СООБЩЕНИЯ
ОБЪЕДИНЕННОГО
ИНСТИТУТА
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
Дубна

E9 - 4915

**B. Carbonel, V.I. Danilov, M. Ianovici,
E.A. Polferov**

ЛАБОРАТОРИЯ ЯДЕРНЫХ ПРОБЛЕМ

CALCULATION OF THE GEOMETRY OF MAGNETIC CHANNELS FOR SYNCHROCYCLOTRONS AND CYCLOTRONS

1970

E9 - 4915

B. Carbonel*, V.I. Danilov, M. Ianovici**,
E.A. Polferov

CALCULATION OF THE GEOMETRY OF MAGNETIC CHANNELS FOR SYNCHROCYCLOTRONS AND CYCLOTRONS

---

* Present address: Institut de Physique Nucleaire, Orsay, France.
** On leave from the Institute for Atomic Physics, Bucharest, Romania.

I. Introduction

1. *General Considerations.*

1.1. Cyclotrons. The beam in this kind of machine is generally extracted by an electrostatic deflector whose extraction ratio varies between 30-60 per cent.

The focusing, after extraction, is achieved by one or several sections of magnetic channels which can be of different conceptions

a) magnetic channels
  - rectangular cross-section slabs (Orsay, Milano)
  - circular cross-section slabs (Tokyo, Dubna)

b) electromagnetic channels.

1.2. Synchrocyclotrons. The use of electrostatic deflectors is generally not possible because of the values of the energy and of the very small separation of the orbits, therefore the beam extraction is usually performed by a resonant system (a peeler- regenerator) followed by an extracting and focusing magnetic channel.

But, unfortunately, most of the synchrocyclotrons which are in operation have a very small extraction ratio (less than 10%). The greatest part of the beam is lost on the channel walls or in the region with a perturbated magnetic field around the iron pieces of the channel.

2. *Presentation of the Problem.*

The principal problem for the owners of these machines is to try to improve the focusing in cyclotrons and the extraction ratio in synchrocyclotrons.

To reach these purposes it is necessary to find some magnetic structures which on the one hand, improve the extraction and the transmission ratios and on the other hand, do not disturb the trajectories of the accelerated beam when introduced into the machine.

In the present paper we consider the case of synchrocyclotrons. The problem for machines working with electrostatic extraction (e.g. cyclotrons) in which there is a big difference between the last internal orbit, and the trajectory of the extracted beam is much simpler as far as the correction is concerned and can be considered as a particular case.

In synchrocyclotrons a magnetic channel is generally composed of several sections of two different types:

1) Extracting sections (Fig. 1).

These extracting sections are composed of two slabs which are magnetized by the field of the machine and give in the channel a negative field[x] of several thousands gauss with a very small gradient.

---

[x] In this case and in what follows the term "negative" means that the own field of the channel is a negative one with respect to the main field. The resulting field (of the machine + the channel) is smaller inside the channel than outside it but, of course, is positive.

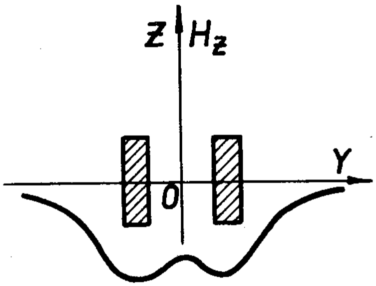


Fig 1.

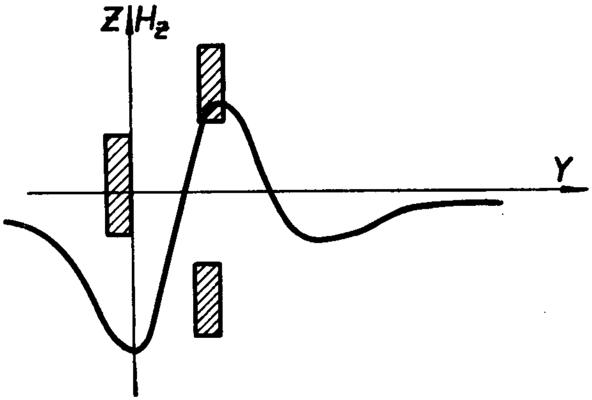


Fig. 2.

2) Focusing sections (Fig. 2).

They are composed of three slabs: this configuration is capable of generating in the channel a high constant gradient which focuses the particles.

Unfortunately, the introduction of this amount of iron is followed by a modification of the field inside the machine towards the center. This perturbation is bigger in the case of two slabs (1300÷1400 G) and less important for three (about 500 G) slabs. The most important problem is to reduce this perturbation to a few G, by introducing correction shims as many and far as it is necessary (Fig. 3).

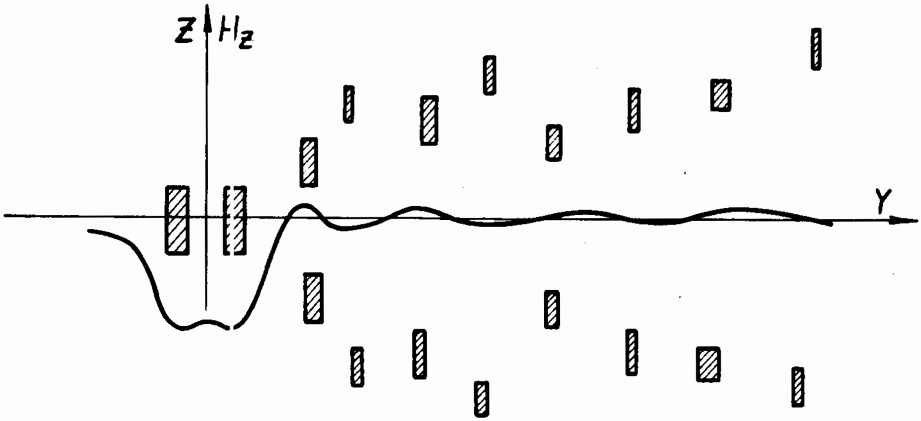


Fig. 3.

This is a time-consuming and boring work and the programmes reported in this paper are directed especially towards this aim.

This problem has several solutions fitting the wanted conditions and the programmes are not able to find all of them but the authors of this report hope that they will be useful for people who work on such problems of calculating and shimming magnetic channels, especially in synchrocyclotrons, but of course, also in cyclotrons where the conditions to be satisfied are easier.

II. Some Basic Formulas

We limited our calculations to the case of shims and slabs with a rectangular cross-section.

We supposed also that they are uniformly magnetized by the main field of the machine with the magnetization M , and we worked with its saturation value $M = 21000/4\pi\, G$.

If the origin of the coordinate system (x,y, z) coincides with the centre of the prism and the axes are aligned with the principal axes of the prism (Fig. 4), the general formula giving the vertical component, H_z of the magnetic field (in Oe or G) at one point $P\ (x,y,z)$ is/1/

$$
\begin{aligned}
H_z(x,y,z) = M \{ & \operatorname{arc\,tg} \frac{y-A}{z-B} \, \frac{x-L}{\sqrt{(x-L)^2+(y-A)^2+(z-B)^2}} - \\
& - \operatorname{arc\,tg} \frac{y-A}{z-B} \, \frac{x+L}{\sqrt{(x+L)^2+(y-A)^2+(z-B)^2}} - \\
& - \operatorname{arc\,tg} \frac{y+A}{z-B} \, \frac{x-L}{\sqrt{(x-L)^2+(y+A)^2+(z-B)^2}} + \\
& + \operatorname{arc\,tg} \frac{y+A}{z-B} \, \frac{x+L}{\sqrt{(x+L)^2+(y+A)^2+(z-B)^2}} - \qquad (1) \\
& - \operatorname{arc\,tg} \frac{y-A}{z+B} \, \frac{x-L}{\sqrt{(x-L)^2+(y-A)^2+(z+B)^2}} + \\
& + \operatorname{arc\,tg} \frac{y-A}{z+B} \, \frac{x+L}{\sqrt{(x+L)^2+(y-A)^2+(z+B)^2}} + \\
& + \operatorname{arc\,tg} \frac{y+A}{z+B} \, \frac{x-L}{\sqrt{(x-L)^2+(y+A)^2+(z+B)^2}} - \\
& - \operatorname{arc\,tg} \frac{y+A}{z+B} \, \frac{x+L}{\sqrt{(x+L)^2+(y+A)^2+(z+B)^2}} ,
\end{aligned}
$$

where L , A , B are the dimensions of the prism in cm. If we consider the following condition : $x = 0$, the slab is much longer in the x direction than in the y and z directions ($L \gg A, B$) we obtain

$$H_z(y,z) = 2M \left\{ -\operatorname{arc\,tg} \frac{y-A}{z-B} + \operatorname{arc\,tg} \frac{y+A}{z-B} + \operatorname{arc\,tg} \frac{y-A}{z+B} - \operatorname{arc\,tg} \frac{y+A}{z+B} \right\} . \tag{2}$$

If the origin of the coordinate system (X, Y, Z) does not coincide with the centre of the prism (Fig. 4) as in the general case

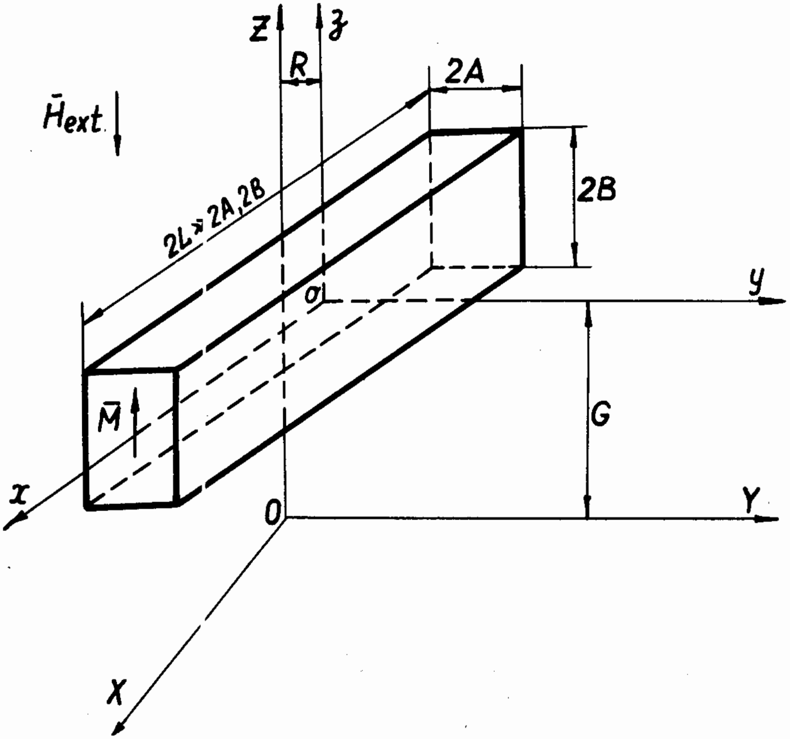


Fig.4. Coordinate system whose origin coincides with the centre of the prism and coordinate system as used in calculations pertaining to the iron slabs or shims.

of a channel with n correction pairs of shims (Fig. 3), we obtain from eq. (2) for a point situated on the median plane ($z = 0$) the following expression

$$H_z(Y,0) = 2M \left\{ \operatorname{arc\,tg} \frac{Y-R-A}{G+B} - \operatorname{arc\,tg} \frac{Y-R+A}{G+B} - \operatorname{arc\,tg} \frac{Y-R-A}{G-B} + \operatorname{arc\,tg} \frac{Y-R+A}{G-B} \right\} . \tag{3}$$

The differentiation of eq. (3) gives the formula of the magnetic field gradient (in Oe/cm or G/cm) on the Y direction

$$\frac{\partial H_z(Y,0)}{\partial Y} = 2M \left\{ \frac{G+B}{(Y-R-A)^2+(G+B)^2} - \frac{G+B}{(Y-R+A)^2+(G+B)^2} - \frac{G-B}{(Y-R-A)^2+(G-B)^2} + \frac{G-B}{(Y-R+A)^2+(G-B)^2} \right\} \tag{4}$$

Since we performed all our calculations in the median plane and considered the length infinite, all the components except H_z are equal to zero and thus eqs. (3) and (4) were used in the programmes.

III. Description of the Programmes

The programmes are written in FORTRAN-63

1. *DUOBAR Programme*

This programme computes the parameters of an extracting channel and of the relative correction shims.

1.1. Method of searching for a required field inside an extracting channel. We have seen that the extracting channel is composed of two slabs situated on the median plane.

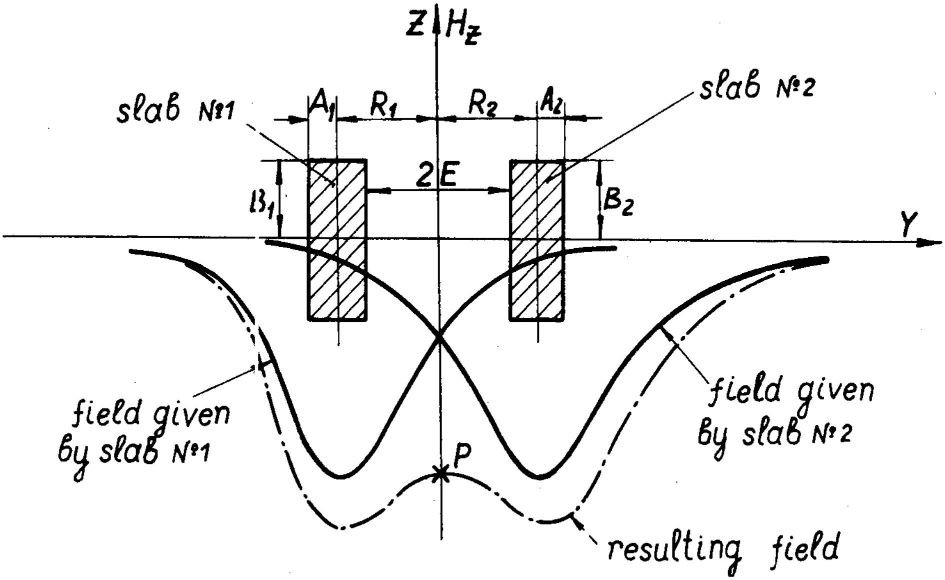


Fig.5. Two-slab configuration with the resulting magnetic field.

Fig.5 shows the shape of the magnetic field given by each slab, and also the resulting field. Depending on the geometrical dimensions of the slab, one can obtain a flat field curve if the aperture is small, or a field bump if the aperture is big. But in both cases, it is possible to adjust exactly the value of the field in P (therefore, only at one point) varying, step by step one of the dimensions of the slabs.

One must choose arbitrary but suitably from the physical point of view the initial dimensions of the slabs A_1, B_1 $A_2 = A_1$, $B_2 = B_1$ and the channel aperture $E = R_1 - A_1 = R_2 - A_2$.

Nevertheless, one can be limited in the choice of B_1 , B_2 by the size of the machine gap, and also obliged to take into account a minimal aperture to be sure not to loose most of the particles. The centre of the slabs is on the median plane, so that $G_1 = G_2 = 0$.

Before the beginning of calculation the array of the values of Y is filled step by step (0.5 cm) from 0 to 89.5 cm. On this segment of the axis Y , towards the center of the machine, the programme will correct the perturbation produced by the channel. The value of 89.5 cm has been chosen arbitrarily and one can consider another value taking care of the dimensions of the array Y in the programme. Anyway, for any value of the step the programme chooses itself the necessary number of shims and stops when the perturbation is smaller than 10 G.

