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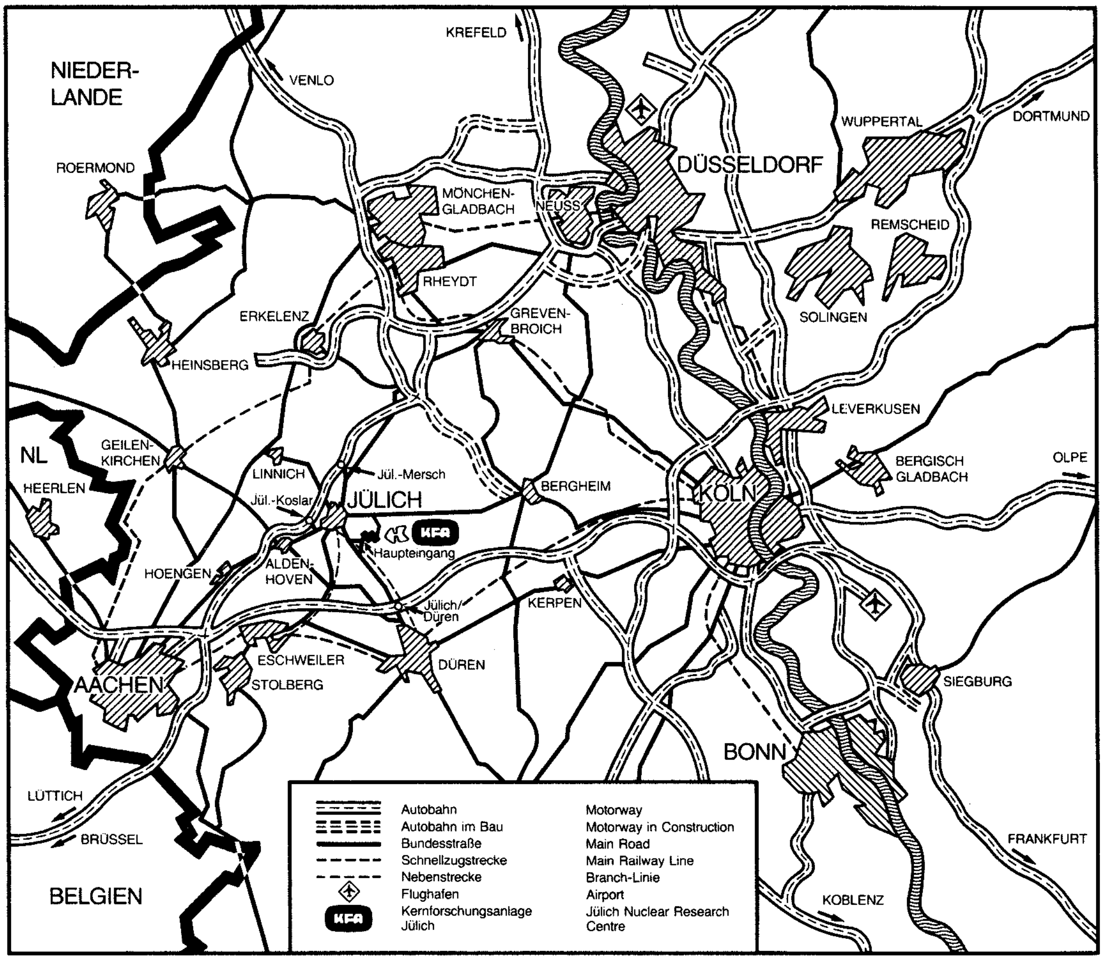


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ABSTRACT

Application of particle collector scoops in front of the pumping ducts of axisymmetric divertor/magnetic limiter configurations is proposed. These scoops should enclose a significant fraction of the recycling particles. The resulting increase in neutral particle pressure in front of the pumping ducts leads to an improved exhaust efficiency. This can permit an extension of the operational margin for density control. Alternatively, aiming at a prescribed exhaust flow in reactor-type devices such as INTOR, the pumping ducts could be reduced in aperture, leaving valuable space for other components. The lay-out of the proposed scheme depends on the heat load on the leading edge in front of the scoop and on the deflector plate in front of the pumping ducts.

The requirements for particle exhaust in a (Tokamak) reactor such as INTOR are usually derived from the need for satisfactory helium removal. Helium contributes to the radiation losses from the core and to the plasma pressure. Hence, for a given $\beta$-limit, it reduces the nuclear power density. Usually, a stationary helium concentration of up to 5 % is considered to be acceptable /1/, though lower concentrations in the core would be rather desirable. This leads to requirements on the total exhaust rate from the plasma boundary which, in addition, are determined by the helium transport from the core towards the edge, i.e. the ratio of the stationary relative concentrations. The method of refuelling also influences the exhaust requirement /2/.

