THEORETICAL LOSSES IN A HELIX WITH SHIELD AND SUPPORT

1. Introduction

If a helix is going to be used as accelerating structure in a linac, the only practicable focusing method seems to be alternating gradient focusing with magnetic lenses placed outside the shield. This puts limitations on the shield diameter, and one would like to keep this diameter as small as possible.

Further, the helix will have to be supported in some way. One possible method is to employ dielectric rods, in which case there is the question how much dielectric one can afford to put in, and whether this is sufficient as a support.

In this report the influence of both the shield and the supports will be examined in some detail. The total effect can be divided up into several individual effects, such as a) the increase in helix loss due to the shield, b) loss in the shield itself, c) increase in total metal loss due to the support, d) loss in the support itself. Each individual effect is small, but when we add them all together we find that the total effect is appreciable. In fact, it seems as if it may be concluded that the energy up to which the helix may compete with the Alvarez type and perhaps be better, is as low as 30 MeV, in contrast to about 50 MeV, as we thought earlier.

2. Assumptions

For the time being we assume the shape of the supports to be as shown in Fig.1 (which is not a shape one would choose in practice). We shall make use of the method Harvie (1948) used for dielectric disc loaded waveguides, i.e. we replace the rods by an anisotropic dielectric filling the entire region between
the helix and the shield, the anisotropic dielectric having the following permittivity components and \( \tan\delta \):

\[
\varepsilon_r = \varepsilon_\| = a\varepsilon + (1-a)\varepsilon_0 \tag{1}
\]

\[
\varepsilon_\perp = (a/\varepsilon + (1-a)/\varepsilon_0)^{-1} \tag{2}
\]

\[
\varepsilon_z = \varepsilon_n \tag{3}
\]

\[
\tan\delta_r = \tan\delta_n = a(\varepsilon/\varepsilon_n)\tan\delta \tag{4}
\]

\[
\tan\delta_\perp = a(\varepsilon_\perp/\varepsilon)\tan\delta \tag{5}
\]

\[
\tan\delta_z = \tan\delta_n \tag{6}
\]

Here \( a \) is the ratio between the volume taken by the dielectric and the total volume between the shield and the helix.

As a justification for applying this method to this problem we can use the following argument: On the helix we have essentially a wave spiralling around along the helix wire with a velocity not far from the velocity of light. That means that the distance between two supports is small compared with the wavelength measured along the helix wire. Consequently the method of replacing the support with an anisotropic medium should apply.

For calculating the losses in the helix itself, we shall use the same method as the one used in an earlier paper (Johnsen, 1954), so long as we have no other method showing better agreement with experimental results. In general the same notation will be used as in that paper.

3. The Fields and the Propagation Constant.

With the assumptions made in Section 2 the field equations are, for the region between the helix and the shield (notation as in Johnsen, 1954)
\begin{align}
E_r &= j(k/\gamma_n)(AI_1(\gamma_n r) - BK_1(\gamma_n r)) \, e^{j(\omega t - kz)} \quad (7a) \\
E_e &= -j(k_0/k)Z_0 H \\
E_z &= (AI_0(\gamma_0 r) + BK_0(\gamma_0 r)) \, e^{j(\omega t - kz)} \quad (7c) \\
H_r &= j(k/\gamma_1)(CI_1(\gamma_1 r) - DK_1(\gamma_1 r)) \, e^{j(\omega t - kz)} \quad (7d) \\
H_e &= (\varepsilon_n/\varepsilon_0)(k_0/k)E_z/Z_0 \quad (7e) \\
H_z &= (CI_0(\gamma_0 r) + DK_0(\gamma_0 r)) \, e^{j(\omega t - kz)} \quad (7f)
\end{align}

where
\begin{align}
\gamma_1^2 &= k^2 - (\varepsilon_1/\varepsilon_0)k_0^2 \quad (8a) \\
\gamma_n^2 &= k^2 - (\varepsilon_n/\varepsilon_0)k_0^2 \quad (8b)
\end{align}

Inside the helix the field equations are unchanged from what they would have been with no shield and no support (for instance equal to eq.(1), p.16/17 in Johnsen, 1954).