The magnetic field given by each slab in the median plane, for $Y = 0$, i.e. in the middle of the channel aperture is calculated. The resulting field is obtained by adding the fields of two slabs.

This field H_1 is compared to the wanted value – H_0 – for $Y = 0$. The width A of the slab is changed step by step if the difference $H_1 - H_0$ is larger than 2%. The height B is kept constant because of the previously exposed considerations and also because A is the parameter which has the greatest influence on the field value.

The aperture of the channel is not changed ($E = R - A = \mathrm{const.}$) and therefore R follows closely each variation of A .

If for one value of A the field H_1 is too large and for the next one $A - \Delta P$ it is too small, i.e. we have an "oscillation" on A and the computer can field no solution the step value ΔP is divided by 2 and the searching for a solution is started again. The reduction of ΔP is repeated until $\Delta P = 0.001$ cm and if a solution is not found the initial precision of the field determination (2%) is changed.

Once the solution H_1 has been found at $Y = 0$, the programme calculates the magnetic field curve along the Y-axis, $H = f(Y)$. This curve is actually the perturbation generated by the channel towards the centre of the machine, perturbation which is to be corrected by setting up a range of iron shims (Fig.6).

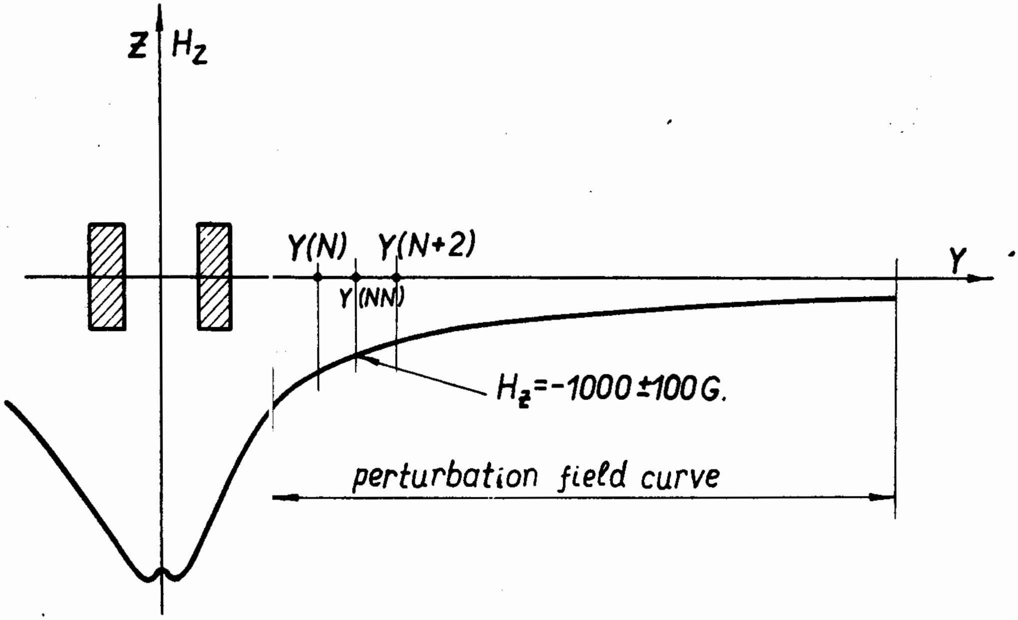


Fig.6. Setting up of the 1st pair of shims for an extracting section.

1.2. Correction of the perturbation field outside the extraction channel. We decided to begin the correction that is to place the first pair of shims at the point where the field has a value of 1000 G , because this value of the perturbation can surely be corrected with a precision of ±100 G imposed on this first pair of shims.

Using the calculated curve H = f(Y) we chose the Y(NN) value for which the field is equal to -1000 ± 100 G (HS = -1000 G) . If this value is not found we look for an Y(NN) value corresponding to -1050± 100 G . Evidently, if the required field value in the channel is around -1000 G , we begin the correction at a different value, e.g. -500 G .

a) First-order correction

The first pair of shims is set up at a distance RRES = Y (NN) from the origin. Thus, we have $R_k = R_{k+1} =$ RRES. The other parameters $A_k = A_{k+1}$, $B_k = B_{k+1}$, $G_k = G_{k+1}$ have at the beginning the same values for each new pair of shims which is set up and the programme changes these values in function of the field value which is to be corrected and of the imposed conditions. In order to start the correction process we have chosen the values $A_k = 0.2$ cm, $B_k = 2$ cm and $G_k = 5$ cm. These values are more or less arbitrary but they must be physically reasonable because in the programme the number of the parameter variations is limited.

The imposed condition for the 1st pair of shims which is to reduce the perturbation to ± 100 G in three points (Y(N) = Y(NN)-0.5 cm; Y(N+1) = Y(NN) and Y(N+2) = Y(NN) + 0.5 cm) is verified and if it is not realised the geometrical parameters of the shims are changed one after the other until they arrive at an imposed limit. The order of variation of the 4 parameters (G_k, R_k, A_k, B_k) is determined by the importance of the influence of each one on the field value. The first parameter which is changed is G_k and respectively G_{k+1} with a step $\Delta G = 0.2$ cm. If an "oscillation" (see III.1.1) on G_k takes place the step value ΔG is reduced twice. The limit of this variation is determined by the condition that the gap between the two shims should not be smaller than a certain value, for instance, 4 cm or that $\Delta G \geq 0.01$ cm. At this moment the variation on R_k and respectively R_{k+1} begins. If the field value at Y(N) is smaller than the field value at Y(N+2) the pair of shims is shifted towards the channel and vice versa. The step of variations is $\Delta P = 0.05$ cm and the number of shiftings is limited to 10. Finally, if after these two variations the required field values are not found, the A_k and A_{k+1} values are increased and the B_k and B_{k+1} values are decreased by $\Delta P = 0.05$ cm. This last variation is limited to 0.3 cm ($A_k < 0.5$ cm, $B_k \geq 1.5$ cm). Simultaneously it is verified if the distance between the channel and the 1 st pair of shims or between two successive pairs of shims is not smaller than $\Delta R = 0.2$ cm.

If all these possibilities have been exhausted the pair of shims is shifted from the channel with 0.5 cm at $Y(NN+1)$ that is in a region where the perturbation field values are smaller. The process of seeking for a solution begins again from the initial values of the shim parameters with eventually a new shifting away from the channel and so on until the imposed conditions are realized. A similar process has been provided for all the pair of shims but in all the cases for which the programme was tested such a shifting never occurred, a reasonable solution being always found at the intial point $Y(NN)$. Nevertheless, if somehow a too important shifting away from the channel of the first pair of shims occurs one can remote the decreasing of B_K and B_{K+1} and finally choose greater initial values for A_K and B_K . However, too large dimensions of the 1st pairs of shims can give a too important negative bump in the adjacent region ($Y > Y(N+2)$) which will be difficult to correct with the next shims and also to distort too much the field in the channel.

If a shifting of the 1st pair of shims away from the channel was necessary the programme goes on to the verification and eventually to the correction of the field in the channel.

If a solution has been found in the region where the perturbation field equals - 1000 G the programme tries to realise the correction closer to the channel. The parameters found for the 1st pair are stored, the position of this pair is shifted by 0.5 cm towards the channel, i.e. from $Y(NN)$ at $Y(NN-1)$ and the process of seeking a solution is started from the initial values of the parameters. If the imposed condition (±100 G) can be realized, the new parameters are again stored and a new shifting towards the channel takes place and so on until the 1st pair of shims arrives at a region where no solution can be found. In this case the previously stored values of the parameters of the 1st pair of shims are taken again and the process goes on to the next stage which is the verification of the field value in the channel.

For this verification the field given at $Y=0$ by the whole iron structure already set up (channel and the 1st pair of shims) is computed. If this value differs by no more than 5% from the initial required values H_0 ($\Delta H = | 0.005 H_0 |$) the programme sets up the 2nd pair of shims. If the difference is greater the main field is corrected but this operation is performed only by changing the value of A_1 (and respectively, of R_1), i.e. the parameter of slab No.1 in order to affect less upon the region where the perturbation field is to be corrected. The correction condition of the 1st pair of shims is then again verified and a new fitting of its parameters is performed if necessary. This process of verification and fitting can be repeated 10 times and if no solution is found the 1st pair is shifted away from the channel. However, in all the tests we performed, never more than 3 passings channel-shims were necessary in order to find correct values.

Now the new perturbation curve is calculated taking into account the two slabs and the 1st pair of shims. A new negative bump appears towards the machine centre and such a new bump will appear after each setting up of a new pair of shims but each one will be smaller than the previous one. Thus, its correction is possible.

Beginning from the 2nd pair of shims the computing process is identical for each new one (NSHIM $= 2,3,4...$). The computer verifies if the negative bump is smaller than -10 G. Then the position ($Y = Y(NN)$) of the minimum is found and at this point a new pair of shims is set up. The parameters are fitted (in the preferential succession G_k, R_k, A_k) in order to achieve the imposed correction condition. After each setting up of a new pair of shims a verification and eventually a new fitting of the previous one is performed (NCORR = NSHIM-1), and then the computer goes on to the next one (NSHIM=NSHIM$+1$). The imposed conditions are the following: for the 2nd pair $\pm$ 10 G, for the 3d one the perturbation must not exceed the limits $-$ 10 G to zero and for all the next ones -5 G to zero.

We noticed that if for the 2nd and 3d pairs of shims variations on R_k still occur beginning from the 4th pair only an increasing of G_k, i.e. of the gap whose initial value is 3 cm ($G_k = 5$ cm, $B_k = 2$ cm) takes place.

New pairs of shims are set up in this way until the negative bump is smaller than -10 G or until a fixed distance in respect of the last value of Y is reached. This last condition is achieved as follows: it is verified if the last pair of shims ,which has been set up is at 20 cm or less with respect to the last chosen value of Y (in our case Y(180) = 89.5 cm) and in this interval the last pair of shims is set up. After the correction of the previous pair the first order correction is finished.

b) Second order correction.

This additional set of shims must correct the small negative bumps which remain in the regions situated between the first order shims. This is achieved with shims whose initial dimensions are twice smaller than those of the previous correction.

These second order correction shims are set up at the minimum of the remanent negative bumps and the correction condition is to reduce to a half the bump value or if this value is larger than -200 G to reduce it to a value smaller than -100 G . In the regions where the minimum is above -10 G no correction is done ("In this region no correction is necessary"). If all the variation possibilities which are the same as for the first-order shims, have been exhausted, and the correction condition is not realized the programme prints "In this region no correction is possible" and the imposed conditions or the initial dimensions can be changed.

At the end of the programme a general Table with all the parameters of the channel and corrections shims as well as the corrected field $H_z = f(Y)$ are printed.

Fig. 7 shows the simplified diagram of the correction process.

2. *TRIBAR Programme*

This programme computes the parameters of a focusing channel and the corresponding correction system.

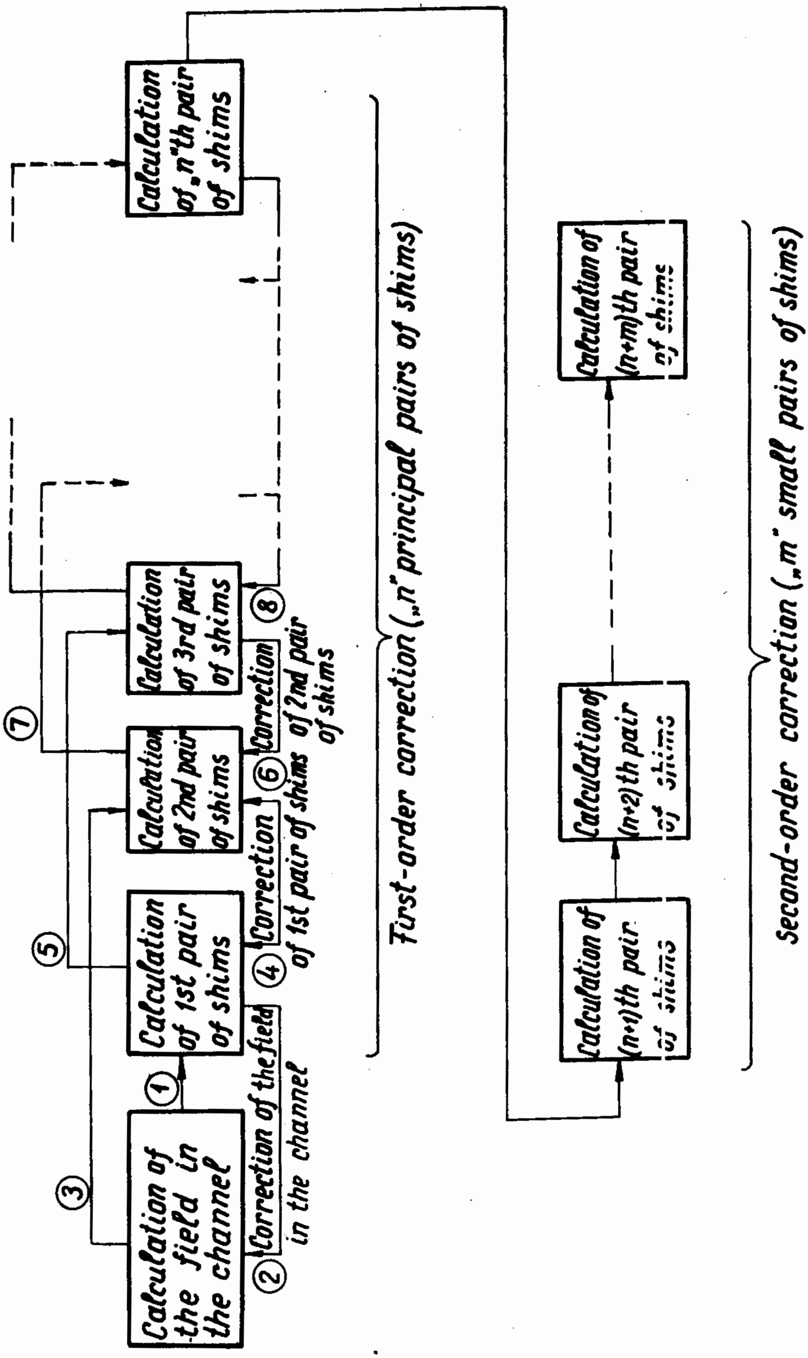


Fig.7. Simplified block diagram of the correction process for the extraction section (DUOBAR Programme).

