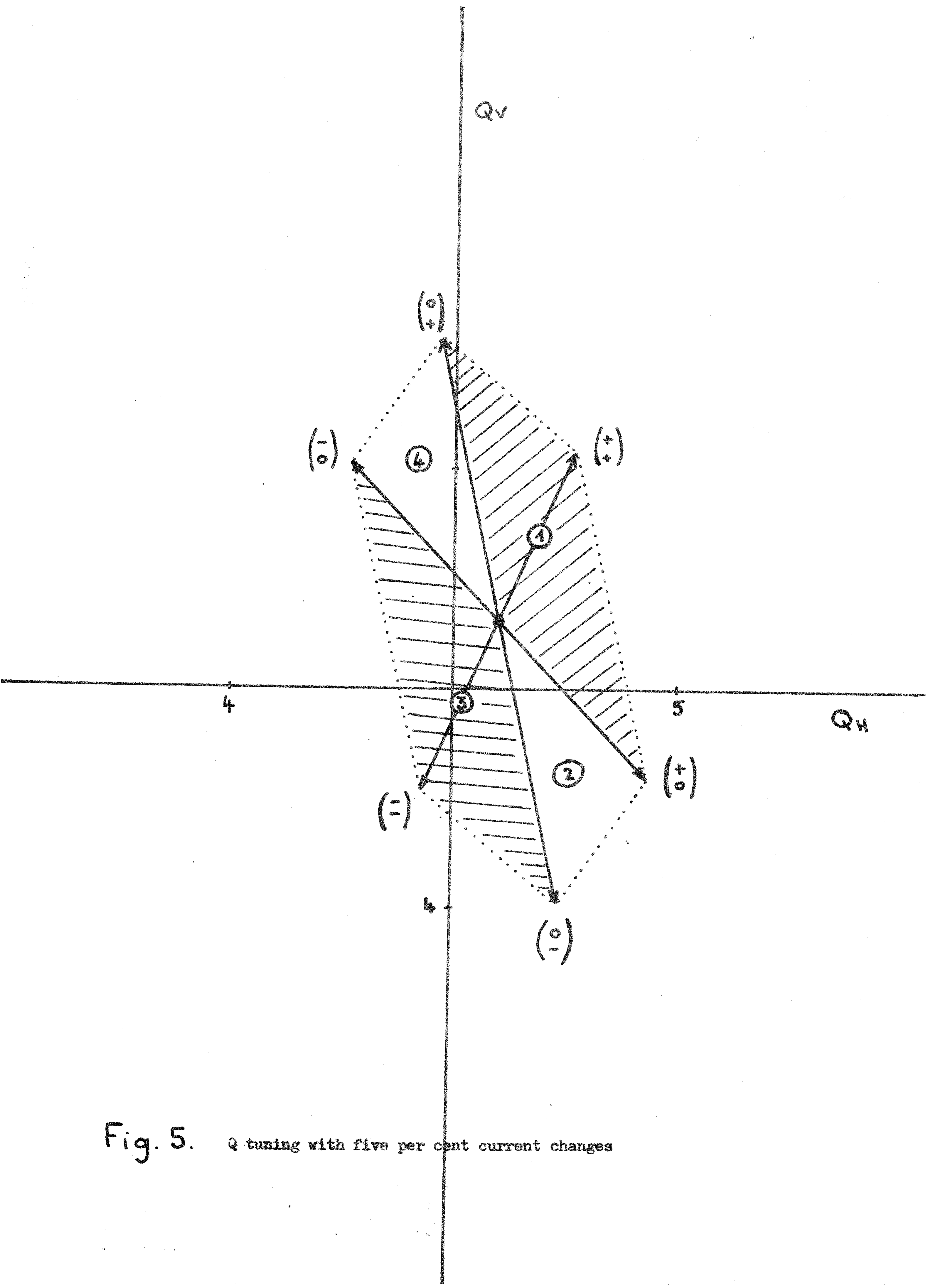

Fig. 5. Q tuning with five per cent current changes