For present day experiments of long pulse duration, a sufficient exhaust rate is desired in order i) to obtain better control of the plasma density (for instance in the presence of carbon walls); ii) to remove surplus particles coming from long pulse neutral beam injection; and iii) to permit the application of intensive multiple pellet fuelling for density profile and impurity control.

Two schemes which serve the purpose of particle exhaust (by external pumping) have been proposed and are being investigated: magnetic divertors /e.g. 3-6/ and pump limiters /e.g. 7-11/. Among the divertor configurations the so-called axisymmetric open poloidal divertor (sometimes also called "poloidal magnetic limiter") is the favoured solution e.g. for INTOR and NET. Since the principle of such a scheme is usually depicted in the poloidal cross-section, it does not become immediately obvious that the arrangement of the exhaust ducts is non-axisymmetric. Actually, the pumping ducts are located in the gaps between the toroidal field coils, and their periodicity follows the periodicity of the coils. An example of such an arrangement is shown in ref. /1/, page 51. There, in order to meet the exhaust requirements, rather large pumping apertures are chosen. These large ducts make difficult the implementation of other machine components such as the shielding, the blanket, etc.

In the poloidal magnetic divertor, the flux of charged particles from the scrape-off layer of an open configuration to the wall generally ends on two toroidally closed divertor plates, the more inboard side "inner plate" and a more outboard side "outer plate". The exhaust flow into the pumping ducts draws gas mainly from the recycling which occurs at the "outer plate" (e.g. ref. /1/, page 232).

However, the plasma approaches these plates along field lines which are primarily inclined along the toroidal direction, i.e. the field lines usually are tangent to the entrance opening of the pumping ducts. As a result, only a very small fraction of the total recycling gas flow may enter the exhaust pumping ducts. For pump limiters it has been shown /10/ that plasma flow perpendicular to the opening of a pumping system enhances the exhaust efficiency significantly. Therefore, it is suggested that this same technique be applied to the design of open poloidal divertors, i.e. the suggestion is to use a non-axisymmetric "outboard" divertor plate and particle collector system matched to the location of the pumping ducts.

The proposal here is to guide a fraction of the divertor "outboard" magnetic field lines and the associated plasma flow into the openings of scoops and onto deflector plates positioned in front of the pumping ducts. The scoops are intended to help contain the neutral particles near the entrance of the ducts. This should lead to significant recycling inside the scoops. It has been found experimentally /11/ that the flux into pump limiters is significantly larger (by a factor up to 3) in the ion drift direction. As such, the divertor scoops proposed here should face in the same direction, namely, the direction of ion drift; the orientation of the field lines has to be adjusted accordingly.

The application of such scoops requires that the particle deflector plates and the "leading edges" of the scoops be able to withstand the heat flux from the plasma (conduction and convection). The design and the prospects for this scheme will depend upon: (i) the sensitivity of performance to variations in the location of the boundary layer and in the direction of the diverted plasma flow there (i.e. changes in $q_a$ and in the position of the separatrix); (ii) the heat load distribution on the leading edge of the scoop and on the deflector plates; (iii) the length of the scoop ducts (i.e. the plasma density build-up and neutral density decay length) and the resulting heat distribution there; and (iv) the length of the toroidal shadow cast by each scoop and its deflector plate (this shadow depends on the inclination of the magnetic field lines and determines the relative fraction of the captured plasma flow and/ or the number and size of the scoops and their deflector plates).

Since the maximum heat load on the leading edge of each scoop will extend over a poloidal distance of only a few centimeters, the technique of oblique incidence can be used in this critical area. For example, the leading edge can be significantly extended in the toroidal direction, resulting in a kind of S-type shape of that part of the scoops.

Conceptual arrangements of such scoops are shown in figs. 1-4. The sideplates of the scoops are mainly intended to enclose the region of high recycling. They are, therefore, shaped essentially parallel to the incoming magnetic field lines. The "outer plate" proposed in ref. /1/, page 232 is replaced in the present concept by the deflector plates at the rear end of the scoops. These, however, have a smaller surface area. So it might become necessary to limit the heat load of these deflector plates.