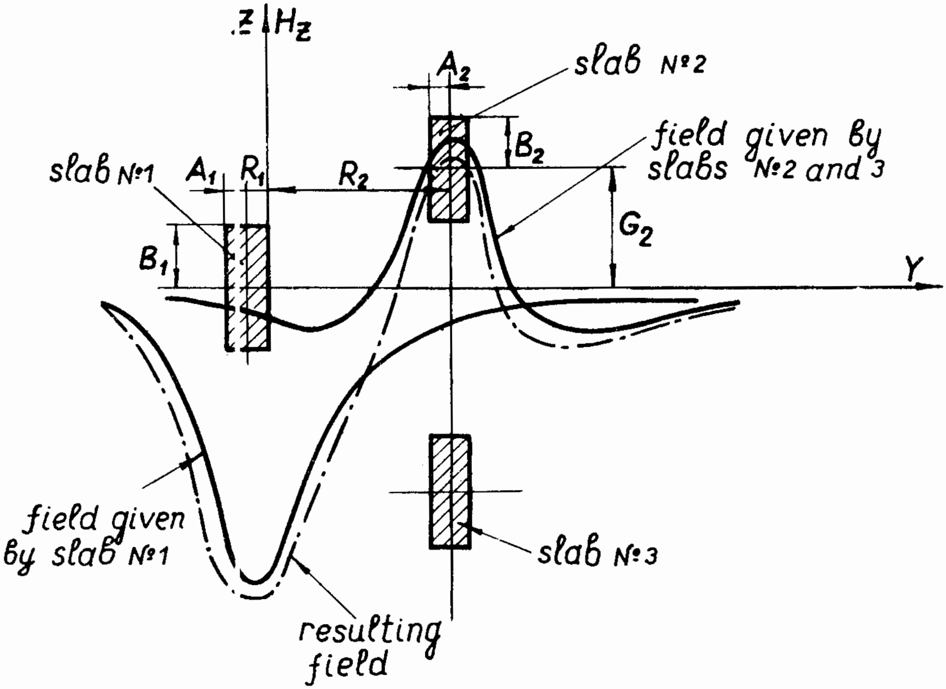


Fig.8. Three slab configuration with the resulting magnetic field.

2.1. Method of searching for the required field inside the focusing channel. Fig.8 shows the superposition of the two fields given, respectively, by one and by two slabs inside the channel. It is easy to see that for particular values of the geometrical parameters of this configuration, one can obtain a quasi-linear gradient and use its focusing properties. These parameters are six:

for slab No.1: the width $2A_1$ and the height $2B_1$,

for slab No.2: the width $2A_2$, the height $2B_2$, the aperture R_2 and the gap G_2 .

The parameters of slab No.3 are identical with those of slab No.2, except that $G_3 = -G_2$.

We decide to use the Newton-Raphson method,/2/ well known and often used because of its efficiency.

We must calculate at once the six parameters of a three slab configuration of the magnetic channel to obtain

either at 3 points 3 fields and 3 gradients,

or at 4 points 4 fields.

The first case will be presented in what follows.

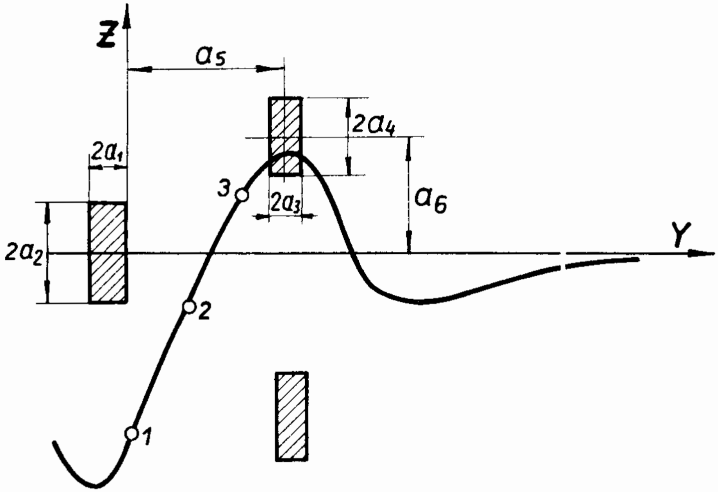


Fig. 9.

The required values of fields and gradients are the point No. i : H_{oi} , and H'_{oi} .

The system to be solved is the following (see Fig.9)

$$
\begin{aligned}
f_1(a_1, a_2, a_3, \dots a_6) &\equiv H_1(a_1, a_2, \dots a_6) - H_{01} = 0 \\
f_2(a_1, a_2, a_3, \dots a_6) &\equiv H_2(a_1, a_2, \dots a_6) - H_{02} = 0 \\
f_3(a_1, a_2, a_3, \dots a_6) &\equiv H_3(a_1, a_2, \dots a_6) - H_{03} = 0 \\
f_4(a_1, a_2, a_3, \dots a_6) &\equiv H'_1(a_1, a_2, \dots a_6) - H'_{01} = 0 \\
f_5(a_1, a_2, a_3, \dots a_6) &\equiv H'_2(a_1, a_2, \dots a_6) - H'_{02} = 0 \\
f_6(a_1, a_2, a_3, \dots a_6) &\equiv H'_3(a_1, a_2, \dots a_6) - H'_{03} = 0 .
\end{aligned}
\tag{5}
$$

Consider a group of values a_1^0 , a_2^0 , a_3^0 ... a_6^0 , which are supposed to be near the solution, a_1 , a_2 ,... a_6 .

Then, we can write

$$a_i = a_i^0 + h_i \tag{6}$$

and develope the function f_i in Taylor series around the point a_i^0 to the first order

$$f_i(a_1, a_2, \dots a_6) = f_i(a_1^0, a_2^0, \dots a_6^0) + \sum_j h_j \frac{\partial f_i(a_1^0, a_2^0, \dots a_6^0)}{\partial a_j} \tag{7}$$

If the solution is

$$f_i(a_1, a_2, \dots a_6) = 0 \tag{8}$$

we obtain the matrix equality

$$[f_i^0] + [\frac{\partial f_i}{\partial a_j}] [h_j] = 0 \quad . \tag{9}$$

The solution of this system will be done practically in two stages with the help of the following array:

$$\begin{aligned}
df_1 &= \frac{\partial f_1}{\partial a_1} da_1 + \frac{\partial f_1}{\partial a_2} da_2 + \dots\dots\dots\dots + \frac{\partial f_1}{\partial a_6} da_6 \\
df_2 &= \frac{\partial f_2}{\partial a_1} da_1 + \frac{\partial f_2}{\partial a_2} da_2 + \dots\dots\dots\dots + \frac{\partial f_2}{\partial a_6} da_6 \\
&\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\
df_6 &= \frac{\partial f_6}{\partial a_1} da_1 + \frac{\partial f_6}{\partial a_2} da_2 + \dots\dots\dots\dots + \frac{\partial f_6}{\partial a_6} da_6 \quad ,
\end{aligned} \tag{10}$$

a) Calculation of partial derivatives at the point a_i^0 .

Giving each parameter a finite increase da_1 , da_2,... da_6 and calculating the increases df_i corresponding to each da_j , one can determine column after column, the ratios $\frac{df_i}{da_j}$ which will be taken equal to $\frac{\partial f_i}{\partial a_j}$.

b) Calculation of the necessary h_j to approach the solution.

If the array of partial derivatives in a_i^0 has been found, we obtain from eq. (9)

$$[\frac{\partial f_i}{\partial a_j}] [h_j] = - [f_i^0] \tag{11}$$

and

$$[h_j] = - [\frac{\partial f_i}{\partial a_j}]^{-1} [f_i^0] \quad , \tag{12}$$

where $[\frac{\partial f_i}{\partial a_j}]^{-1}$ is the inverse matrix of $[\frac{\partial f_i}{\partial a_j}]$.
Hence, from the iteration p to the following, one has

$$[a_j]_{p+1} = [a_j]_p + [h_j] \quad . \tag{13}$$

c) Practical Realization

Although this method has proved its efficiency in other cases, the most important problem is to know the convergence conditions and to maintain the process of iteration in strictly stable areas. It is also necessary to find solutions which are physically "acceptable" (the channel must be set up in the machine gap which has a fixed size).

For all these reasons, we were obliged to search for an approximate solution at two points No.1 and No.3 or 4 before beginning the iteration process, for all the points. The study of the geometrical parameters of the magnetic configuration capable of fitting the wanted conditions, is then performed in two steps:

1) Search for an approximate solution. One begins to look for such a solution, fitting at $\pm 5\%$ the required conditions in the point 1 and $\pm 20\%$ in the point 3 (for the case with three points, see Fig. 8) or 4 (for the case with 4 points).

In order to find a solution at point 1 the programme changes with a constant step only the width A_1 of the 1st slab, and at point 3 (or 4) only the heights B_2 and, respectively, B_3 of the 2nd and 3d slabs.

If an "oscillation" (see III, 1.1) occurs on A_1 or B_2 and B_3 a little variation is given to B_1 or to A_2 and A_3, respectively. If there is no "oscillation" but a solution is not found after 30 variations of A_1 or B_2 and B_3 the other parameters are varied successively, i.e. A_2, R_2, G_2 and B_1 with a greater step and the process begins again from the initial values for the other dimensions. The variations of all the parameters are limited by limit values. When all these limit values have been exceeded the programme stops and the user has to change either the limit values or the required field values.

2) Once this rough approximative solution has been found, the iteration process begins. This process which is generally very fast (a few iterations) leads to a solution fitting all the conditions at all the points.

The value of the inverse matrix $\left[\frac{\partial f_i}{\partial a_j} \right]^{-1}$ is calculated by the SUBROUTINE INVERSE.

The imposed geometrical limitations lead to reasonable solutions, with an accuracy better than 10%. Anyway, it would not be useful to continue the process, imposing a better accuracy, because eqs. (3) and (4) based upon the assumption of the uniform magnetization of the iron pieces give the field and gradient also with an accuracy (5-10%).

2.2. Correction of the perturbation field outside the focusing channel. The perturbation set up by a three-slab channel presents some differences with respect to this created by a two-slab configuration and therefore the correction process will be also somewhat different.

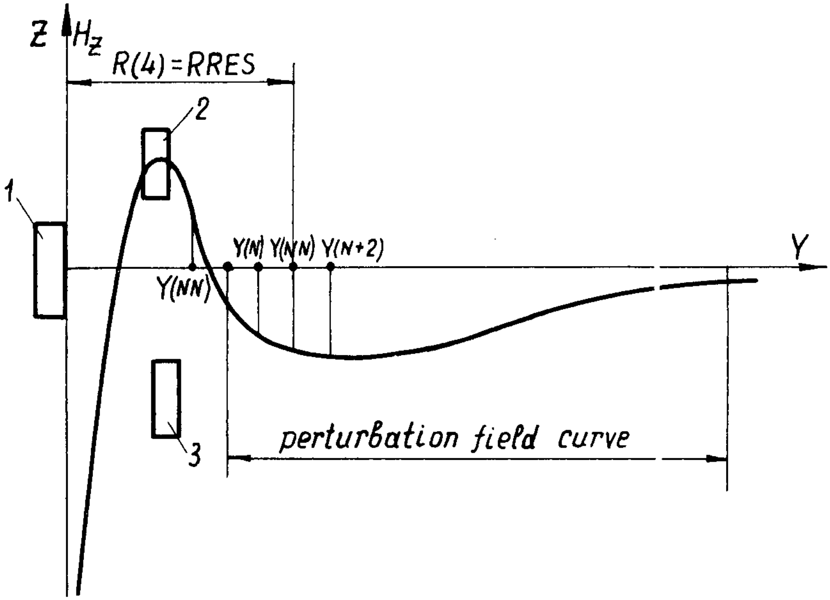


Fig.10. Setting up of the 1st pair of shims for a focusing section.

The typical perturbation field curve is shown in Fig.10. and one can see that it presents a minimum similar to that which appears in the previous case after the setting up of the 1st pair of shims but greater in absolute value . Therefore, it is useless trying to correct this great negative bump with a single pair of shims since its dimensions would be very large and it would completely distort the field inside the channel. The programme begins correcting the bump at its beginning near the channel. The point Y (NM) where the field is still positive is determined and then the 1st pair of shims is set up at Y(NN) , where NN = NM + 3 (Fig.10). The correction condition of ± 100 G is easily carried out. The setting up of this 1st pair of shims decreases the negative bump of the perturbation curve shifting it at the same time towards the machine centre. After that the process is practically identical to that used in the DUOBAR programme.

The only differences are:

1) The negative bump after setting up the 1st pair is greater, hence the correction conditions imposed on the 2nd pair are only ± 25 G .

2) The central region of the three-slab channel is not screened with respect to the correction shims by slab No.2, as for the two-slab configuration. Therefore, the influence of these shims on the field inside the channel is greater and the programme must verify and correct the channel field not only after the setting up of the 1st pair of shims but after the first 7 pairs of the 1st order correction and after the first 6 pairs of the 2nd order correction.

The simplified diagram of the correction process, is given in Fig.11.

IV. Shortcomings of the Programmes

The shortcoming of the programme DUOBAR is that inside the channel the required field value is obtained only at one point.

For the programme TRIBAR we must say that:

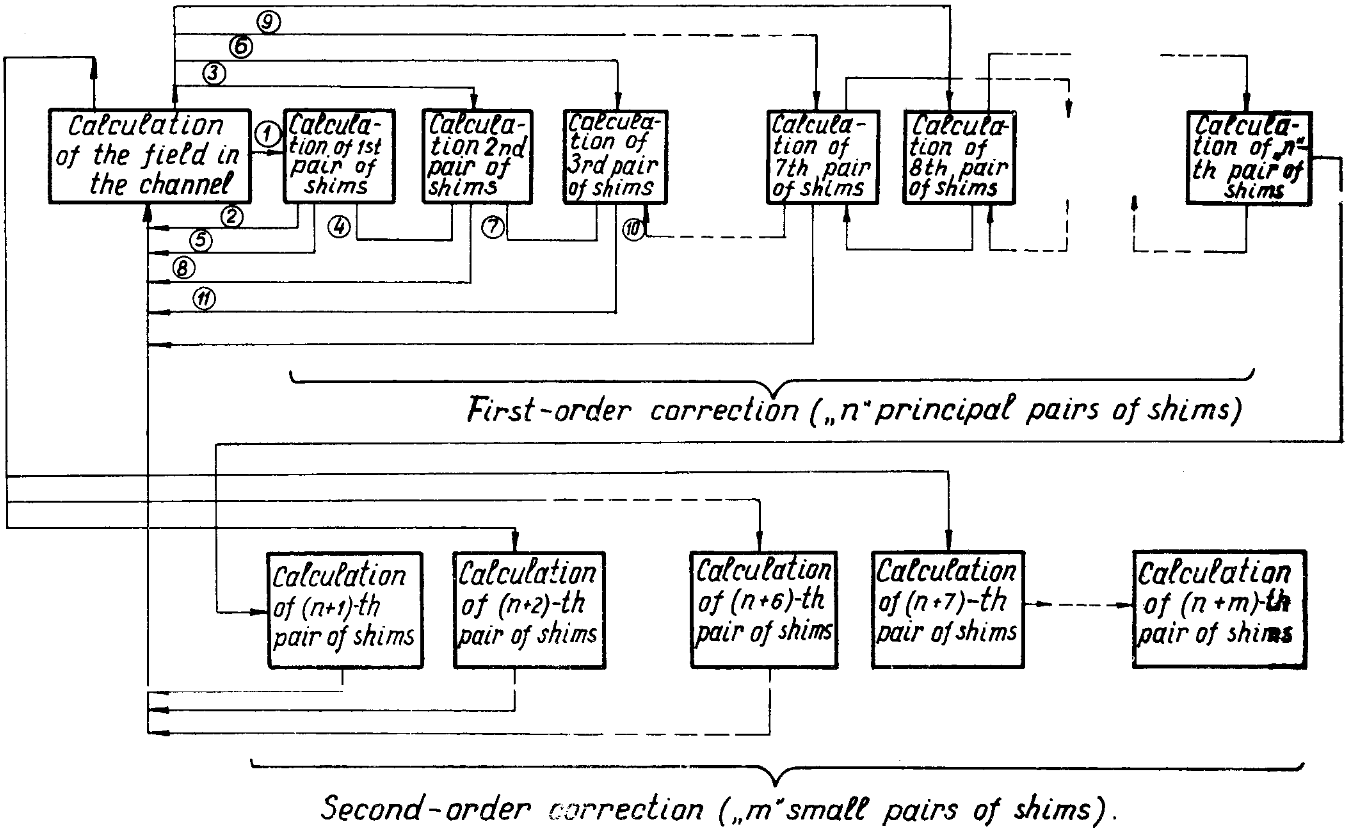


Fig.11. Simplified block diagram of the correction process for the focusing section (TRIBAR Programme).