If we examine (8) more closely we notice that for all cases of interest to us, the influence of the support on \( \gamma \) is quite negligible, so that we can in fact write
\begin{align}
\gamma_1 &\simeq \gamma_n \simeq \gamma \quad (9)
\end{align}

where
\begin{align}
\gamma^2 &= k^2 - k_0^2 \quad (10)
\end{align}

This approximation simplifies the calculations considerably and we shall take advantage of it in all later calculations. (It should, however, be recognized that this makes the calculations invalid for large \( \gamma_1 \) and \( \gamma \), and phase velocities.)
By applying the usual boundary conditions for a helix we find the following expressions for the constants in (7)

\[ A/B = -K_0(\gamma b)/I_0(\gamma b) \]  
\[ C/D = K_1(\gamma b)/I_1(\gamma b) \]  
\[ B = K_0(\gamma a)/(\ell/2)I_0(\gamma a) + K_0(\gamma a) \]  
\[ D = -J\varepsilon(\gamma a)K_0^{-2}(\gamma a) \tan \psi/((\ell/2)I_1(\gamma a) - K_1(\gamma a)) \]  
\[ (a\kappa_0 \cot \gamma)^2 = (a\gamma)^2 I_1(\gamma a)K_0(\gamma a)/(I_1(\gamma a)K_1(\gamma a)) \hat{K} \]  

where \( \hat{K} \) is a correction factor due to the shield and to the support. This correction factor we find to be

\[ \hat{K} = \frac{1}{1-K_0(\gamma b)I_0(\gamma a)/I_1(\gamma b)K_1(\gamma a)} \frac{1}{1-(1-\varepsilon_e/\varepsilon_0)\gamma aI_0(\gamma a)K_1(\gamma a)} \frac{1}{1-(\varepsilon_e/\varepsilon_0)\gamma aI_0(\gamma a)K_1(\gamma a)} \]  

As long as \( \varepsilon_e/\varepsilon_0 \) is reasonably small, say below 1.5, it is noticed from Fig. 2 that we make a rather small error if we replace (16) by the much simpler expression

\[ \hat{K} = \frac{\varepsilon_0}{\varepsilon_e} \frac{1-K_0(\gamma b)I_0(\gamma a)}{1-K_1(\gamma b)I_1(\gamma a)/I_1(\gamma b)K_1(\gamma a)} \]  

For the loss calculations this simplification gives a slightly conservative result.

In Fig. 3 the correction factor \( \hat{K} \) has been plotted for several cases with no dielectric support. The corresponding \( \hat{K} \) with support is then found by just multiplying the curves in Fig. 3 by \( \varepsilon_e/\varepsilon_0 \) as seen from (16a).
Correspondingly, the actual relation between the geometrical parameters and the propagation constant, given by eq. (15), is plotted in Fig. 4, also for the case of no support. The corresponding figures with a support would be found approximately by multiplying the ordinates of the curves in Fig. 4 by \((\epsilon_0/\epsilon_n)^{1/2}\).

As noticed, the shield tends to increase the pitch angle for the same propagation constant, and we find in the limit that \(\tan \gamma \) tends towards \(\beta/(1-\beta^2)\) as \(b\) tends towards \(a\). This means that the wave following the helix wire is slowed down as the shield approaches the helix, and gets in the limit the velocity of light, as one would expect.

The dielectric supports increase this effect, but in a different way. Whereas the shield tends to stretch out the curves to a 45° line, the dielectric tends to rotate the whole set of curves a little towards the horizontal axis.

4. Metal Losses.

a. In the helix.

The loss per unit length of the helix is

\[ R_h = \frac{1}{2} I^2 R/s \quad (17) \]

where \(I\) is the amplitude of the current in the helix wire, \(R\) is the resistance of one winding of the wire and \(s\) is the pitch.

For the current we put (cf., also Johnsen, 1954, p.45)

\[ I = ((H_z)_{z=-a} - (H_z)_{z=a})s \quad (18) \]

and for the resistance we have

\[ R = \varnothing R_s 2a/(\cos \gamma) \quad (19) \]

where \(R_s\) is the surface resistance of the surface material used in the helix, and \(\varnothing\) is a correction factor taking into account the uneven current distribution on the wire.
Making use of the field equations, eqs. (15), (17), (18) and (19), we find after some calculation

\[
P_h E^2 = \left( \lambda / (4 \pi \omega \xi^2) \right)^{1/2} (\xi / \xi^2)^{-1} (c/ \nu)^{2-1} I_o (y a)/(y a K_0 (y a) I_1 (y a) I_1 (y a)) (\xi \cos \gamma)^{-1} \tag{20}
\]

where \( \hat{c} \) is a correction factor due to the shield and the supports. For \( \hat{c} \) we find the expression

\[
\hat{c} = \frac{1-K_0 (y a) I_0 (y a) / (I_0 (y b) K_0 (y a))}{1-\left(1-\frac{\epsilon_0}{\epsilon_1}\right) \gamma a K_0 (y a) I_1 (y a) (1+K_0 (y b) I_1 (y a) / (I_0 (y b) K_1 (y a)))} \tag{21}
\]