One design approach to limit that heat load is to choose the orientation of the lower scoop plate (see fig. 1a and 1b) such that it is slightly inclined towards the incoming field lines and intercepts some fraction of the plasma heat flow (called "minor heat flow" in that figure). In turn, each lower plate then acts also as heat flux target and as such must not lie in the "shadow" of the preceding scoop. The funnel-like shape of the scoop as shown in fig. 1 is an example. Here, the lower or bottom plate extends solely in the toroidal direction. The split in the heat flow between (i) the lower plate, (ii) the side plates, and (iii) the deflector plate is a parameter subject to optimization. Among other things, it depends on geometrical relations (e.g. shadowing), on the amount of heat transferred by radiation and atomic processes to the side plates, and on the desired exhaust efficiency.

Also shown in this figure (b) is the inclination of the scrape-off layer together with the direction of those magnetic field lines which define the midplane of the scrape-off layer. Their intersection with the lower scoop plate and with the particle deflector plate defines also the areas of maximum heat flow there, whereas their intersection with the upper side plate defines the region of maximum heat flow at the leading edge.

In order to relieve this most vulnerable spot, the leading edge at the front end of the upper side plate around the zone of maximum heat flow - i.e. where it intersects the diverted boundary layer - can be extended in the direction of the magnetic field lines in order to take advantage of oblique inclination of the heat flow there. The principle of such a modification - as compared to fig. 1 - is shown in fig. 2. In that specific case the two lateral side plates of the scoop are chosen to be of equal length, although it might be advantageous for optimization to have lateral plates of different length, e.g. by significantly extending the outboard lateral side plate as compared to the example shown in fig. 2. A magnified view of the extended leading edge of the upper side plate is shown in fig. 3.

In order to improve the containment of the recycled particles inside the scoop, a further modification is applied and its principle is shown in two variations in figs. 4 (a and b) and 5 (a and b). There the lateral side plates of the scoop are inclined parallel to the plane of the scrape-off layer thus permitting to narrow the entrance channel of the scoop which results in a reduction of the particle back-flow from the scoop into the main discharge chamber. Also in this improved geometry use can be made (fig. 5 a and b) of oblique inclination at the region where the leading edge of the scoop intersects the boundary layer. Of course, by inclining or shaping the particle deflectors plate and the lower scoop plate appropriately, the principle of oblique inclination of the heat flow may be also there used better than shown in these figures.

In that sense, other arrangements than those shown in figs. 1-5 may be used. In particular, if only a minor fraction of the particle flow impinging on the wall is to be collected inside such scoops, the scoops may be shaped in the form of oblique channels (i.e. parallel to the magnetic field lines) embedded in the original "outboard" divertor plate. In that case, the problem of the leading edge occurs at the corner between this channel and the "outboard" divertor plate.

Fig. 6 is intended to present an overall schematic view of the location of the scoop with respect to the (poloidal) plasma cross section and to the vacuum chamber.

The optimization of such scoops requires experimental studies and computational boundary layer modelling in order to find satisfactory answers to the critical questions raised here and to demonstrate the prognosed improvement of particle exhaust. It is proposed, therefore, to include such investigations in the research programme of the forthcoming experiments on axisymmetric magnetic limiters such as ASDEX-Upgrade /12/, Big Dee /13/, and possibly also JET /14/.

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FIGURE CAPTIONS

Fig. 1

a) Schematic view of a particle collector scoop for "axisymmetric" magnetic limiters which collects a selected fraction of the plasma flow parallel to $\vec{B}$ and directs the neutral gas flow into the pumping duct.

b) The inclination of the scrape-off layer is also shown together with the strips exposed to the heat flow and with the direction of those magnetic field lines which define the midplane of the scrape-off layer.

Fig. 2 a and b

The same arrangement as shown in Fig. 1 but with the leading edge of the upper scoop plate extended (in direction of the field lines) at the area of maximum heat load.

