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RESULTS OF NUMERICAL COMPUTATIONS OF THE SAMPLING EFFICIENCY OF A THIN WALLED SLIT SAMPLER IN CALM AIR

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1. INTRODUCTION

Numerical computations of particle trajectories have been conducted with a special well-suited numerical method which was mentioned on the annual meeting of the GAF, last year. The sampling efficiency is calculated from the position of "separating trajectories", for the upper edge and the lower edge of the slit. From them we find the catching distances X_{ch} and X_{cl} for the upper half and the lower half of the slit resp. Deposition inside the slit is neglected for the sampling filter is supposed to be located in the entrance of the slit. The critical catching distance (X_a) for an efficiency of 100 % in a 2-D flowfield, is given by

$$X_a = \frac{q}{2\,V_s} = \text{const.}\ \frac{q}{d_p^2}$$

where q = volume flow per unit of length;
V_s = sedimentation velocity;
d_p = particle diameter.

The 2-D potential flow around a slit was given by a conformal transformation of a flat potential flow.
With calm air conditions we want to say that general movements of the air have been neglected, in the knowledge that they may considerably influence the results. The same holds for the influence of turbulent diffusion.

2. THE EQUATION OF MOTION

Suppose that a spherical particle is falling through the flow field of a sampling device, and the force of the friction is given by Stokes' law. Then the dimensionless equation of motion for a particle in a potential flow around a 2-D slit of width D_o is:

$$\underbrace{\text{Stk}' \cdot \frac{d^2\vec{r}}{dt^2}}_{\boxed{\text{inertial lag in velocity}}} + \underbrace{\frac{d\vec{r}}{dt}}_{\boxed{\text{particle velocity}}} + \underbrace{\beta\,\frac{\vec{a}}{|a|^2}}_{\boxed{\text{flow velocity}}} + \underbrace{\vec{i}_y}_{\boxed{\text{sedimentation velocity}}} = 0$$

where $\vec{a}$ = transformed place vector;
$\vec{i}_y$ = vertical unit vector representing the sedimentation velocity.

The only parameters in this equation are Stokes' number (Stk') and β which are defined here as

$$\mathrm{Stk}' = \frac{2\pi\tau V_s}{D_o}$$

$$\beta = \frac{U_o}{V_s} = \frac{X_a}{\frac{1}{2}D_o}$$

where: τ = relaxation time;
V_s = sedimentation velocity;
D_o = slitwidth;
U_o = sucking velocity;
X_a = critical catching distance.

Then the efficiency is constant only when both Stk' and β are constant. So a criterion on the sampling efficiency of a slit has to fulfil both conditions. For the flow around a 2-D point sink another form of Stokes' number is used by LEVIN (1957)

$$\mathrm{Stk} = \frac{2\pi\tau V_s^2}{q} = \mathrm{const.}\ \frac{d_p^6}{q},$$

when we suppose that the relaxation time (τ) is proportional to the sedimentation velocity (V_s).

and

$$\mathrm{Stk} = \frac{\mathrm{Stk}'}{\beta}.$$

From these equations we see that the normally used Stokes' number is proportional to the sixth power of the particle diameter and that for comparison of the results the independent parameter Stk' may be replaced by the parameter Stk, as we do.

3. RESULTS

3.1 $\boxed{\mathrm{Stk} = 0.02 \text{ and } 10^{-1} < \beta < 10^{3}}$ (Figure 1)

The computed efficiency as a function of β (the quotient of slitwidth and critical catching distance) at Stk = 0.02.

- The efficiency of the upper half η_h is a decreasing function of β, which is supposed to go to zero when β goes to infinity.
- The efficiency of the lower half η_1 is increasing with β as long as the critical catching distance is smaller than the width of the slit ($\beta < 2$). It is decreasing for $\beta > 2$, and it is supposed to become constant for η_1 = 100 % at smaller values of Stk.
- The mean efficiency is decreasing for all values of β and is going to η = 50 %.

Interpretation of figure 1 (see figure 2)

- The variation of β may be seen as the variation of the slitwidth ($2R_o$) and the sucking speed (U_o) for a constant volume rate $q = 2U_o R_o$, with respect to a constant critical catching distance (X_a) and a constant sedimentation velocity (V_s).
- The cause of assymptotic behaviour of η_h and η_1 for small values of β is clarified by the picture for β = 0.1. The separating trajectories are both to the negative side of the vertical axis and the theoretical approximation

of a "2-D point sink" is of no value. A better theoretical approach is to suppose that the separating trajectory on the lower edge is a given by a linear superposition of sedimentation velocity and sucking velocity.