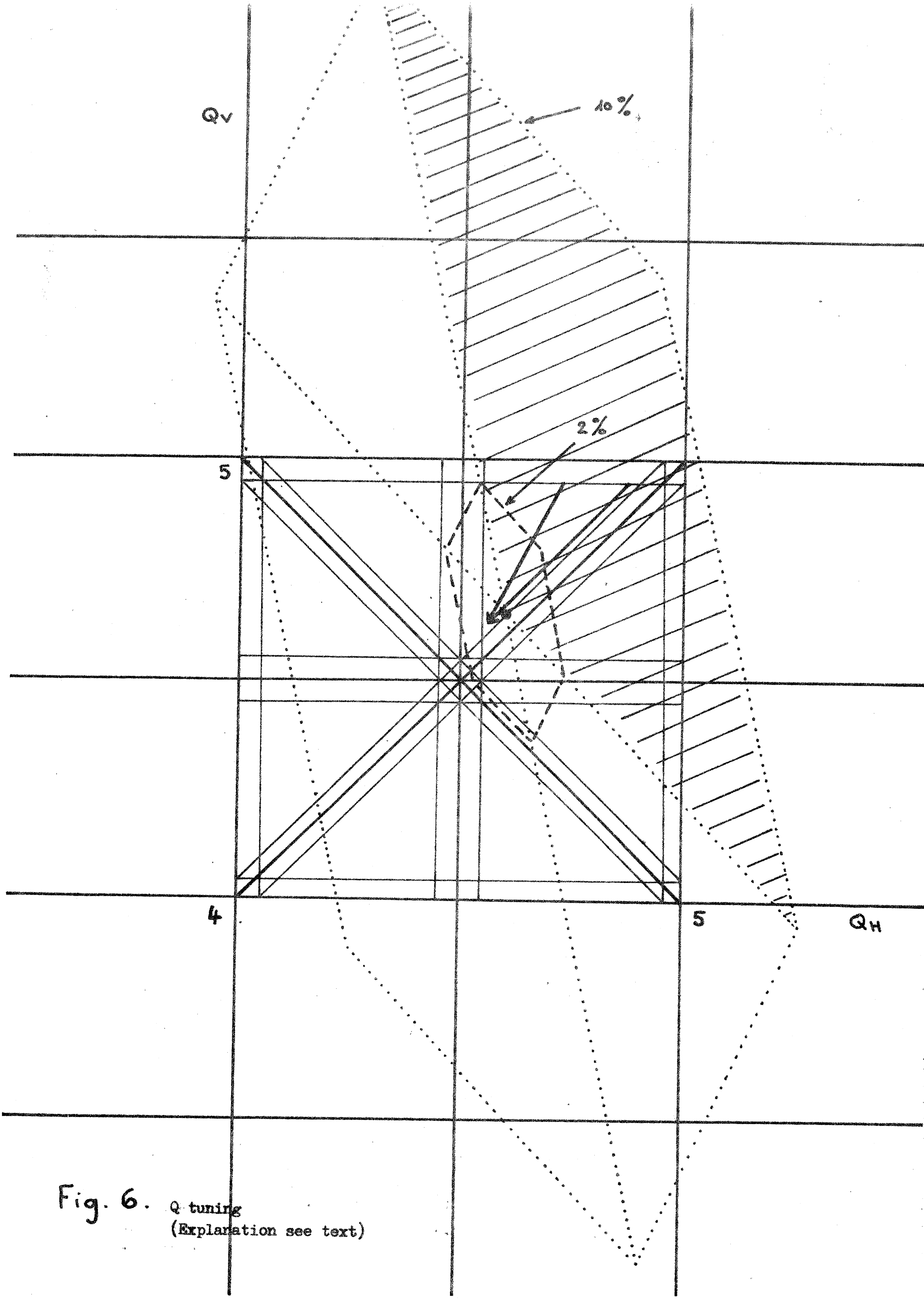

Fig. 6. Q tuning
(Explanation see text)