Fig. 3

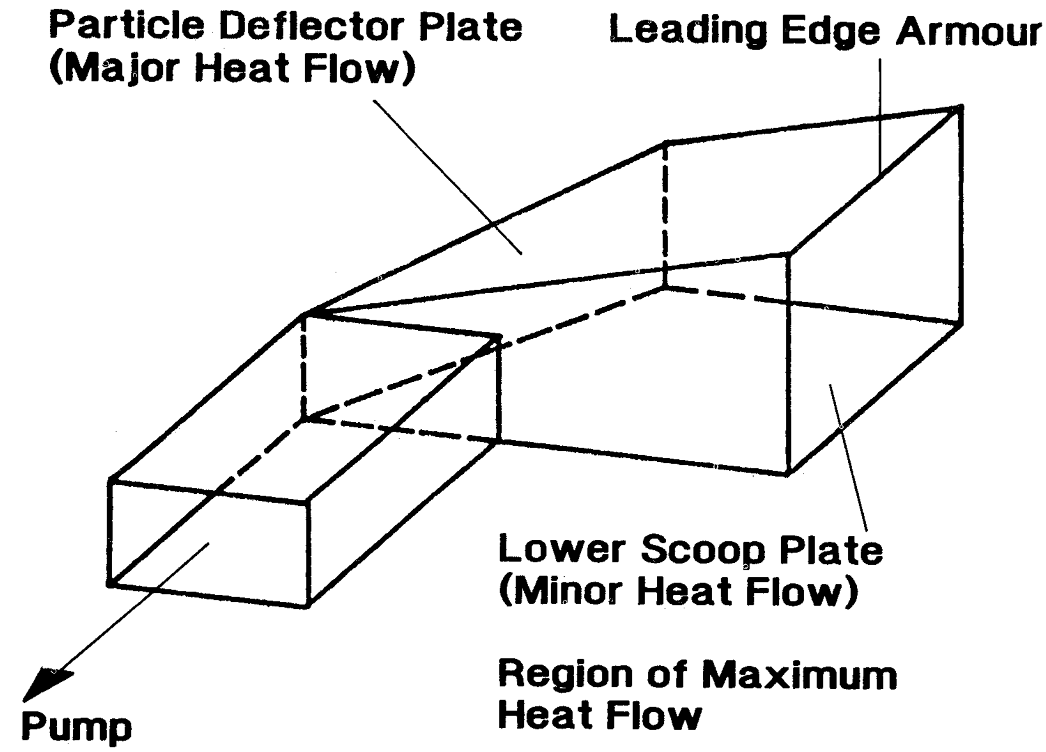
Enlarged view of the upper scoop plate as shown in Fig. 2 indicating the S-shaped leading edge and the thickness $\delta$ of the boundary layer there. Not shown is the armour at the leading edge against the heat load. Please note that the direction of the upper scoop plate is chosen parallel to the magnetic field lines of the boundary layer.

Fig. 4 a and b

Similar arrangement as shown in Fig. 1 but with the side plates of the scoops being closer and nearly parallel to the scrape-off layer in order to increase particle confinement in the scoop.

| | |
|---|---|
| Fig. 5 a and b | The same arrangement as shown in Fig. 4 but with the leading edge of the upper scoop plate extended (in direction of the field lines) at the area of maximum heat load. |
| Fig. 6 | Poloidal cross section of the plasma together with the plasma boundary layer (for an INTOR type device) and together with a rear end view of the scoop as shown in Fig. 1. |

a)


Particle Deflector Plate
(Major Heat Flow)
Leading Edge Armour
Lower Scoop Plate
(Minor Heat Flow)
Pump

b)