- For $\beta > 0.5$ it is seen that the deposition on the upper wall of the slit is the main source of the decreasing efficiency.

3.2 $\boxed{\beta = 100 \text{ and } 10^{-6} < Stk < 1}$ (Figure 3 ,5)

- For the upper half of the slit the constant value of the efficiency for $Stk < 2 \cdot 10^{-3}$ is caused by sedimentation of particles on the upper wall of the slit. The decreasing efficiency for $Stk > 2 \cdot 10^{-3}$ is caused by the inertial behaviour.
- For the lower half of the slit the computated efficiency coïncides with a theoretical approximation of the efficiency by LEVIN. It is clearly seen that the effect of sedimentation on the upper wall of the slit by far overrules the inertial effect which was calculated by LEVIN (1957).

3.3 $\boxed{\beta = 1 \text{ and } 10^{-9} < Stk < 10}$ (Figure 4, 6)

- For the upper half of the slit the efficiency is nearly constant for $Stk < 10^{-3}$, for $\eta_h = 80\ \%$ for $Stk = 10^{-9}$.
- For the lower half of the slit the efficiency approaches to the constant value of 107 % for $Stk < 10^{-2}$.

  Here the lower half of the slit is no longer a theoretical 2-D point sink. The theoretical separating point lies within the slit for

$$Z_a = \frac{-X_a}{\pi} = \frac{-R_o}{\pi} \qquad \text{when } \beta = \frac{X_a}{R_o} = 1.$$

  This also explains why $\eta_1 > 1$ (see also fig. 6 and 7).
- The mean efficiency is nearly constant at $\eta = 92\ \%$ for $Stk = < 2 \cdot 10^{-3}$.

Graphs of the trajectories for $\beta = 1$ (Figure 6 and 7)

$Stk = 3.7 \times 10^{-9}$ fig. 6

$Stk = 1$ fig. 7

The influence of the inertia is seen from comparison of the trajectories along the upper edge of the slit.

4. CONCLUSIONS

- For $Stk < 2 \cdot 10^{-3}$ the efficiency becomes constant at a value which is depending on the value of β.
- At $Stk = 0.02$ the efficiency is a decreasing function of β, approaching to $\eta = 50\ \%$ for $\beta > 10^3$.

From this is concluded that the efficiency decreases for smaller particles until it becomes constant at 50 %. This seems to contradict the general notion that: so smaller the particles are, so better they follow the flow lines. The conclusion may be explained by the fact that in a 2-D flow field the critical catching distance is much greater for smaller particles than in a 3-D flow field, so the influence of sedimentation will be greater in a 2-D flowfield. As far as we know this effect has never been found in practice, but in practice we also do not have 2-D flow fields which are extended far enough to detect the effect. We are trying to verify these computations experimentally with a slit of 1 x 100 cm^2. The results of these computations are being reported (Ter Kuile) 1976).