1) since limitations have been imposed on the channel dimensions the programme cannot find a solution for any value of the field or gradient at all the points inside the channel. If the limits have been reached, these values and the field (and gradient) corresponding values are printed and the user of the programme can change the imposed limits or the required field (or gradient values).

2) The subroutine ITER, finds a particular solution which is not the only one and may be not the best one.

3) The resulting positive peak outside the channel is too broad and the correction of all the perturbation is not so precise as for the DUOBAR.

V. Required Data and Results of Calculations

In the data deck of each programme the following information is to be introduced:

1. Programme DUOBAR. A card with the initial values of A_1 , B_1 , A_2 , B_2 , R_1 and G_1 (see III.1) and a card with the required value of the channel field at $Y = 0$, H_{01} .

2. TRIBAR Programme. A card with the value of NPOINT, the number of points at which we calculate the channel field and which can be equal to 3 (for 3 fields and 3 gradients) or 4 (for 4 fields).

A card with the required values of the field (and gradient) in the channel. For 3 fields and 3 gradients the first values are the field values followed by the gradient values at the same points.

A card with the Y values in which we calculate the field (and the gradient) in the channel.

The final results are printed in a Table which contains the geometrical parameters of the channel of the 1st order and 2nd order correction shims and the corrected field curve.

Figs. 12, 13 show the configurations obtained for an extracting and respectively, a focusing section with the correction shims and the field curves with and without correction.

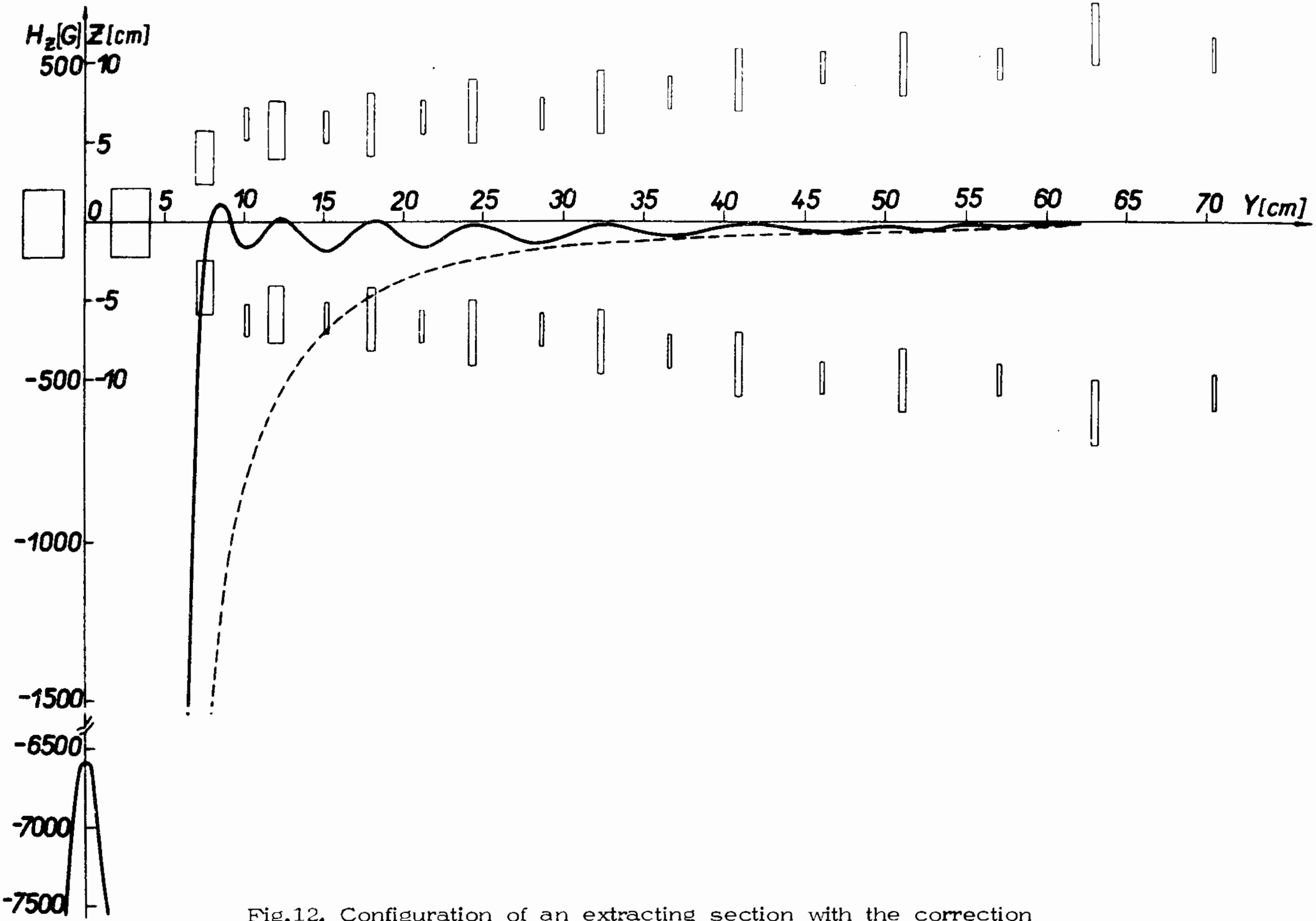


Fig.12. Configuration of an extracting section with the correction shims and the resulting field curve after correction (full-line) and without correction (broken line).

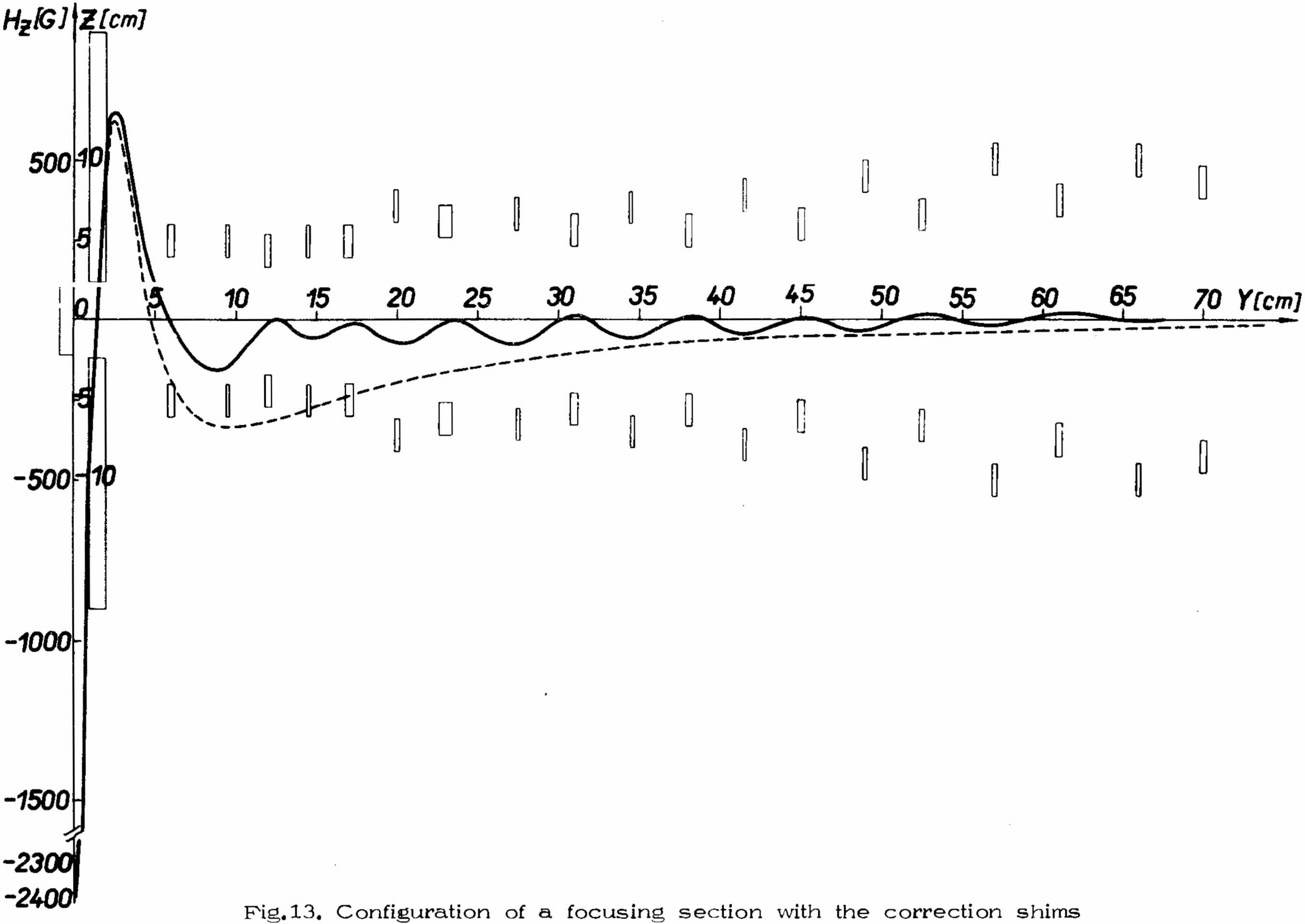


Fig.13. Configuration of a focusing section with the correction shims and the resulting field curve after correction (full-line) and without correction (broken line).

For the extracting channel the required field value was $H_{01} = -6300$ G and we imposed a height of the slabs of 4.3 cm and a channel aperture of 3 cm.

For the focusing channel the required field values were -2500 G, -1400 G, -600 G and 150 G, respectively, at $Y = 0$, 0.5, 1, 1.5 cm.

Below we give also a list of the programmes, indices the block diagrams of the two programmes and of the subroutines and a complete listing of each programme.

VI. Signification of the Indices and Parameters

For the DUOBAR Programme

KLING

KLING = 1 – Calculation of the field H_1 in the channel at $Y = 0$.

KLING = 2 – Calculation of the field at three points under the correction shims.

KLANG

KLANG = 0 – Calculation of the channel parameters and of the 1st pair of shims.

KLANG = 1 – Correction of the system channel – 1st pair of shims.

KLANG = 2 – Calculation and correction of the system channel – – 1st pair of shims is finished.

JANA

JANA = 1 – Correction of the parameters of the i-th pair of shims.

JANA = 2 – Calculation of the parameters of the i-th pair of shims.

KLYNG

KLYNG = 1 – Shimming of the 1st order

KLYNG = 2 – Shimming of the 2nd order.

INC

INC = 0 – Shimming of the 2nd order.

INC > 1 – The number of shiftings of the 1st pair of shims towards the channel.

IT – The number of verifications (and corrections) of the system channel –1st pair of shims.

ICOUNT Number of corrections of the parameters of the 1st pair of shims before the setting up of the 2nd pair of shims.

KLAC

KLAC = 1 - There was no variation of the parameters of the channel or of the - i-th pair of shims.

KLAC = 2 - The variation of the parameters of the channel or of the i-th pair of shims begins.

ISWITC

ISWITC = 1 - The calculation of the field in the channel or at three points under the shim.

ISWITC = 2 - The calculation of the complete magnetic field curve $H = f(Y)$.

NSHIM - The number of pairs of shims.

NSHIM1 - The number of the 1st order correction pairs of shims.

NCORR - Number of the pair of shims which is corrected.

NSH Number of the magnetic iron bodies (slabs of the channel or shims) which has been set up.

K - number of the first slab or shim from the channel system or from the pair of shims which is under calculation or correction.

LA - The number of variations of the parameter A of the channel slabs.

LG - The number of variations of the parameter G of the pair of shims.

HL - The maximum value in gauss of non-corrected field perturbation at three points under the shim beginning from the 4th pair of the 1st order correction and for the 2nd order correction shims.

DELTAY - Step in cm on the Y -axis.

DELTAP - Step of variation in cm for the parameters A , B and R.

DELTAG - Step of variation in cm for the parameter G .

DELTAR - Minimum allowed distance between the channel and the 1st pair of shims or between two pairs of shims.

DELTAH - Precision of calculation for the field in the channel (gauss).

SIG - Saturation value of the magnetization (in gauss).

HS - Absolute value of the perturbation field at which the correction begins.

KLIC - Number of variations of the parameter R for each pair of shims.

KLYK - Number of variations of the parameter A for each pair of shims.

For the TRIBAR Programme

NPOINT - Number of points inside the channel in which the required fields (or gradients) are obtained.

NPAR - Number of geometrical channel parameters which are changed during the iteration process.

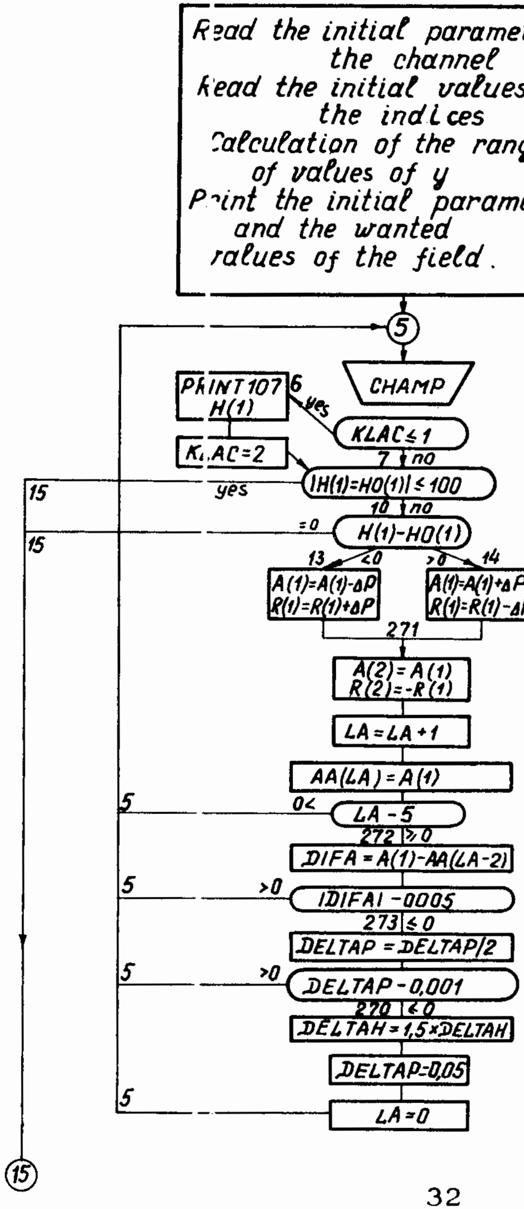
The other indices or parameters have the same signification as for the DUOBAR Programme.