With the same approximation as used to obtain (16a) we can also simplify this expression to

\[
\hat{c} \approx \left( \frac{\epsilon_0}{\epsilon_1}\right) \left[1-K_0 (y b) I_0 (y a) / (I_0 (y b) K_0 (y a)) \right] \left[1-K_1 (y b) I_1 (y a) / (I_1 (y b) K_1 (y a)) \right] \tag{21a}
\]

We leave a discussion of these results till later.

\section{Losses in the shield.}

If the current lines in the shield have a pitch angle \( \gamma \), the losses in the shield are, per unit length

\[
P_s = \frac{R_s H_x H_z}{\zeta_{s}^2} \cos^2 \gamma \tag{22}
\]

After some calculation we find the following expression for this loss, expressed in terms of the loss in the helix itself

\[
P_s P_h = \pi \xi / \phi \cos \gamma / \cos^2 \gamma / \gamma (y b) I_1^2 (y a) / I_1^2 (y b) \tag{23}
\]

Before this can be discussed more thoroughly an expression for \( \gamma \) must be found.
We have
\[ \tan \phi_i = \frac{-(H_i/H_{z_r=b})}{1-\epsilon_r/\epsilon_0} \]  \hspace{1cm} (24)

We insert from (7e) and (7f) and find after some calculation
\[ \tan \phi = \frac{I_o(\gamma a)I_1(\gamma b)}{I_o(\gamma b)I_1(\gamma a)} \frac{\epsilon_r/\epsilon_0}{1-(1-\epsilon_r/\epsilon_0)\gamma a I_o(\gamma a)I_1(\gamma a)(1+\epsilon_r/\epsilon_0)I_1(\gamma a)/(I_o(\gamma b)I_1(\gamma a))} \]  \hspace{1cm} (25)

which, with the approximation introduced to obtain (16a), can be written as
\[ \tan \frac{\phi_2}{\tan \phi} \approx \frac{I_o(\gamma a)I_1(\gamma b)}{I_o(\gamma b)I_1(\gamma a)} \]  \hspace{1cm} (25a)

This inserted in (23) gives
\[ \frac{p_s}{p_h} = \frac{\pi}{\phi/\zeta} \frac{I_o(\gamma a)I_1(\gamma a)}{\gamma a I_1(\gamma a)} \cos \psi + \frac{\beta^2}{1-\beta^2} \frac{\pi}{\phi/\zeta} \frac{I_o(\gamma a)I_1(\gamma a)}{\gamma b K_0(\gamma a)I_1^2(\gamma b)} \frac{\gamma a I_1(\gamma a)}{\gamma b K_0(\gamma a)I_1^2(\gamma b)} \]  \hspace{1cm} (26)

We first discuss the last term in this expression. At the output end of the accelerator \( \beta^2/(1-\beta^2) \) is about 0.1, and is everywhere else smaller. Near the output end we shall always have \( \gamma a < 0.5 \) and \( b/a > 2 \). From Fig. 5 it is then noticed that the last term in (26) will always be smaller than about 0.02 at the output end, when the effect of the supports is neglected, and will usually be considerably smaller, especially away from the output end. With the accuracy we can expect to get by this calculation of the losses, we can therefore neglect this last term in (26) completely, also in the case of having dielectric supports, which will raise this term by maximum 30-40 o/o.

C. Total metal losses.

From (26) and (20) the following expression is now obtained for the total metal losses
\[ p_o/E^2 = (\lambda_o/(4\pi\varepsilon_0\varepsilon'))^{\gamma/2}(\rho/\zeta)Z^{-1}_o((c/\gamma)^{2-1})^{-\gamma/2}Y_\eta_0(\gamma_a,\gamma_b) \] (27)

where

\[ Y_\eta_0(\gamma_a,\gamma_b) = \frac{\varepsilon''}{\varepsilon'} \frac{I_0(\gamma_a)}{\gamma a K_0(\gamma_a)I_1(\gamma_a)K_1(\gamma_a)} \frac{\lambda}{\cos\gamma} \frac{\pi\xi}{\gamma_b} \frac{I_2^2(\gamma_b)}{I_1^2(\gamma_b)} \frac{K_0(\gamma_b)I_1(\gamma_a)}{1-I_0(\gamma_b)K_0(\gamma_a)} \frac{1}{1-K_1(\gamma_b)K_1(\gamma_a)} \] (28)

The function \( \eta_0(\gamma_a,\gamma_b) \) is quite equivalent to \( \eta(\gamma_a) \) in Johnson (1954), and can be compared directly. But there neither the shield nor the supports were taken into account.