5. LITERATURE

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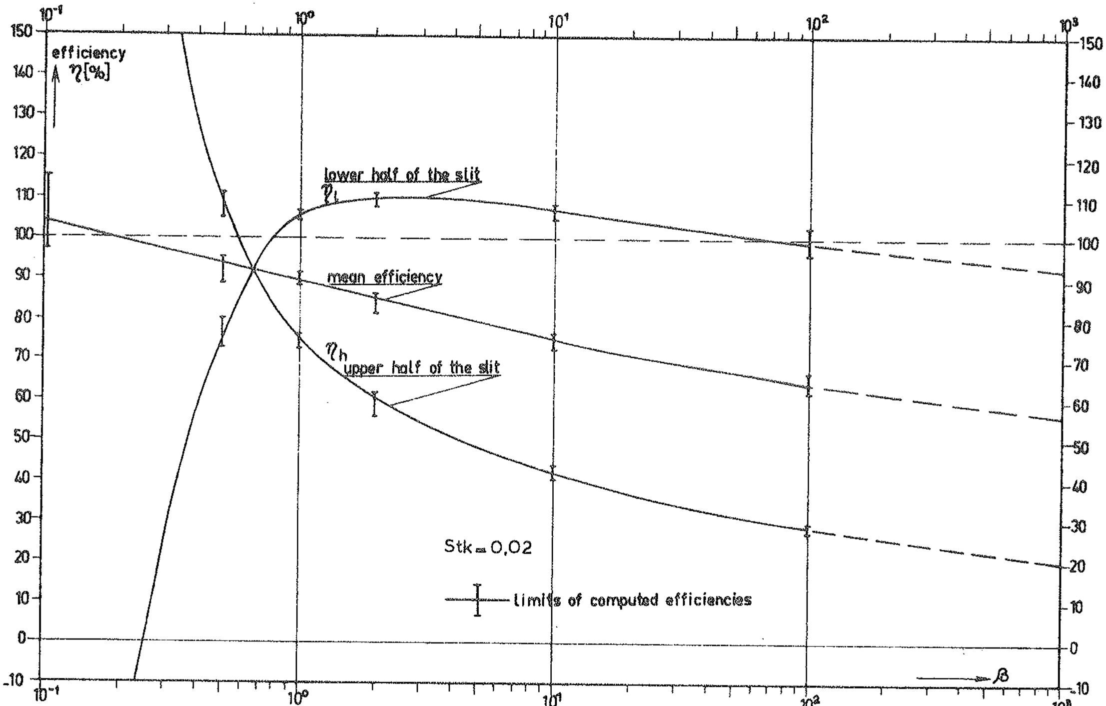
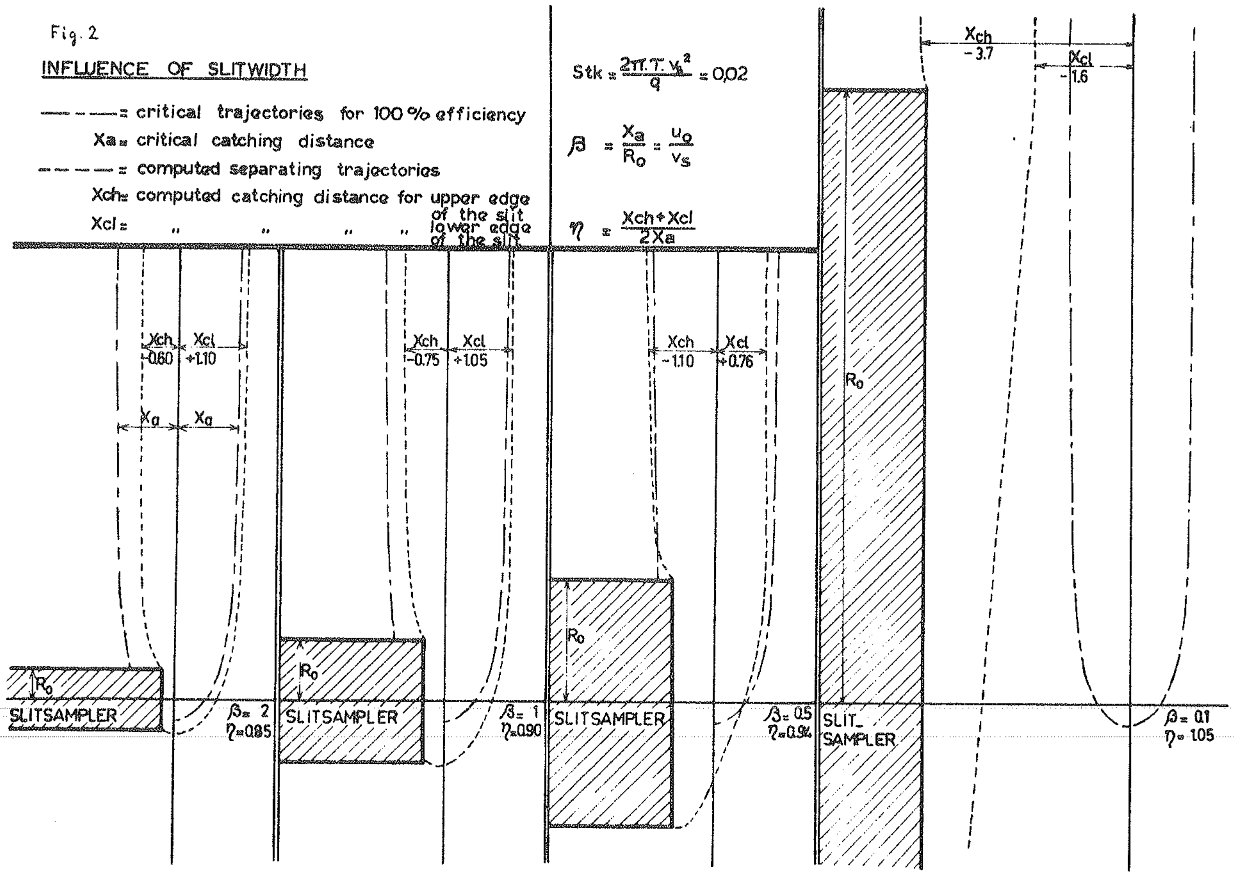