References

1. *V.I. Danilov, O.V. Savchenko. Prib. i Techn. Exper., 3, 17 No.3, (1959).*
2. *E. Durand. Solutions numeriques des équations algebriques, Tome II -Paris - Masson, 1961.*

Received by Publishing Department
on February 5, 1970.

BLOCK DIAGRAM OF THE PROGRAMME DUOBAR.



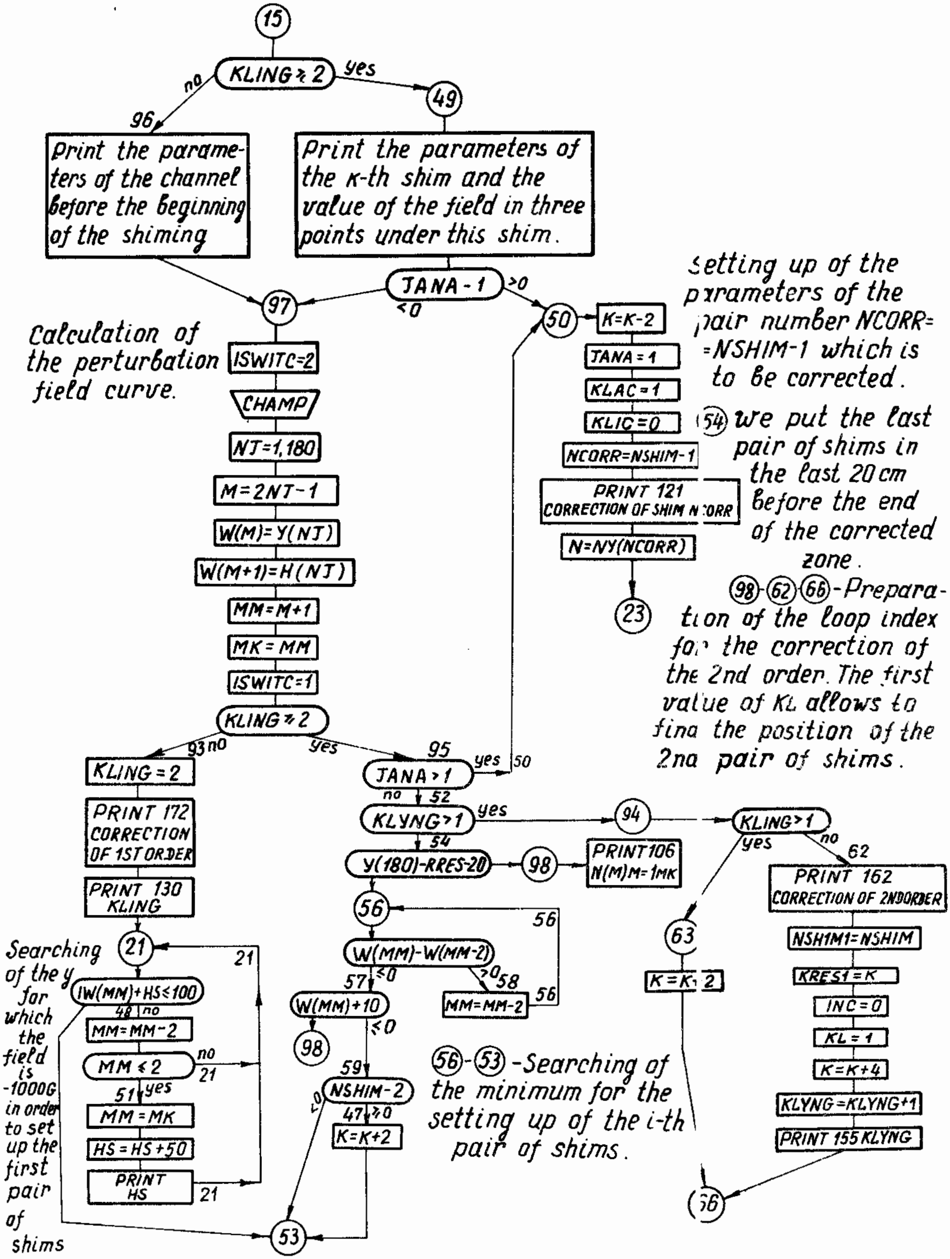
Calculation of the field in the magnetic channel.

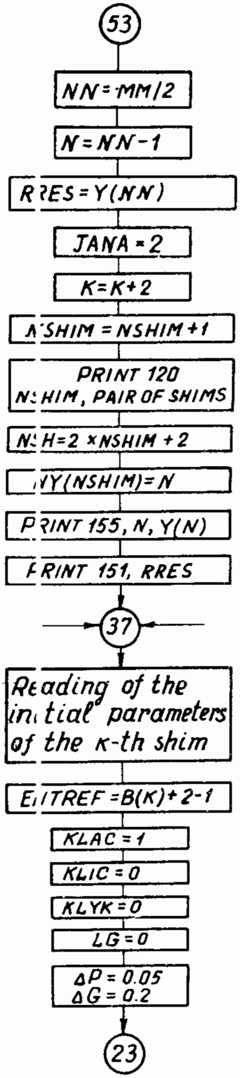
Verification of the difference between the calculated and the wanted fields in the channel.

Elimination of an oscillation if the step of variation is too big.

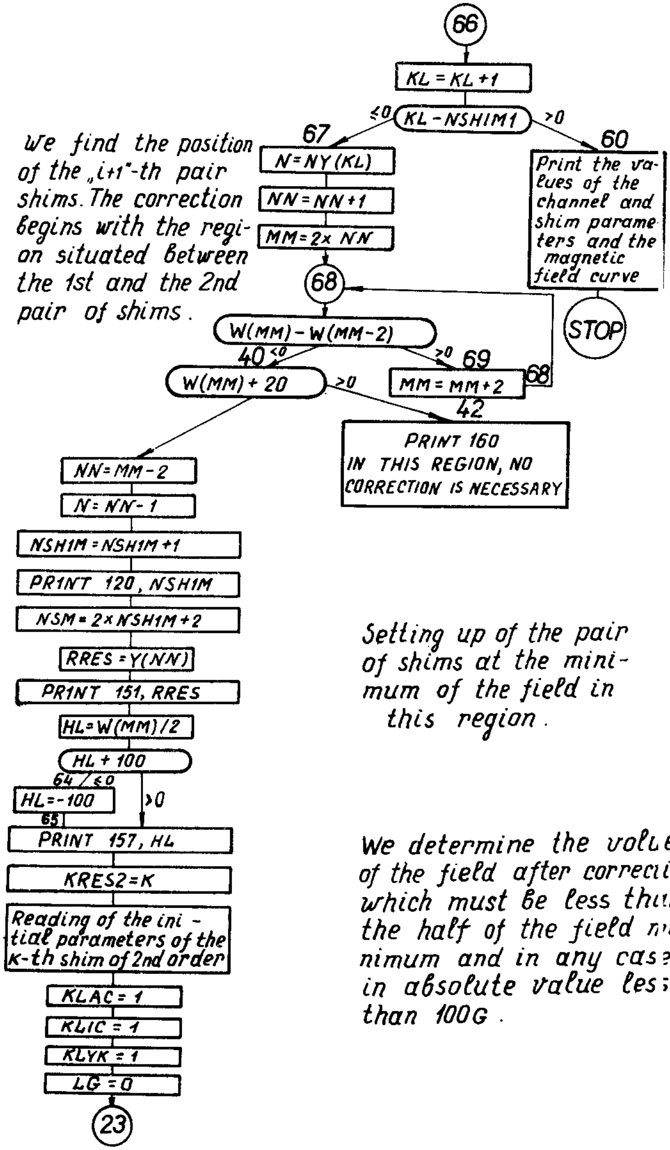
Reduction of the step

If the step turns too small the precision of the calculation is reduced.


15
KLING ≥ 2
no
yes
96
49
Print the parameters of the channel before the beginning of the shiming
Print the parameters of the κ-th shim and the value of the field in three points under this shim.
JANA - 1
>0
<0
97
50
K=K-2
Calculation of the perturbation field curve.
ISWITC=2
CHAMP
NT=1,180
M=2NT-1
W(M)=Y(NT)
W(M+1)=H(NT)
MM=M+1
MK=MM
ISWITC=1
KLING ≥ 2
JANA=1
KLAC=1
KLIC=0
NCORR=NSHIM-1
PRINT 121 CORRECTION OF SHIM NCORR
N=NY(NCORR)
23
setting up of the parameters of the pair number NCORR=NSHIM-1 which is to be corrected.
(54) we put the last pair of shims in the last 20 cm before the end of the corrected zone.
(98)-(62)-(66)-Preparation of the loop index for the correction of the 2nd order. The first value of KL allows to find the position of the 2nd pair of shims.
93 no
yes
95
KLING=2
JANA>1
yes
50
no
52
PRINT 172 CORRECTION OF 1ST ORDER
KLYNG>1
yes
94
KLING>1
yes
no
54
62
PRINT 130 KLING
Y(180)-RRES-20
98
PRINT 106 N(M)M=1MK
PRINT 162 CORRECTION OF 2NDORDER
56
56
NSHIM1=NSHIM
21
21
Searching of the y for which the field is -1000G in order to set up the first pair of shims
IW(MM)+HS≤100
48
no
W(MM)-W(MM-2)
<0
57
>0
58
56
63
KRES1=K
MM=MM-2
MM=MM-2
K=K+2
INC=0
W(MM)+10
<0
KL=1
MM≤2
no
21
98
51
yes
K=K+4
MM=MK
59
NSHIM-2
<0
≥0
47
(56)-(53)-Searching of the minimum for the setting up of the i-th pair of shims.
KLYNG=KLYNG+1
HS=HS+50
K=K+2
PRINT 155 KLYNG
PRINT HS
21
66
53



setting up of the
i-th pair of shims.



Correction of the 2nd order. KL determines the position of the „i+1"-th pair of shims.
Verification if we have not overpassed the position of the last pair of shims.

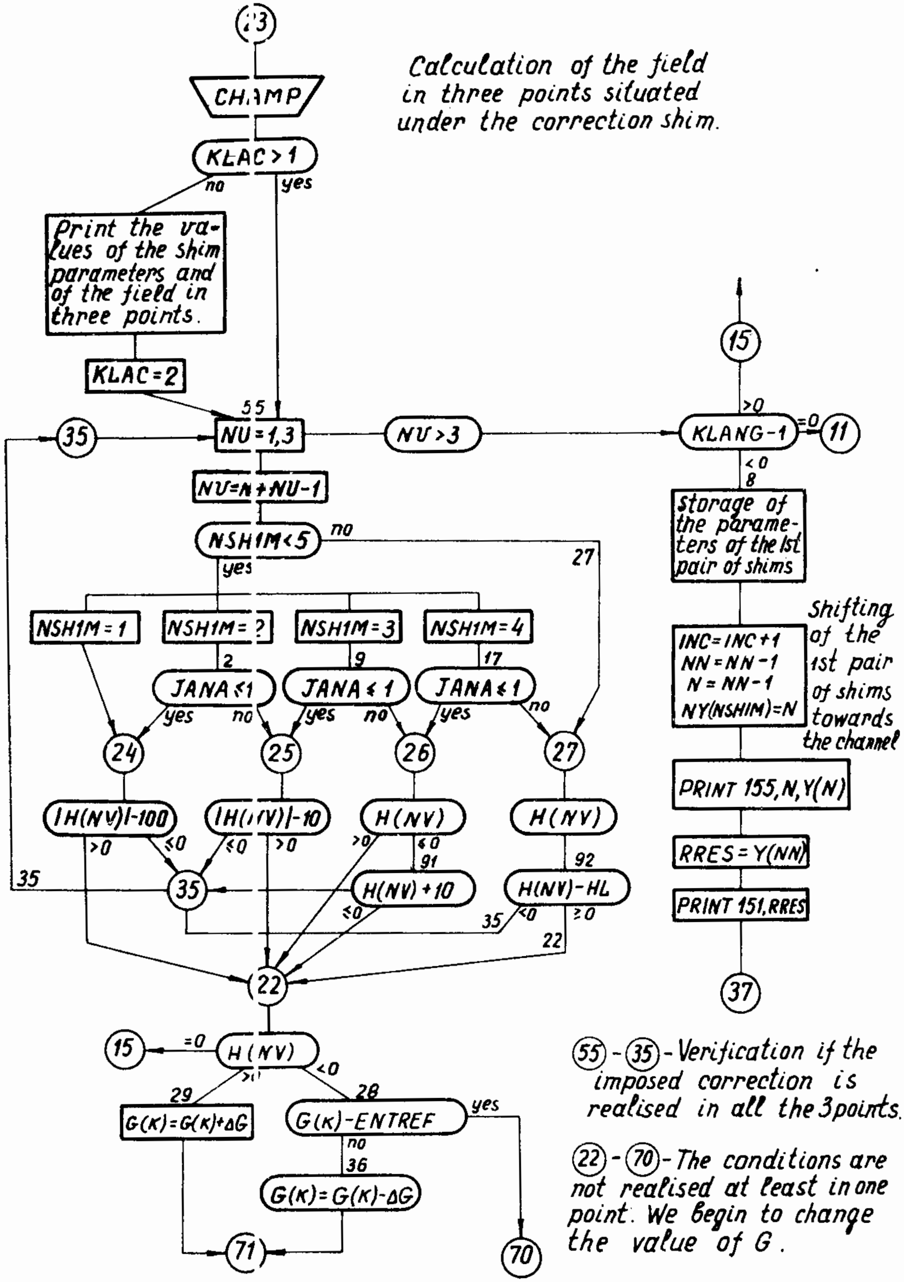
We find the position of the „i+1"-th pair shims. The correction begins with the region situated between the 1st and the 2nd pair of shims.

We find the minimum of the field between the „i+1"-and i-th pairs of shims.
If the minimum is less than -20 G no correction is necessary in this region.

Setting up of the pair of shims at the minimum of the field in this region.