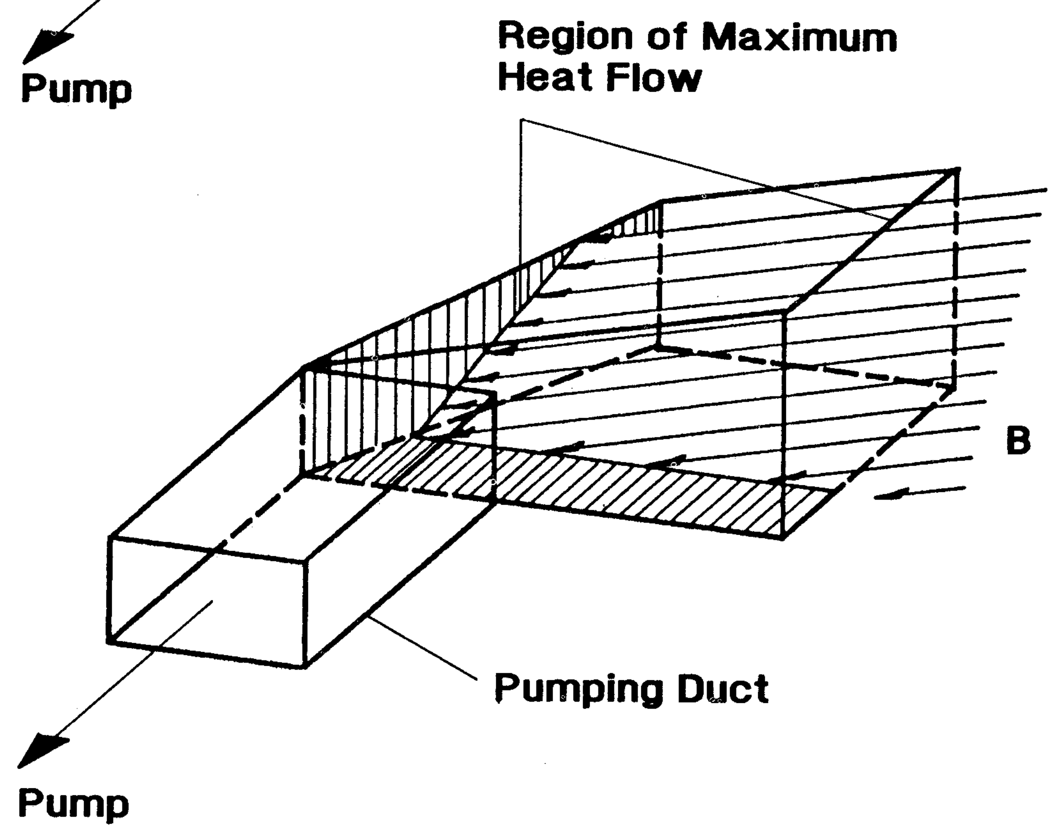
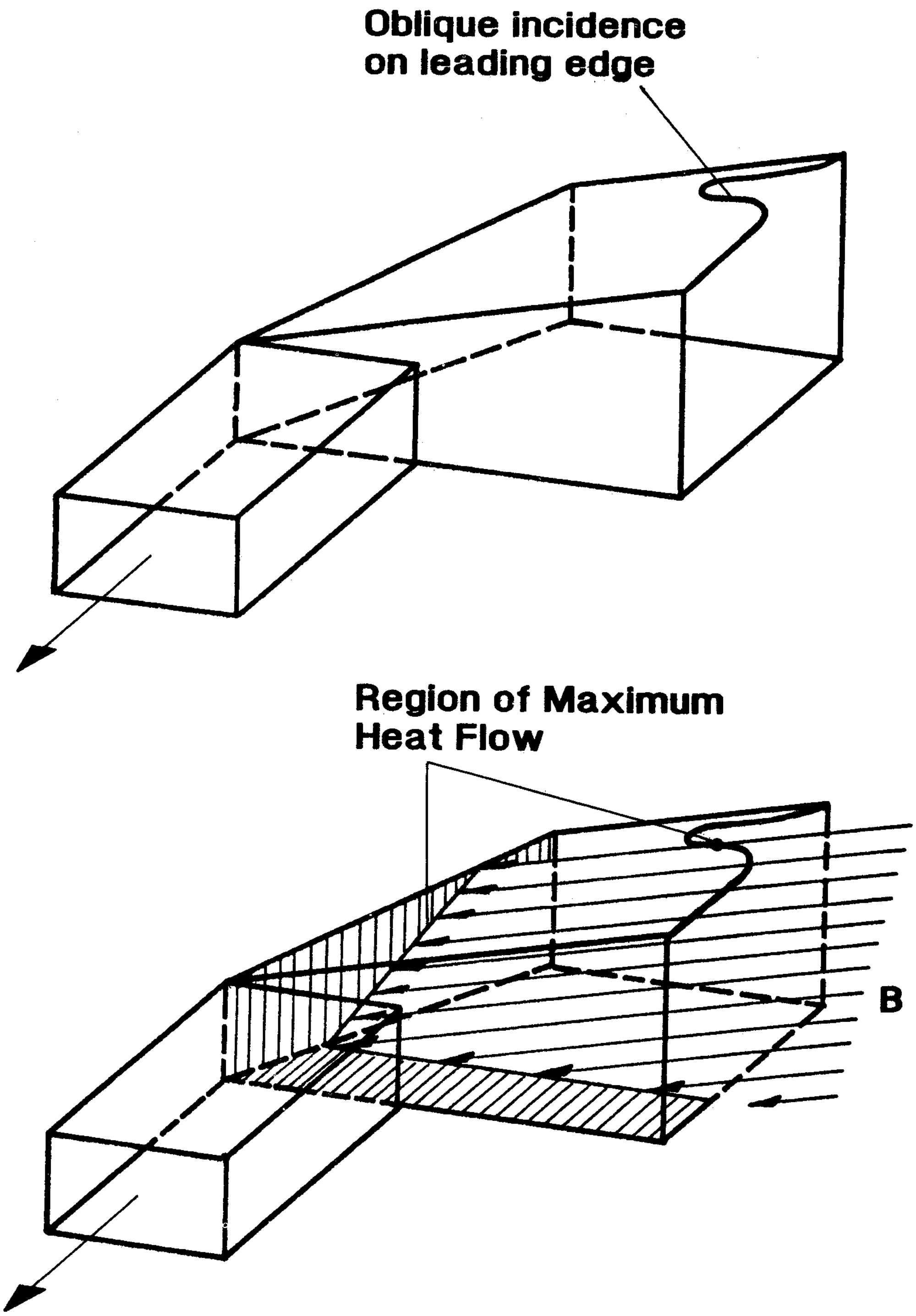