Fig. 1 COMPUTED EFFICIENCY (η) FOR A SLITSAMPLER AS A FUNCTION OF THE QUOTIENT (β) OF CATCHING DISTANCE AND SLITWIDTH AT Stk = 0.02.

Fig. 2

INFLUENCE OF SLITWIDTH



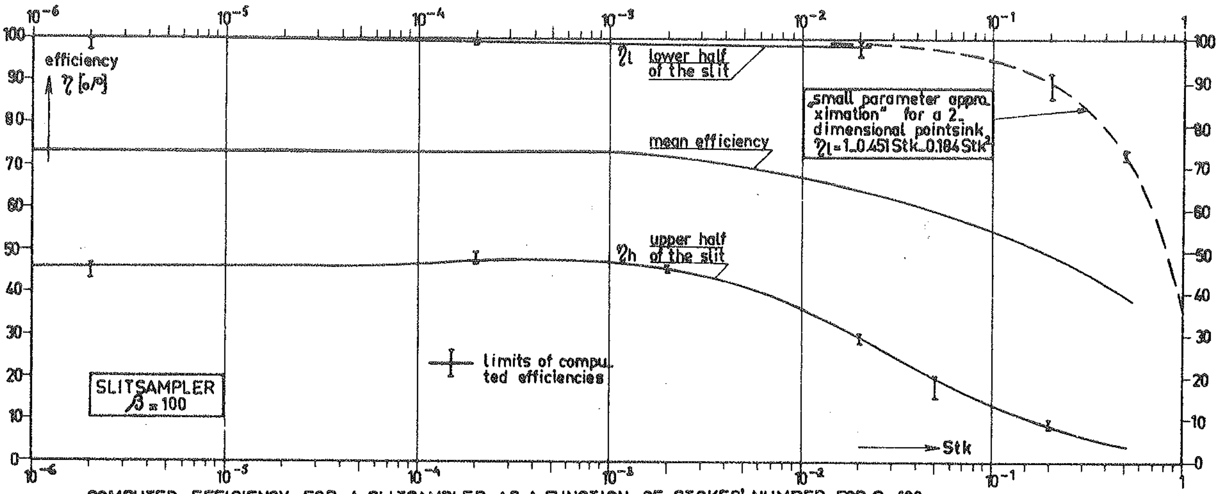


Fig. 3 COMPUTED EFFICIENCY FOR A SLITSAMPLER AS A FUNCTION OF STOKES' NUMBER, FOR $\beta = 100$.