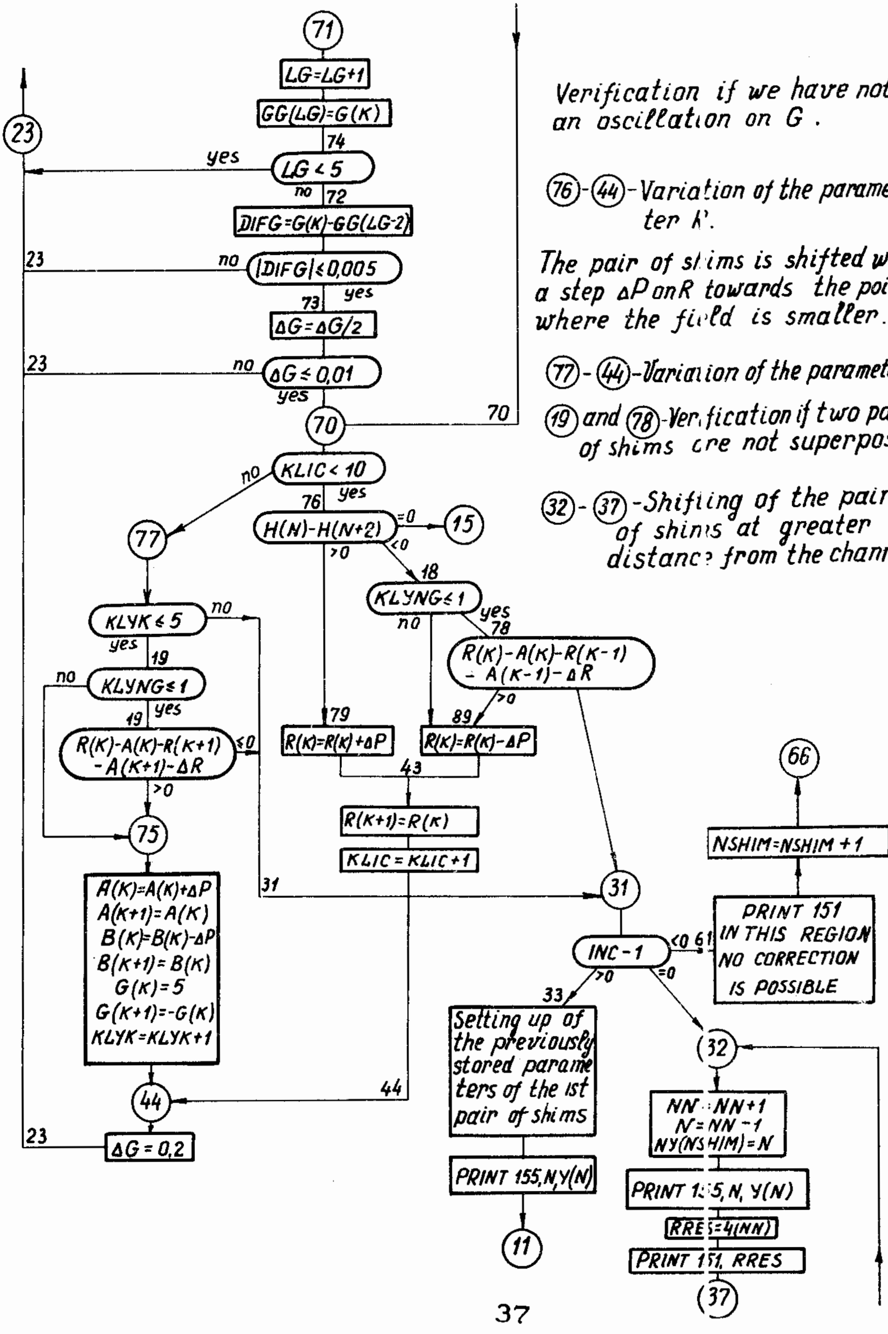
We determine the value of the field after correction which must be less than the half of the field minimum and in any case in absolute value less than 100 G.

Calculation of the field in three points situated under the correction shim.



55 - 35 - Verification if the imposed correction is realised in all the 3 points.

22 - 70 - The conditions are not realised at least in one point. We begin to change the value of G.



Verification if we have not an oscillation on G.

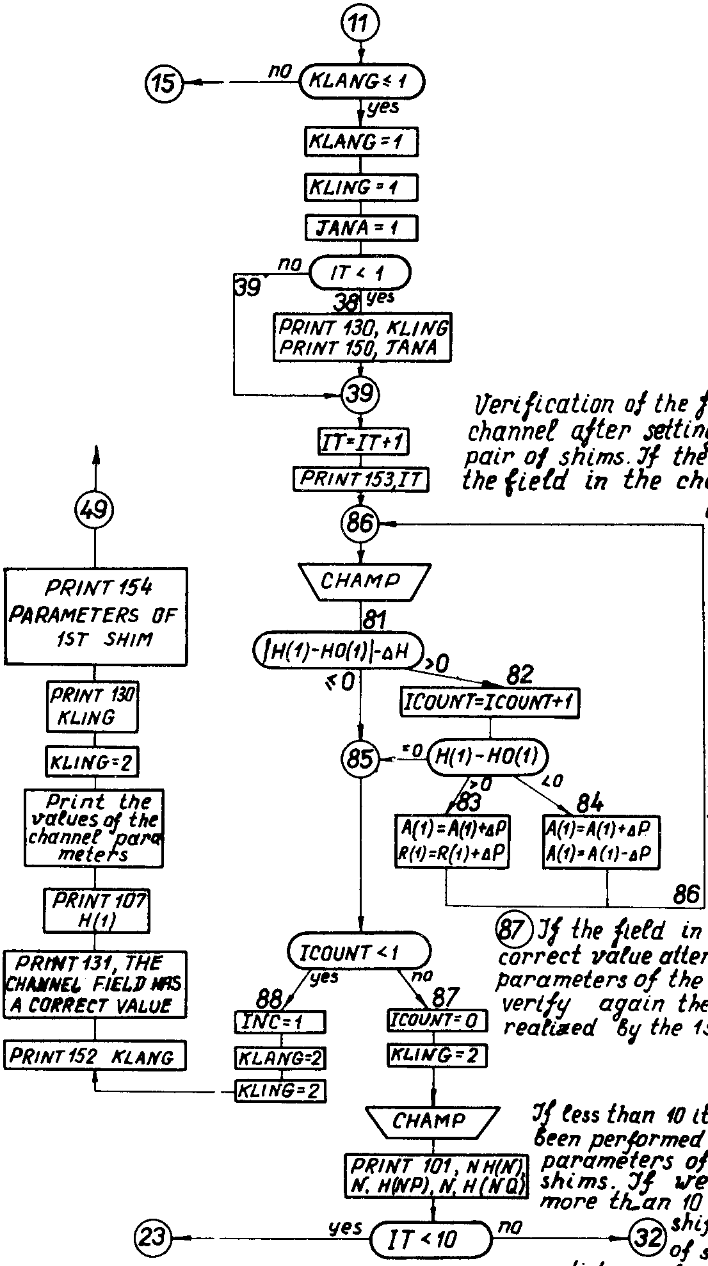
(76)-(44)-Variation of the parameter R.

The pair of shims is shifted with a step ΔP on R towards the point where the field is smaller.

(77)-(44)-Variation of the parameter A

(19) and (78)-Verification if two pairs of shims are not superposed.

(32)-(37)-Shifting of the pair of shims at greater distance from the channel.



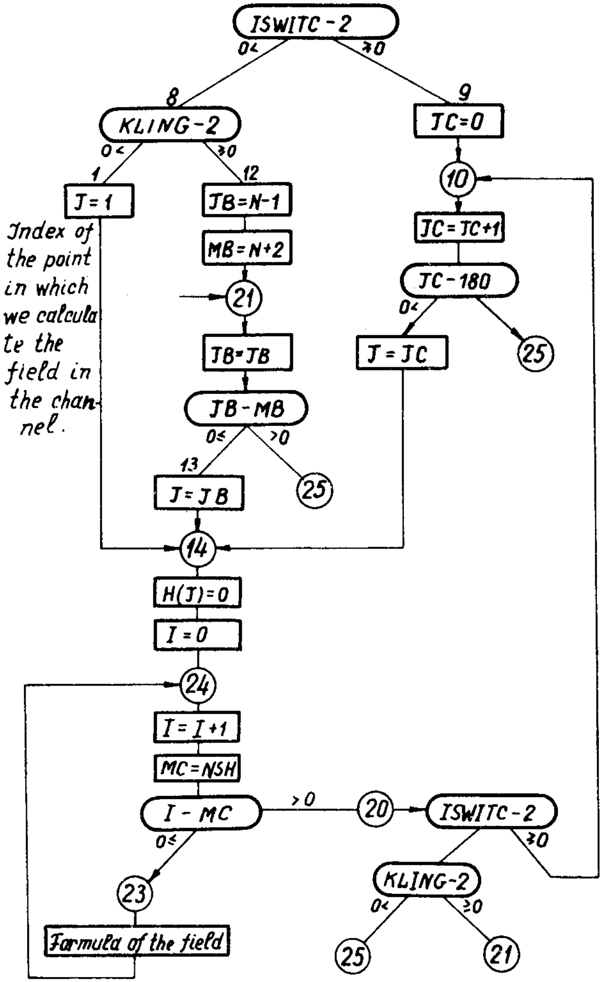
Verification of the field in the channel after setting up the 1st pair of shims. If the value of the field in the channel is not correct we change the value of A(1).

(88) If the field in the channel has a correct value without any correction we go further on to the 2nd pair of shims.

(87) If the field in the channel has a correct value after variation of the parameters of the channel we verify again the correction realized by the 1st pair of shims.

If less than 10 iterations have been performed we correct the parameters of the 1st pair of shims. If we performed more than 10 iterations we shift the 1st pair of shims at a greater distance from the channel.

BLOCK DIAGRAM
OF THE SUBROUTINE CHAMP
FOR THE PROGRAMME DUOBAR



⑨-⑭- Indexes of the points of the perturbation field curve.

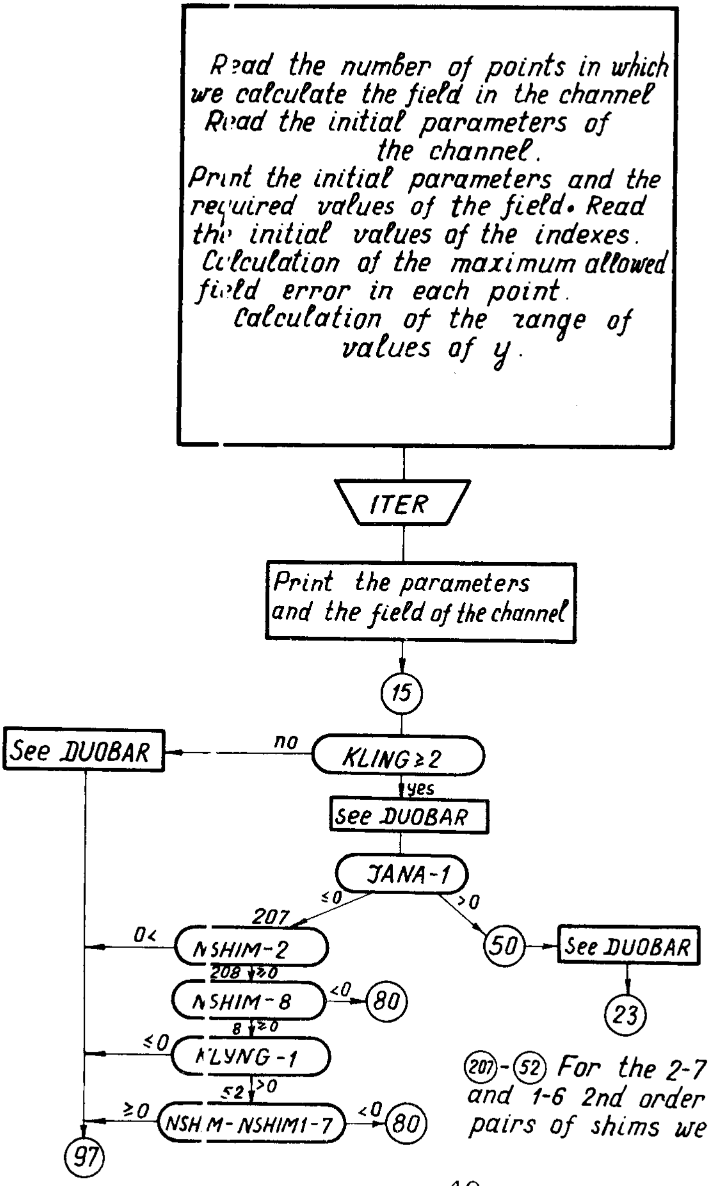
⑫-⑭- Indexes of the three points under each pair of shims.

㉔- Indexes for each piece of iron (slab or shim).

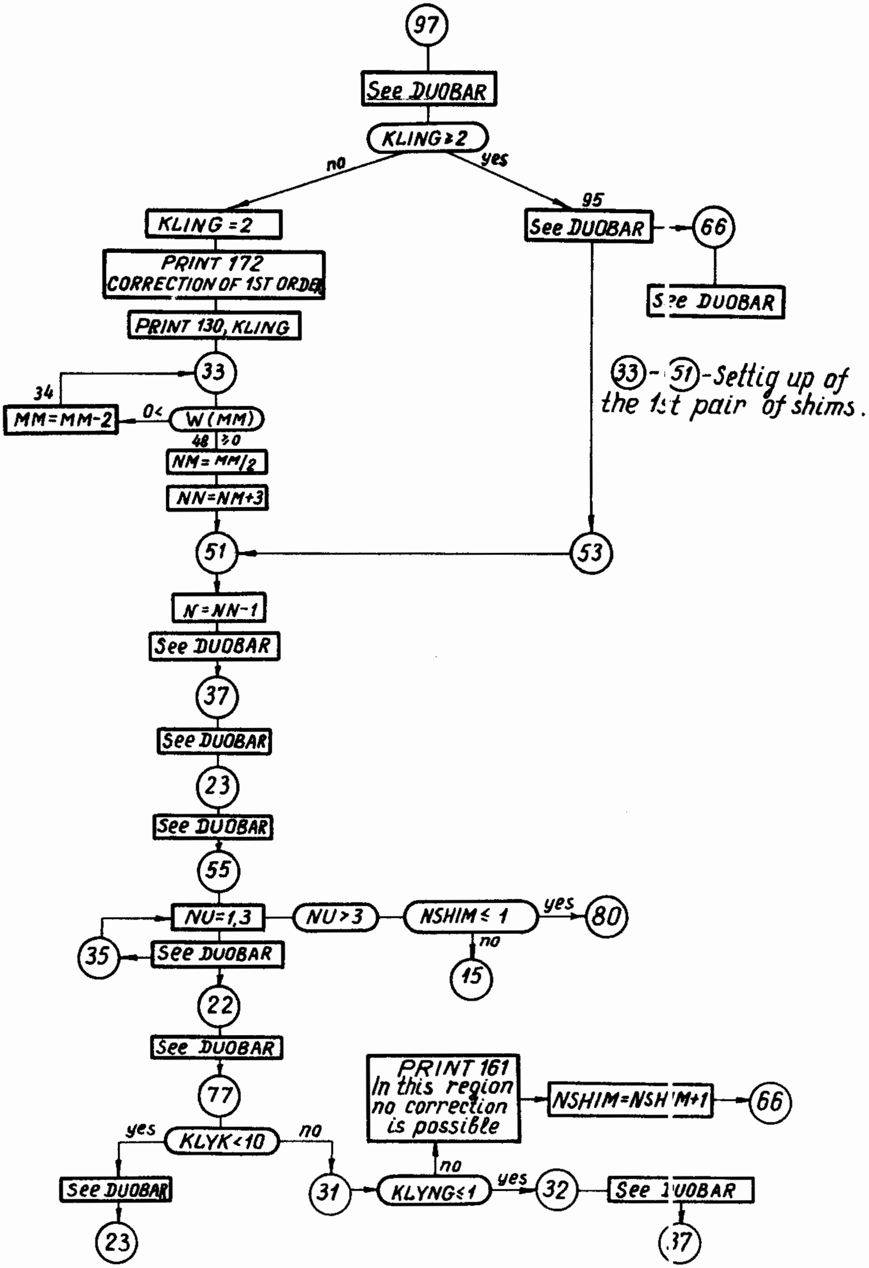
We fix the number of iron pieces with a contribution to the total value of the field at a given moment.
We verify if we have calculated the field of all the iron pieces at a given moment.

㉓- We calculate the sum of fields given by each iron piece.