Region of Maximum
Heat Flow
B
Pumping Duct
Pump

FIG. 1

a)

b)



Oblique incidence
on leading edge
Region of Maximum
Heat Flow
B


FIG. 2

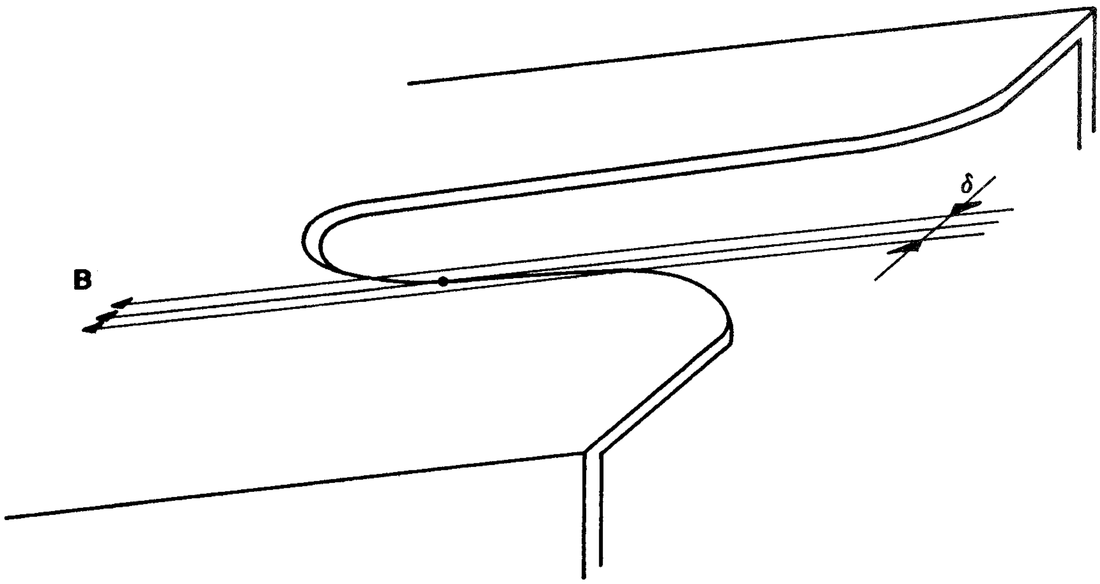
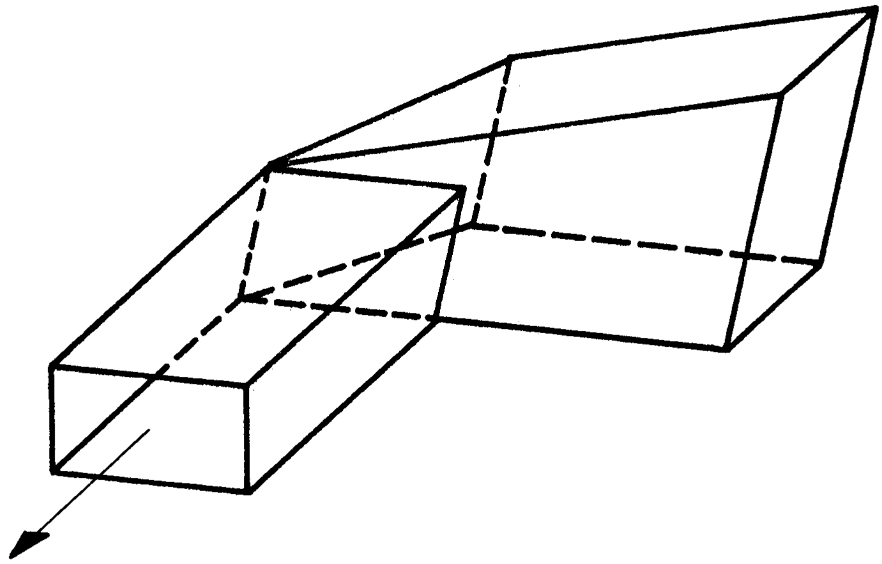



FIG. 3

a)



b)