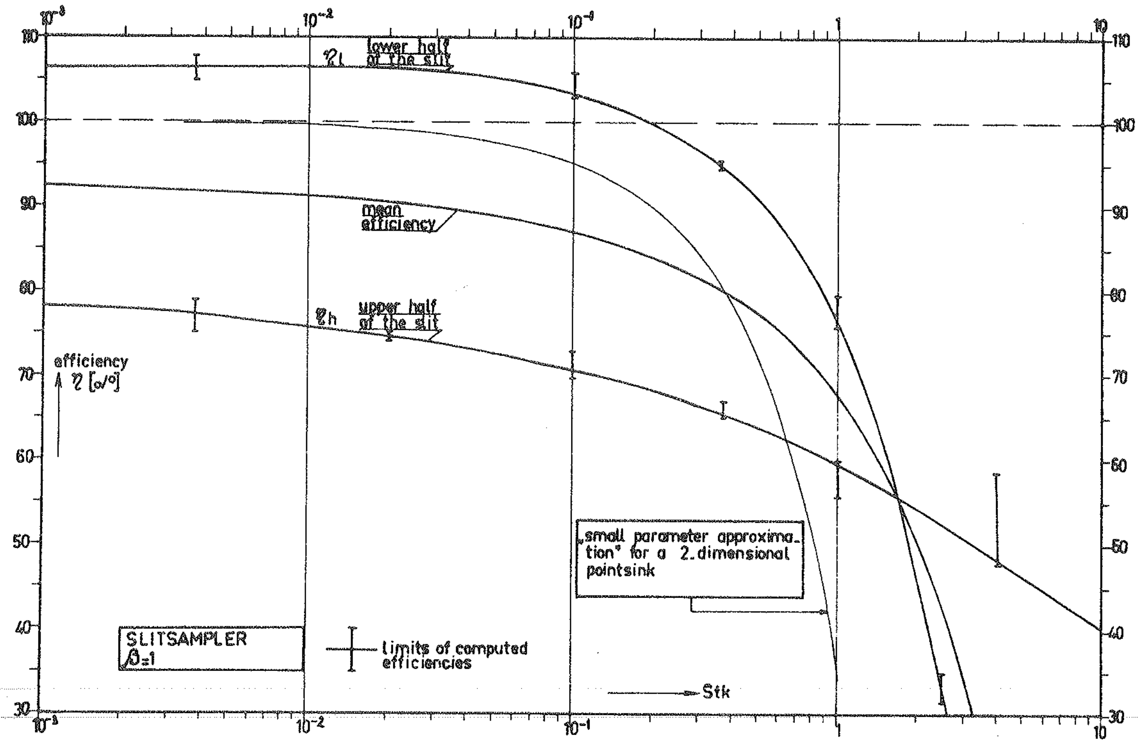
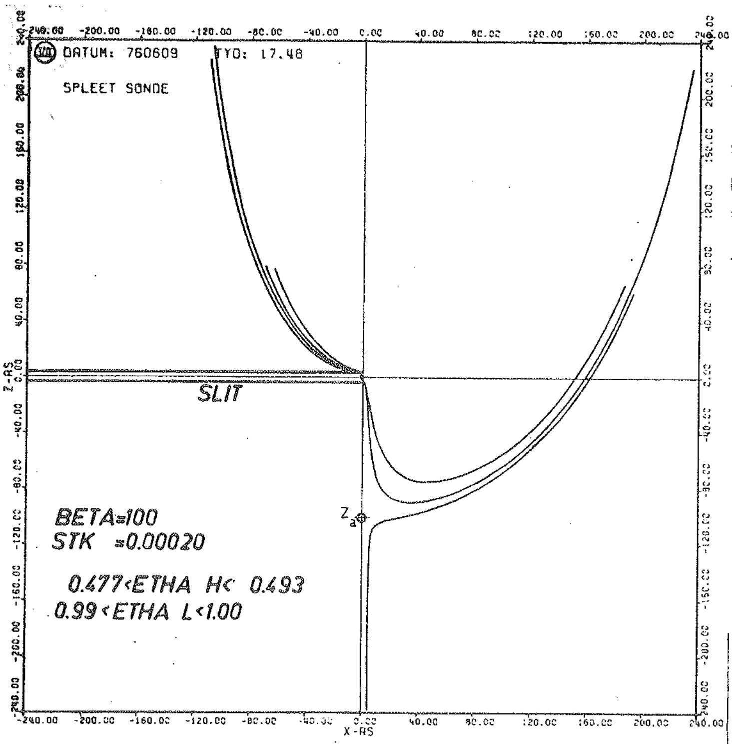


Fig. 4 COMPUTED EFFICIENCY FOR A SLITSAMPLER AS A FUNCTION OF STOKES' NUMBER, FOR $\beta = 1$.