It is firstly noticed that the support has an appreciable effect on the metal losses, and even if the supports were made of a lossless dielectric the shunt impedance may be reduced by a factor \( 0.75 = 0.8 \) due to the support, as it may be difficult to obtain \( \varepsilon''/\varepsilon' \) smaller than \( 1.2 = 1.3 \). In addition to this comes the reduction in shunt impedance due to the loss in the support itself, which will be considered in the next section.

The influence of the shield is seen from Fig.6, where \( (\varepsilon''/\varepsilon')\eta_0(\gamma_a,\gamma_b) \) is plotted, assuming \( \cos\gamma = 1 \) and \( \rho/\zeta = 4 \) (cf. Johnson, 1954, p. 47).

We start discussing these curves by considering the high-energy end first. The maximum shield diameter will depend on practical considerations, mainly on the A.G. focusing system, and so will be independent of the diameter of the helix itself. That means that at this end \( \gamma_b \) is given, and not \( b/a \). At out-put end \( \gamma_b = 1 \) corresponds to about 16 cm shield diameter. A curve for this value of \( \gamma_b \) is drawn in Fig.6 as a representative example. With this diameter the focusing magnets would still be of reasonable size, and a rather large increase in shield diameter and magnet size would be needed to change appreciably the arguments and results that follow.
It is now important that the shunt impedance should be as large as possible near the output end, as most of the losses go into the high energy end. At the output end we should therefore be at the maximum of the $\gamma_b = 1$ curve, which determines $\gamma_a = 0.25$. (In fact, it would have been better to go a little to the left of the peak, say to $\gamma_a = 0.2$.) Having determined the shield and helix diameters at the output end, one would like to keep these diameters constant along quite a large part of the machine. As we go away from the output end we therefore go along the curve $b/a = 4$, and reach the maximum of this curve at $\gamma_a = 0.5$, i.e. at about 12 MeV, and we can work on the same curve quite a bit further, perhaps down to about 5 MeV, as we approach the region where the losses anyway become less important. There may, however, be reasons for changing the shield diameter at a somewhat higher energy than indicated here.

We are now in this section mainly interested in seeing how much the shunt impedance is reduced by the shield. We then use as a reference the maximum of the curve $b/a = \infty$, as this is the point near which we would have tried to work if we had not been limited in shield diameter. At the output end it is then noticed that the shield has reduced the shunt impedance by a factor of about 0.7, which increases to about 0.9 in the region 10-20 MeV. The average for the whole accelerator will be something in between. It looks reasonable to assume 20-25 o/o decrease in the average, due to the shield.

It should be remembered that the support also increases the metal losses, as already mentioned, probably by a factor of 1.2 - 1.3, which brings the average shunt impedance due to the metal losses down to about 60-70 o/o of the theoretical shunt impedance of the bare helix. This is a rather severe reduction in shunt impedance, which should be taken into account in a comparison between the helix and the Alvarez type.
5. Dielectric Losses.

The fields set up by the structure are found in Section 3. The losses per unit length of the supports are then given by

\[ p_d = \frac{\omega}{2} \int_{\mathcal{R}} \int_{\mathcal{R}} (\varepsilon \frac{\partial E}{\partial t} + \varepsilon \frac{\partial E}{\partial t} + \varepsilon \frac{\partial E}{\partial t} + \varepsilon \frac{\partial E}{\partial t}) r dr dz \]  \hspace{1cm} (29)

The loss due to \( E \) is small and can be neglected. We then get

\[ p_d/E^2 = (\lambda_0 \delta_n/2)(\varepsilon_n/\varepsilon_0)\varepsilon_0^{-1} \beta^2/(1-\beta^2)^2 \int_{a}^{b} x F_n^2(x) dx \]  \hspace{1cm} (30)

where

\[ F_n(x) = (A/B)I_n(x) + (-1)^n K_n(x) \]  \hspace{1cm} (31)