BLOCK DIAGRAM
OF THE PROGRAMME TRIBAR

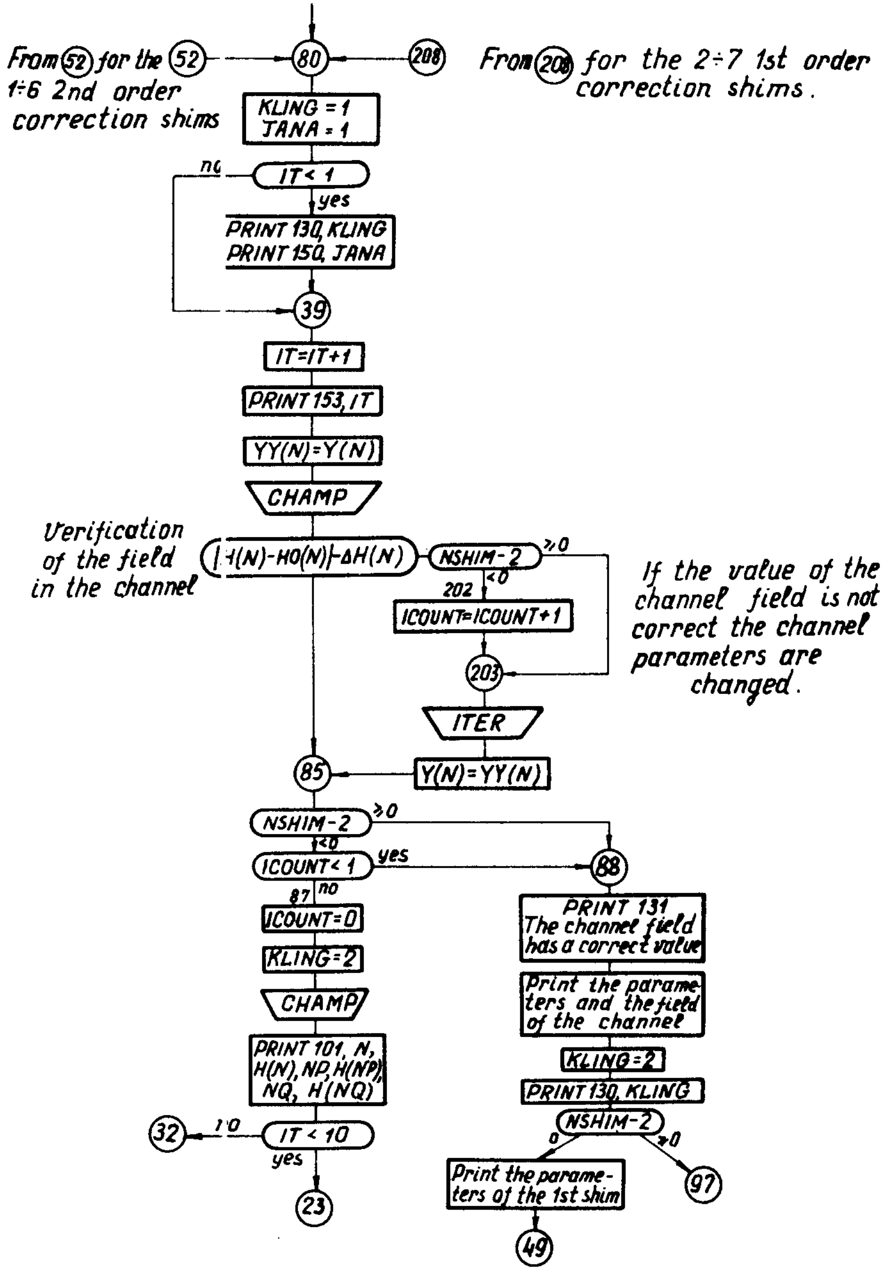


(207)-(52) For the 2-7 1st order and 1-6 2nd order correction pairs of shims we go to (80)

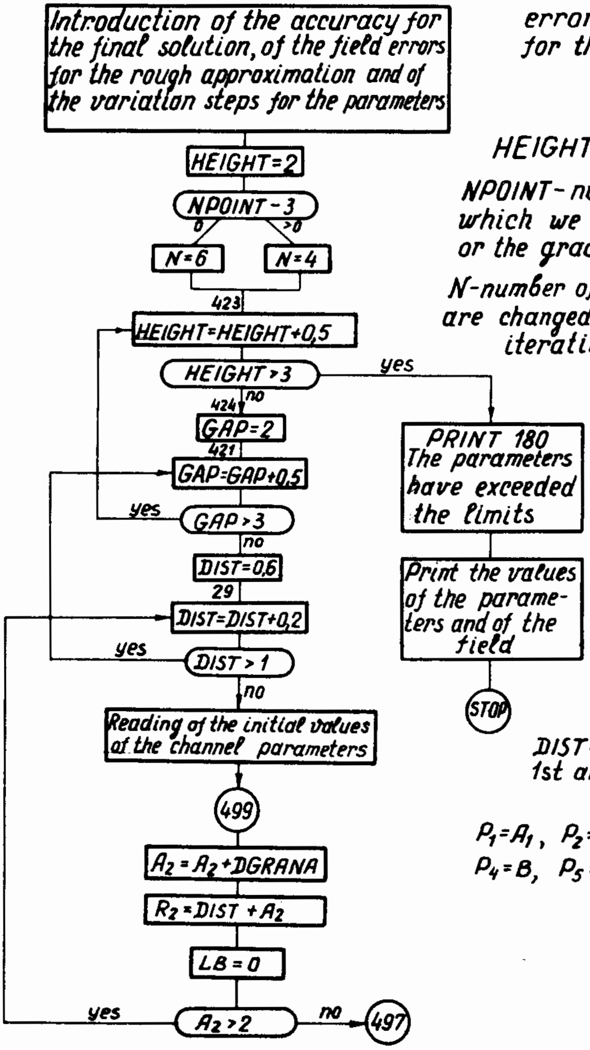


㉝-(51)-Settig up of the 1st pair of shims.

After the setting up of the 1st pair of shims.



BLOCK DIAGRAM
OF THE SUBROUTINE ITER



AQRACY- maximum error in each point for the final solution.

HEIGHT-height of 1st slab

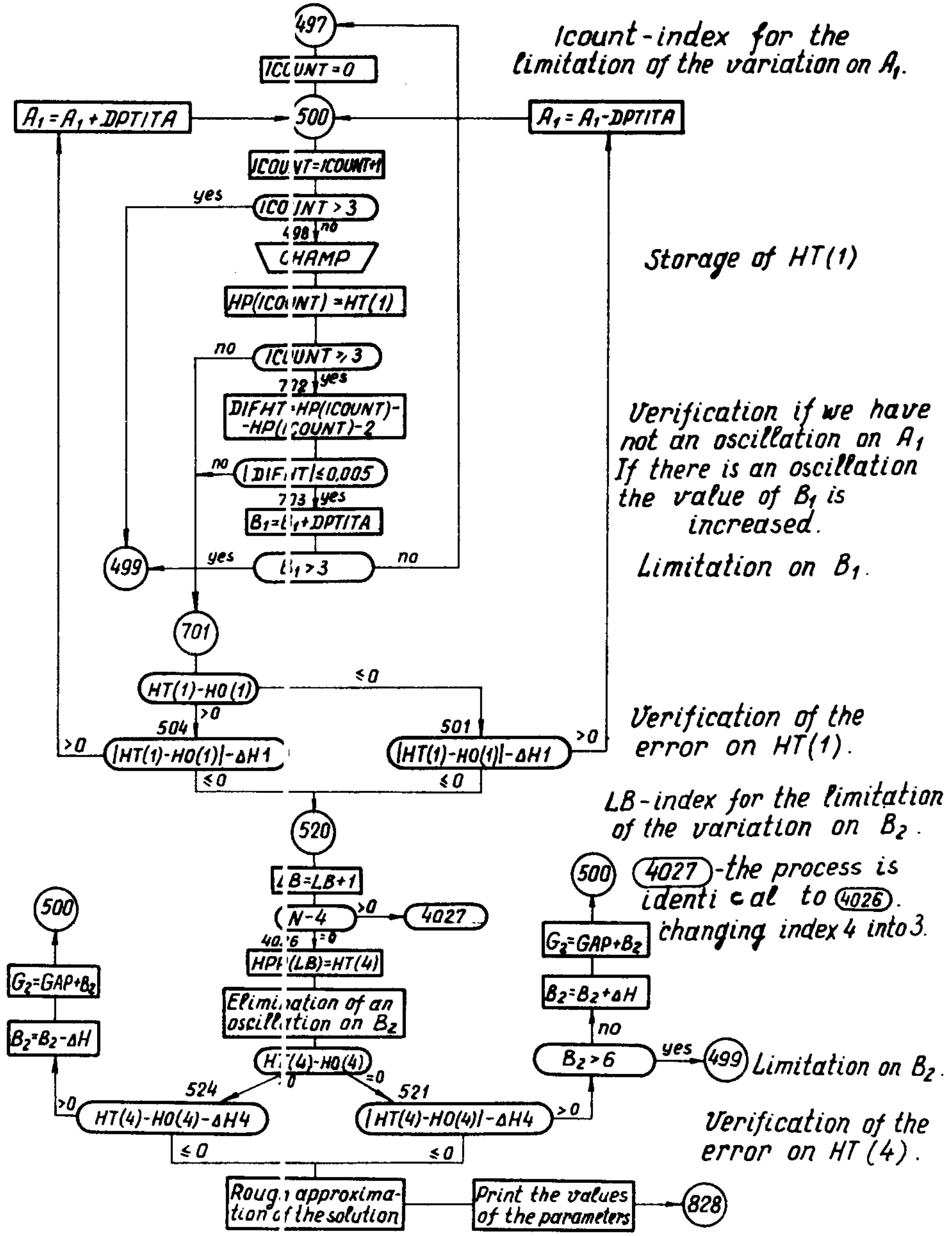
NPOINT-number of points in which we calculate the field or the gradient in the channel.

N-number of parameters which are changed during the final iteration process.

GAP=half gap between 2nd and 3rd slabs.

DIST=gap between 1st and 2nd or 3rd slabs.

$P_1=A_1$, $P_2=B_1$, $P_3=A_2$,
$P_4=B$, $P_5=R_2$, $P_6=G_2$



Icount-index for the limitation of the variation on A_1.

Storage of HT(1)

Verification if we have not an oscillation on A_1. If there is an oscillation the value of B_1 is increased.

Limitation on B_1.

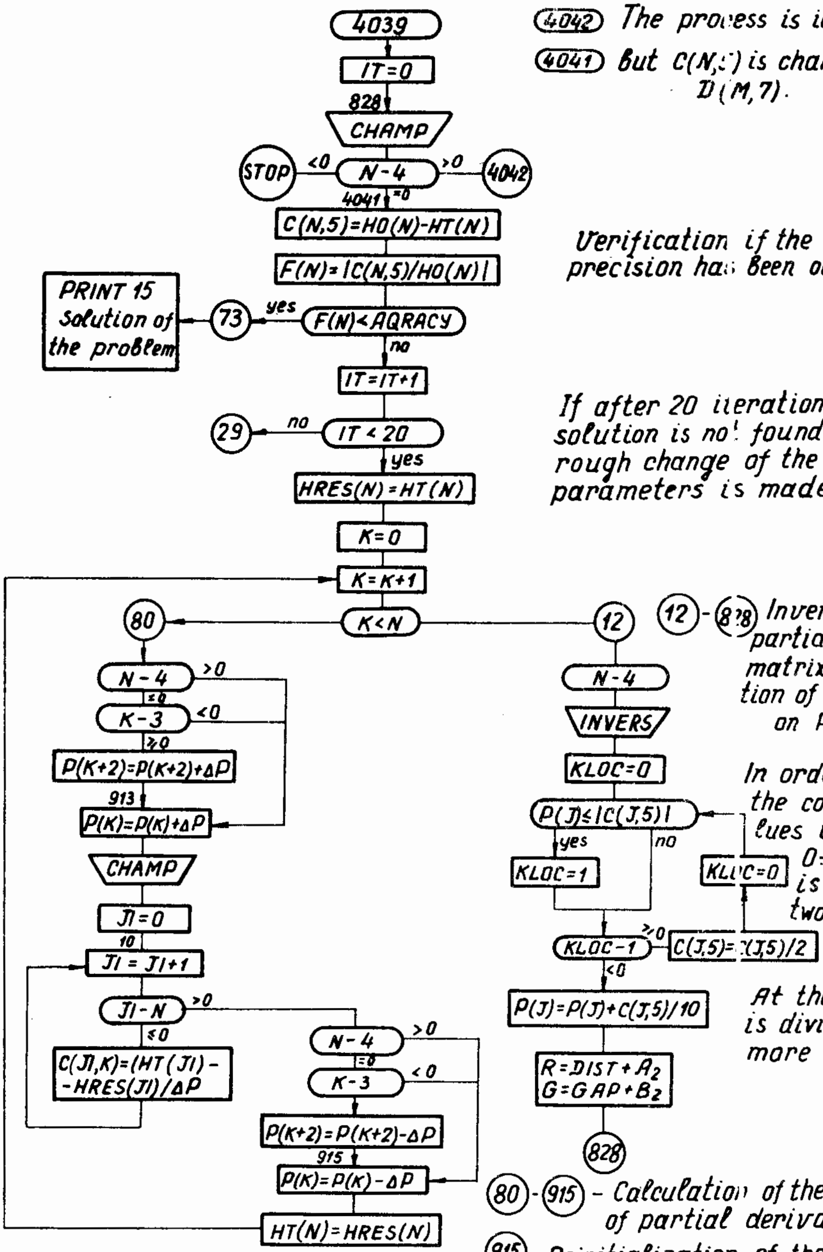
Verification of the error on HT(1).

LB-index for the limitation of the variation on B_2.

(4027)-the process is identical to (4026). changing index 4 into 3.

Limitation on B_2.

Verification of the error on HT(4).



(4042) The process is identical to
(4041) But C(N,5) is changed into D(M,7).

Verification if the imposed precision has been obtained.

If after 20 iterations a solution is not found a rough change of the parameters is made.

(12)-(828) Inversion of the partial derivates matrix and calculation of the correction on P→C(J,5).