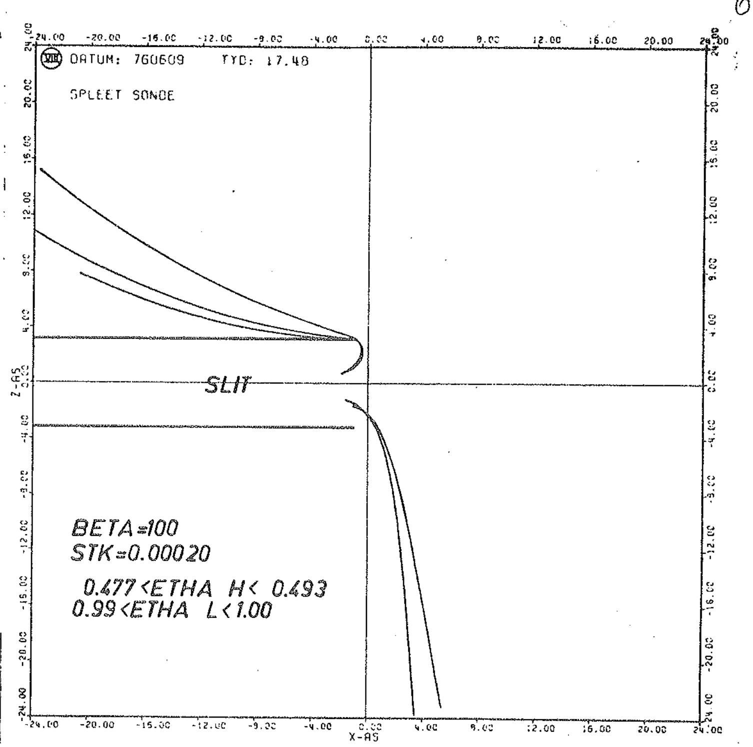


Fig. 5B is an enlargement of Fig. 5A to show that the lower wall of the sampling slit does not limit the sampling efficiency

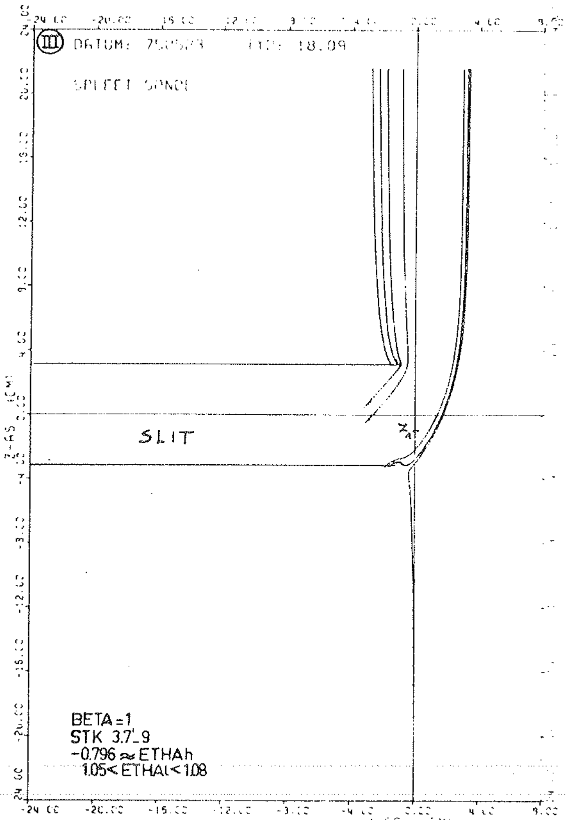


Fig 6

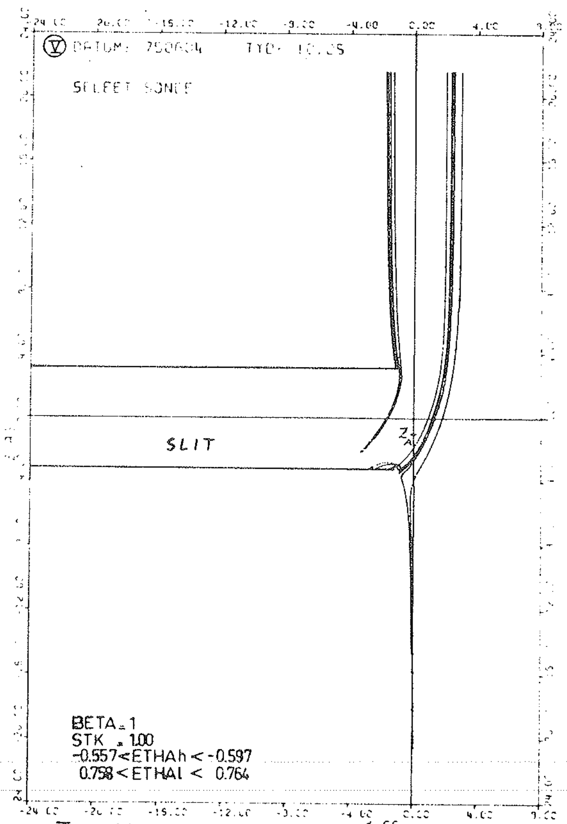


Fig 7