For the integral we make use of the formula

\[ \int_{a}^{b} x F_n^2(x) dx = (x^2/2)F_n^2(x) - F_{n-1}(x)F_{n+1}(x) \]  \hspace{1cm} (32)

In eq. (30) we neglect \( \beta^2 \) compared with unity under the integral sign (giving a slightly conservative result), and when making use of (32) we get

\[ p_d/E^2 = (\lambda_0 \delta_n/2)(\varepsilon_n/\varepsilon_0)\varepsilon_0^{-1} \beta^2/(1-\beta^2)^2 \gamma_\eta_d(ya,yb) \]  \hspace{1cm} (33)

where

\[ \gamma_\eta_d(ya,yb) = \frac{1}{\gamma a I_o^2(ya) + I_o(yb)K_1(ya) - K_0(yb)I_o(yb)I_1(ya) - K_0(ya)I_o(yb)I_1(ya)} \]  \hspace{1cm} (34)
In Fig. 7 \( \eta_d(\gamma_a, \gamma_b) \) is plotted. From this it is noticed that one should in general make the helix radius as small as possible in order to make the support losses as small as possible. This may be a little surprising, but the explanation lies in the fact that the smaller we make the helix diameter, the more it concentrates the field in a small region near the helix, leaving the region near the shield almost field-free in the limit.

This has the consequence that one should choose a slightly smaller helix diameter than one would do by merely considering Fig. 6. How much smaller will depend on the magnitude of the losses in the dielectric compared with the metal losses. This will be considered in connection with an example in the next section.

If we compare eq. (33) with (27) two important differences between the metal losses and the dielectric loss are noticed, apart from the difference in \( \eta_o(\gamma_a, \gamma_b) \) and \( \eta_d(\gamma_a, \gamma_b) \), and these differences are in \( \beta \) and \( \lambda_o \). The dielectric losses depend more strongly on these two parameters than the metal losses do. The main consequence of this is that the relative importance of the dielectric loss increases as the particle energy increases, and may in fact be a limiting factor for the energy up to which it is an advantage to use a helix.


In a few examples we choose the basic parameters for eq. (27) as follows

\[
\begin{align*}
\sigma & = 6 \times 10^7 \text{ mho/m} \quad \text{(silver coating is assumed)} \\
\phi/\zeta & = 4 \quad \text{(cf. Johnsen, 1954, p. 47)} \\
\lambda_o & = 1.5 \text{ m}
\end{align*}
\]

which leaves us with
\[ \eta_c = 4l(1-\beta^2)^{1/2}/\beta \quad \eta_c(\gamma_a, \gamma_b) \quad \text{megohm/m} \]

We further assume, as indicated in Section 4, that \( \gamma_b = 1 \) at the output end, and that \( \gamma_a = 0.25 \) at this point in order to be on the maximum of the \( \gamma_b = 1 \) curve. As also indicated in Section 4, we keep the diameter of the helix and of the shield constant down to 5 MeV.

Further, we assume the same average acceleration in all sections, namely 1.7 MeV/m, and that \( \theta_0 = 30^\circ \).

For the dielectric support we consider two examples:

a. Quartz support, filling \( \gamma/10 \) of the volume between the helix and the shield.

\[ \varepsilon/\varepsilon_0 \approx 4.0 \quad \tan \delta \approx 0.0002 \]

This gives (cf. eqs. (1) and (4)):

\[ \varepsilon_n = 1.3 \quad \tan \delta_n = 0.0000615 \]

With the assumptions made we get for the shunt impedance due to the dielectric losses alone

\[ \eta_d \approx 6.28(1-\beta^2)/\beta^2 \quad \eta_d(\gamma_a, \gamma_b) \quad \text{megohm/m} \]

b. Teflon support, filling \( \gamma/5 \) of the volume between the helix and the shield.

\[ \varepsilon/\varepsilon_0 \approx 2 \quad \tan \delta \approx 0.0002 \]

this gives

\[ \varepsilon_n/\varepsilon_0 = 1.2 \quad \tan \delta_n = 0.0000667 \]

The main difference between the two examples lies in the fact that teflon has only half the permittivity of quartz, but considerably less mechanical rigidity, which means that more of it is needed; twice as much we have assumed here. This
results altogether in a slightly smaller equivalent parallel permittivity. The shunt impedance due to the dielectric losses alone remain equal in the two examples.