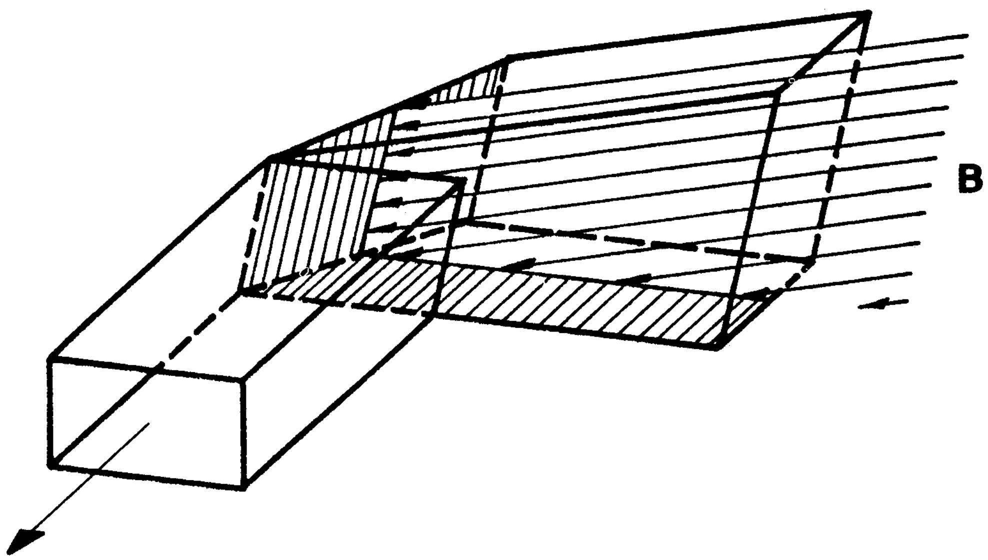
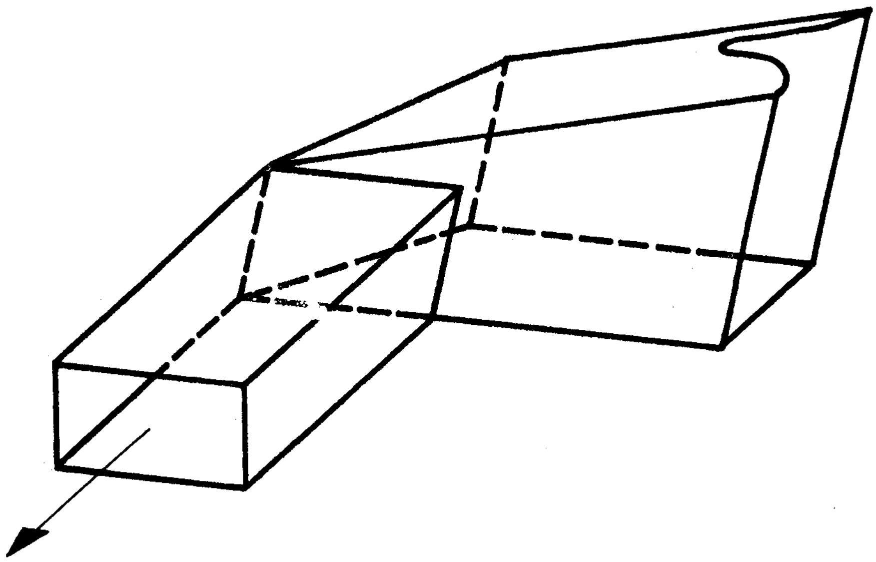



FIG. 4

a)



b)