Figures for the shunt impedance are shown in the following table. The total losses from 5 MeV to 50 MeV have been calculated approximately to be

In example a: 5.8 MW
In example b: 5.4 MW

The part of the accelerator below 5 MeV has not been included in the table, as the losses in this part are anyway small, and other considerations determine the dimensions in this part.

<table>
<thead>
<tr>
<th>U MeV</th>
<th>a</th>
<th>b</th>
<th>a and b</th>
<th>a</th>
<th>b</th>
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<td>50</td>
<td>0.250</td>
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<td>13.7</td>
<td>65.8</td>
<td>10.5</td>
</tr>
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<td>40</td>
<td>0.280</td>
<td>15.3</td>
<td>16.6</td>
<td>79.5</td>
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<td>20.6</td>
<td>104</td>
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<td>27.5</td>
<td>147</td>
<td>21.6</td>
</tr>
<tr>
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<td>0.460</td>
<td>30.0</td>
<td>32.5</td>
<td>185</td>
<td>25.4</td>
</tr>
<tr>
<td>10</td>
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<td>39.5</td>
<td>243</td>
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</tr>
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<td>0.653</td>
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</tr>
<tr>
<td>5</td>
<td>0.800</td>
<td>43.2</td>
<td>47.9</td>
<td>346</td>
<td>38.4</td>
</tr>
</tbody>
</table>

It is noticed that there is not much difference between the two examples. Example b has a little higher shunt impedance, due to the fact that the permittivity
is more important than the dielectric loss, but it looks as if we have only the two possibilities of teflon and quartz, the latter being preferable from the mechanical point of view.

7. Conclusion.

As seen from this report, there are three factors that have reduced the shunt impedance compared with that of the bare helix: i) The effect of the shield. This effect depends mainly on the shield diameter, which should be as large as possible. ii) The effect of the supports on the metal losses. This depends mainly on the equivalent parallel permittivity, which should be as small as possible. iii) The losses in the supports themselves, which depend mainly on the product $\delta \varepsilon$, which should be kept smallest possible.

Each of these factors is small, but together they have an appreciable effect, and increase the total losses by a factor 1.5-1.8 compared with the losses in a hypothetical accelerator with no shield and support.

A little less than half of this is due to the shield. If one could make the diameter larger (at least in the region above about 15 MeV where most of the power is consumed), that would have some favourable effect; but a considerable increase in diameter is needed to decrease the effect of the shield appreciably. For instance, it looks as if a shield of about 25 cm diameter is needed in order that its effect on the shunt impedance should only be about 10 o/o of the bare helix shunt impedance, compared with about 20-25 o/o in the example considered. Such an increase in diameter results, however, in a rather bulky and power-consuming lens system.

The effects of the dielectric support, however, may be somewhat reduced by proper shaping of the support. The most obvious thing to do would be to by-pass every second winding or two out of three windings by rather deep "bays" in the support.
as indicated in Fig. 8. This would reduce both the equivalent permittivity and loss factor in the neighbourhood of the helix, where it is most important. (A by-pass like this is also important in order to reduce the break-down possibilities.)

How much can be gained in this way is hard to estimate and needs a special investigation. However, it looks as if it will be difficult to build a helix type accelerator for 50 MeV having less than about 1.4-1.5 times the power consumption of a corresponding Alvarez type of the same length. It is true that the helix requires only one tenth of the pulse length of the Alvarez type, but the rating of the available valves in this region are not very sensitive to pulse length. This will therefore not make up for the factor 1.4-1.5 in higher power consumption, and more expensive RF-power supply seems to be needed for the helix.

The difference in power consumption between the two types can be reduced by increasing the length of the helix. A closer economical examination would be needed to see if in this way one could keep the cost of a helix type as low, or lower than that of an Alvarez type, and other features of the two types would also have to be considered in that connection.

If we, however, also take into account the experience that has already been obtained in USA on the Alvarez type, and is being gained at the moment in England, it is hard to see that the advantages of the helix justifies a choice of the latter type.

The conclusion drawn about the losses in the helix type is valid for a 30 MeV accelerator, but not necessarily for a smaller one. Below about 30 MeV it still seems to me that the helix is preferable, but not so preferable that CERN should build one type for the low energy range and another one for the top energy range.

The results are purely theoretical and should be taken with some reservation till experimental verification is available. Experiments are in progress in Paris.
and we hope to have results in a few months time.

It is a pleasure to thank Miss Hanney who carried out the computing for the curves presented in the report.

References:


Kjell Johnsen
Fig. 3

Fig. 4
Fig. 5
Fig. 8