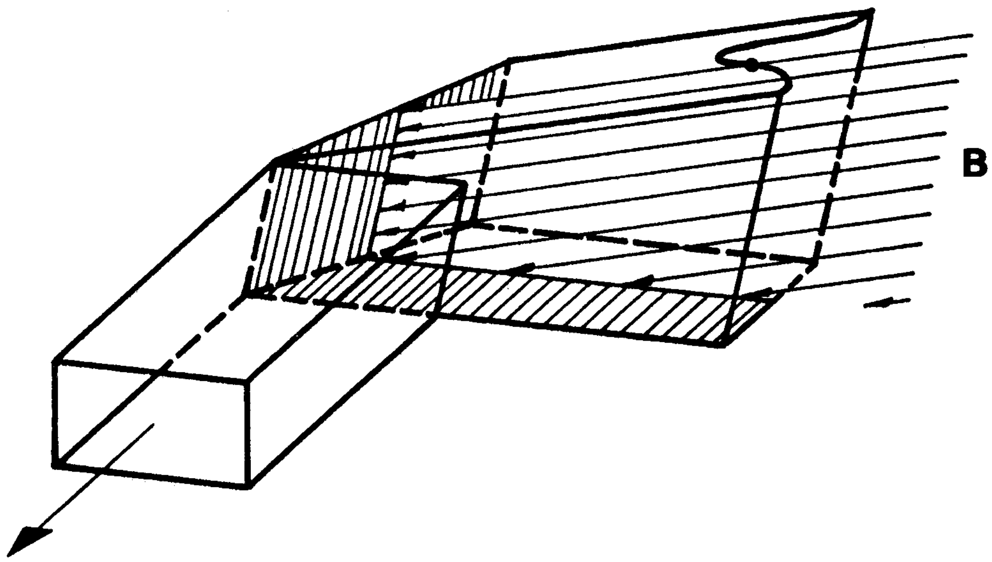



FIG. 5

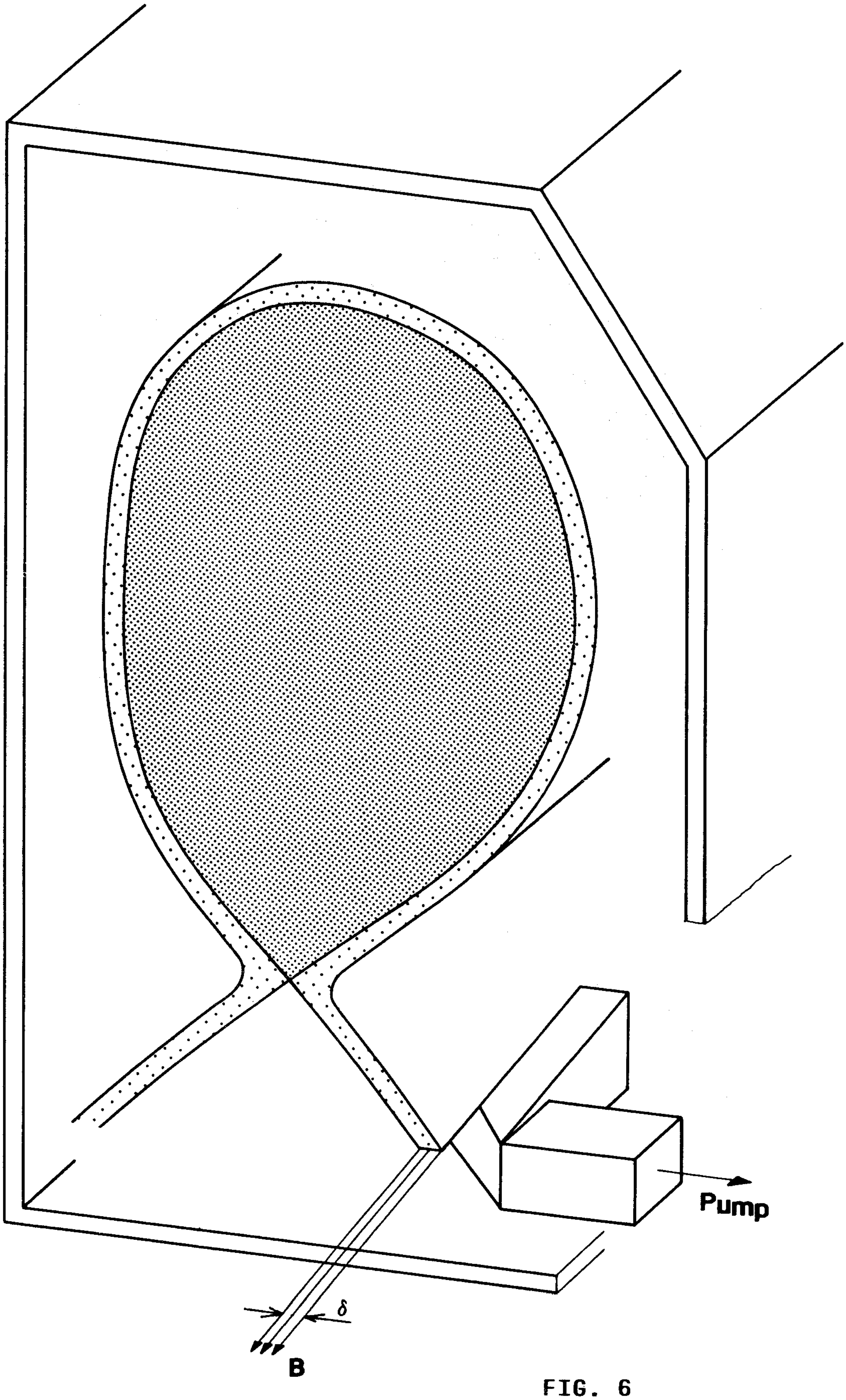



FIG. 6