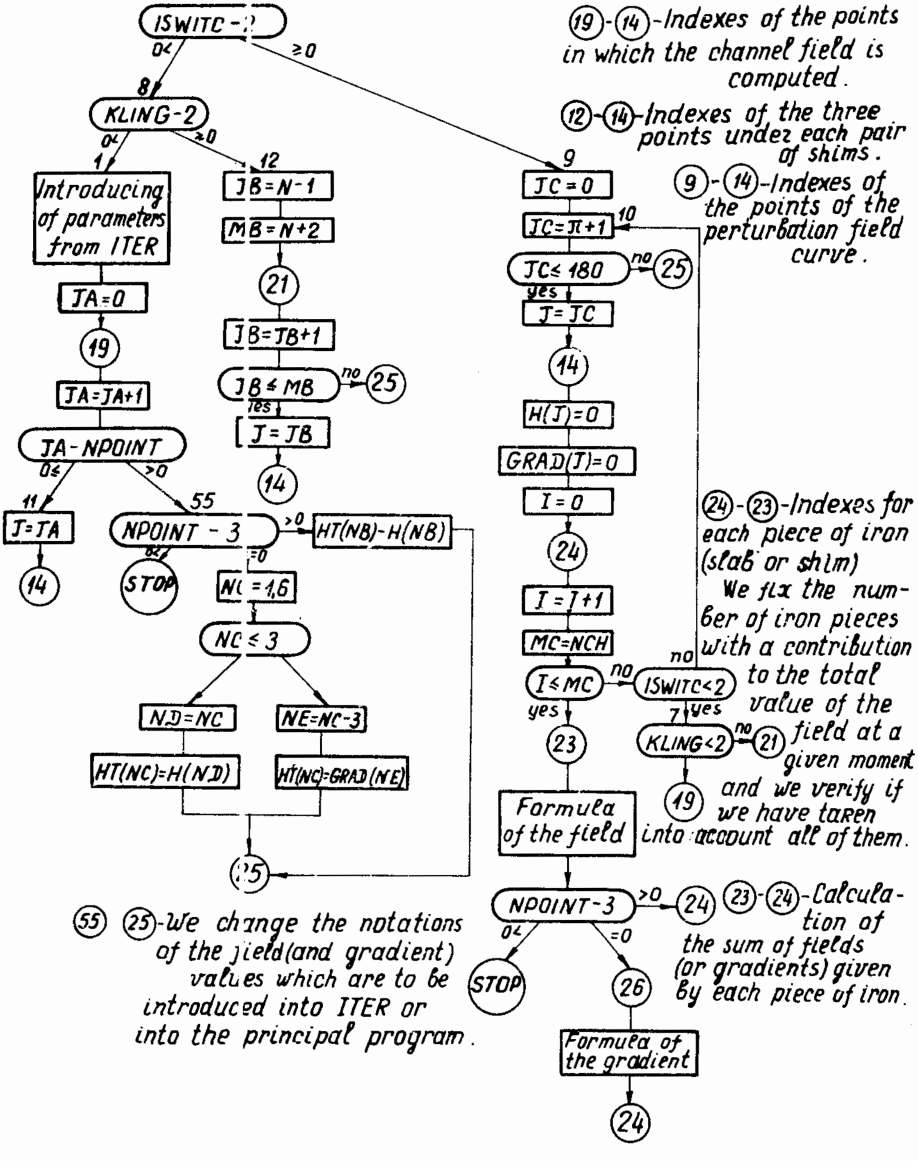
In order to obtain the correction values in the range 0÷2P C(J,5) is divided by two so often is necessary.

At the end C(J,5) is divided once more by 10.

(80)-(915) - Calculation of the table of partial derivates.

(915) - Reinitialization of the parameters.

BLOCK DIAGRAM OF THE SUBROUTINE CHAMP FOR THE PROGRAMME TRIBAR.



⑲-⑭-Indexes of the points in which the channel field is computed.

⑫-⑭-Indexes of the three points under each pair of shims.

⑨-⑭-Indexes of the points of the perturbation field curve.

㉔-㉓-Indexes for each piece of iron (slab or shim)
We fix the number of iron pieces with a contribution to the total value of the field at a given moment and we verify if we have taken into account all of them.

㉓-㉔-Calculation of the sum of fields (or gradients) given by each piece of iron.

(55) ㉕-We change the notations of the field (and gradient) values which are to be introduced into ITER or into the principal program.

```
      PROGRAM DUOHAR
      DIMENSION H (1),W(360),AA(500);GG(500),NY(100)
      COMMON/BLOCK1/H(180),Y(180),A(40),B(40),R(40),G(40)
     1N,SIG,KLING,ISWITC,NSH
      READ 100,A(1),B(1),A(2),B(2),R(1),G(1)
  100 FORMAT(6E8.4)
      R(2)=-R(1)
      G(2)=G(1)
      READ 104,H0(1)
  104 FORMAT(E8.4)
      INC=1
      IT=0
      ICOUNT=0
      KLAC=1
      ISWITC=1
      NSHIM=0
      NSH=2
      K=1
      LA=0
      HL=-5.
      DELTAY=0.5
      DELTAF=0.05
      DELTAR=0.2
      DELTAH=ABS( .02*H0(1))
      PI=3.14159265
      SIG=21000./(4.*PI)
      HS=1000.
      Y(1)=0
      DO 3 II=2,180
      Y(II)=Y(II-1)+DELTAY
    3 CONTINUE
      PRINT 171
  171 FORMAT(1H ,15X,////)
      PRINT 108
  108 FORMAT(1H , 8HINITIAL PARAMETERS,5X,///)
      PRINT 102,K,A(K),K,B(K),K,R(K);K,G(K)
      PRINT 109,H (1)
  109 FORMAT(1H , 6HAT Y(1)=0,H0(1)=E15.7,/)
      PRINT 171
      PRINT 110
  110 FORMAT(1H , 6HFINAL CONDITIONS;/)
      PRINT 111
  111 FORMAT(1H ,30HH(1)-H0(1)=LESS THAN 5 PERCENT,/)
      PRINT 112
  112 FORMAT(1H ,49HAUTOMATIC CORRECTION AT MIN DISTANCE OF THE SLAB,/)
      PRINT 113
  113 FORMAT(1H ,21HFIRST SHIM +,- 100 G.,/)
      PRINT 114
  114 FORMAT(1H , 7H2ND SHIM +,- 10G.,/)
      PRINT 115
  115 FORMAT(1H ,22H3RD SHIM -10G. TO ZERO,/)
      PRINT 116
  116 FORMAT(1H ,8X,47HALL NEXT SHIMS OF 1ST ORDER -5G. TO ZERO,/)
      PRINT 117
  117 FORMAT(1H ,8X,57HTHE 2ND ORDER SHIMS REDUCE HALF OF THE LOCAL PERT
     1URBATION,//////)
```

```
      PRINT 118
118   FORMAT(1H ,43X,34HDETERMINATION OF THE CHANNEL FIELD,/)
      JANA=1
      PRINT 150,JANA
150   FORMAT(1H ,5HJANA=I5,///)
      KLING=1
      PRINT 130,KLING
130   FORMAT(1H ,6HKLING=I5,/)
      KLANG=0
      PRINT 152,KLANG
152   FORMAT(1H ,6HKLANG=I5,/)
      KLYNG=1
      PRINT 156,KLYNG
156   FORMAT(1H ,6HKLYNG=I5,/)
5     CALL CHAMP
      IF(KLAC-1)6,6,7
6     PRINT 107,H(1)
107   FORMAT(1H ,5HH(1)=E15.7,/)
      KLAC=2
7     IF(ABS(H(1)-H0(1))-DELTAH)15,95,10
10    IF(H(1)-H0(1))13,15,14
13    A(1)=A(1)-DELTAP
      R(1)=R(1)+DELTAP
      GO TO 271
14    A(1)=A(1)+DELTAP
      R(1)=R(1)-DELTAP
271   A(2)=A(1)
      R(2)=-R(1)
      LA=LA+1
      AA(LA)=A(1)
      IF(LA-5)5,272,272
272   DIFA=A(1)-AA(LA-2)
      IF(ABS(DIFA)-0.005)273,273,5
273   DELTAP=DELTAP/2.
      IF(DELTAP-0.001)270,270,5
270   DELTAH=1.5*DELTAH
      DELTAP=0.05
      LA=0
      GO TO 5
93    KLING=2
      PRINT 171
      PRINT 172
172   FORMAT(1H ,35X,23HCORRECTION OF 1ST ORDER,///)
      PRINT 130,KLING
21    IF(ABS(W(MM)+HS)-100.)53,53,48
48    MM=MM-2
      IF(MM-2)51,51,21
51    MM=MK
      HS=HS+50.
      PRINT 103,HS
103   FORMAT(1H ,3HHS=E15.7,//)
      GO TO 21
95    IF(KLYNG-1)54,54,94
54    IF(Y(180)-RRES-20.)98,56,56
56    IF(W(MM)-W(MM-2))57,57,58
57    IF(W(MM)+10.)59,59,98
```

```
58   MM=MM-2
     GO TO 56
59   IF(NSHIM-2)53,47,47
47   K=K+2
56   NN=MM/2
     N=NN-1
     RRES=Y(NN)
     JANA=2
     K=K+2
     NSHIM=NSHIM+1
     PRINT 120,NSHIM
120  FORMAT(1H ,I2,14H PAIR OF SHIMS,///)
     NSH=2*NSHIM+2
     NY(NSHIM)=N
     PRINT 155,N,Y(N)
155  FORMAT(1H ,2HY(,I3,2H)=E15.7,//)
     PRINT 151,RRES
151  FORMAT(1H ,5HRRES=E15.7,//)
57   A(K)=0.2
     A(K+1)=A(K)
     B(K)=2.
     B(K+1)=B(K)
     R(K)=RRES
     R(K+1)=R(K)
     G(K)=5.
     G(K+1)=-G(K)
     ENTREF=R(K)+2.1
     KLAC=1
     KLIC=0
     KLYK=0
     LG=1
     DELTAP=0.05
     DELTAG=0.2
22   CALL CHAMP
     IF(KLAC-1)12,12,55
12   PRINT 102,K,A(K),K,B(K),K,R(K),K,G(K)
102  FORMAT(1H ,2HA(,I2,2H)=E12.4,4X,2HB(,I2,2H)=E12.4,
    1 4X,2HR(,I2,2H)=E12.4,4X,2HG(,I2,2H)=E12.4,/)
     NP=N+1
     NQ=N+2
     PRINT 101,N,H(N),NP,H(NP),NQ,H(NQ)
101  FORMAT(1H ,2HH(,I3,2H)=E15.7,3X,2HH(,I3,2H)=E15.7,
    1 3X,2HH(,I3,2H)=E15.7,///)
     KLAC=2
55   DO 35 NU=1,3
     NV=N+NU-1
     IF(NSHIM-5)90,27,27
90   GO TO(24,2,9,17),NSHIM
2    IF(JANA-1)24,24,25
9    IF(JANA-1)25,25,26
17   IF(JANA-1)26,26,27
24   IF(ABS(H(NV))-10.)35,35,22
25   IF(ABS(H(NV))-10.)35,35,22
26   IF(H(NV)-0.)91,91,22
91   IF(H(NV)+10.)22,22,35
27   IF(H(NV)-0.)92,92,22
```

```
92    IF(H(NV)-HL)22,22,35
35    CONTINUE
      IF(KLYNG-1)8,11,15
8     A3=A(K)
      A4=A(K+1)
      B3=B(K)
      B4=B(K+1)
      R3=R(K)
      R4=R(K+1)
      G3=G(K)
      G4=G(K+1)
      NS=NY(NSHIM)
      INC=INC+1
      NN=NN-1
      N=NN-1
      NY(NSHIM)=N
      PRINT 155,N,Y(N)
      RRES=Y(NN)
      PRINT 151,RRES
      GO TO 37
22    IF(H(NV)-0.)28,15,29
28    IF(G(K)-ENTREF)70,70,36
36    G(K)=G(K)-DELTAG
      GO TO 71
29    G(K)=G(K)+DELTAG
71    G(K+1)=-G(K)
      LG=LG+1
      GG(LG)=G(K)
      IF(LG-5)23,72,72
72    DIFG=G(K)-GG(LG-2)
      IF(ABS(DIFG)-0.005)73,73,23
73    DELTAG=DELTAG/2.
      IF(DELTAG-0.01)70,70,23
70    IF(KLIC-10)76,77,77
76    IF(H(N)-H(N+2))18,15,79
18    IF(KLYNG-1)78,78,89
78    IF(R(K)-A(K)-R(K-1)-A(K-1)*DELTAR)31,31,89
89    R(K)=R(K)-DELTAP
      GO TO 43
79    R(K)=R(K)+DELTAP
43    R(K+1)=R(K)
      KLIC=KLIC+1
      GO TO 44
77    IF(KLYK-5)19,19,31
19    IF(KLYNG-1)30,30,75
30    IF(R(K)-A(K)-R(K-1)-A(K-1)*DELTAR)31,31,75
75    A(K)=A(K)+DELTAP
      A(K+1)=A(K)
      B(K)=B(K)-DELTAP
      B(K+1)=B(K)
      G(K)=5.
      G(K+1)=-G(K)
      KLYK=KLYK+1
44    DELTAG=0.2
      GO TO 23
3     IF(INC-1)61,32,33
```

```
32  NN=NN+1
    N=NN-1
    NY(NSHIM)=N
    PRINT 155,N,Y(N)
    RRES=Y(NN)
    PRINT 151,RRES
    GO TO 37
33  A(K)=A3
    A(K+1)=A4
    B(K)=B3
    B(K+1)=B4
    R(K)=R3
    R(K+1)=R4
    G(K)=G3
    G(K+1)=G4
    N=NS
    NY(NSHIM)=N
    PRINT 161
    PRINT 133
133 FORMAT(1H ,43HWE SET UP THE SHIM IN THE PREVIOUS POSITION,///)
11  IF(KLANG-1)80,80,15
80  KLANG=1
    KLING=1
    JANA=1
    IF(IT-1)38,39,39
38  PRINT 130,KLING
    PRINT 150,JANA
    DELTAH=ABS( .05*H0(1))
39  IT=IT+1
    PRINT 153,IT
153 FORMAT(1H ,3HIT=I5,/)
86  CALL CHAMP
81  IF(ABS(H(1)-H0(1))-DELTAH)85,85,82
82  ICOUNT=ICOUNT+1
    IF(H(1)-H0( ))83,85,84
83  A(1)=A(1)-DELTAP
    R(1)=R(1)+DELTAP
    GO TO 86
84  A(1)=A(1)+DELTAP
    R(1)=R(1)-DELTAP
    GO TO 86
85  IF(ICOUNT-1)88,87,87
87  ICOUNT=0
    KLING=2
    CALL CHAMP
    NP=N+1
    NQ=N+2
    PRINT 101,N,H(N),NP,H(NP),NQ,H(NQ)
    IF(IT-10)23,32,32
88  INC=1
    KLANG=2
    PRINT 152,KLANG
    PRINT 131
131 FORMAT(1H ,37HTHE CHANNEL FIELD HAS A CORRECT VALUE ///)
    PRINT 107,H(1)
    KRES=K
```

```
      DO 303 K=1,2
      PRINT 102,K,A(K),K,B(K),K,R(K),K,G(K)
303   CONTINUE
      K=KRES
      KLING=2
      PRINT 130,KLING
      PRINT 154
154   FORMAT(1H ,22HPARAMETERS OF 1ST SHIM,//)
      GO TO 49
50    K=K-2
      JANA=1
      KLAC=1
      KLIC=0
      NCORR=NSHIM-1
      PRINT 121,NCORR
121   FORMAT(1H ,19HCORRECTION OF SHIM ,I2,///)
      N=NY(NCORR)
      GO TO 23
15    IF(KLING-2)96,49,49
96    DO 304 K=1,2
      PRINT 102,K,A(K),K,B(K),K,R(K),K,G(K)
304   CONTINUE
      K=1
      PRINT 107,H(1)
      GO TO 97
49    PRINT 102,K,A(K),K,B(K),K,R(K),K,G(K)
      NP=N+1
      NQ=N+2
      PRINT 101,N,H(N),NP,H(NP),NQ,H(NQ)
      IF(JANA-1)97,97,50
97    ISWITC=2
      CALL CHAMP
      DO 16 NJ=1,180
      M=2*NJ-1
      W(M)=Y(NJ)
      W(M+1)=H(NJ)
16    CONTINUE
      MM=M+1
      MK=MM
      IF(NSHIM-1)245,246,246
245   PRINT 171
      PRINT 173
173   FORMAT(1H ,42X,30HFIELD CURVE WITHOUT CURRECTION,//)
      PRINT 105
105   FORMAT(1H ,43X,1HY,26X,1HH,//)
      PRINT 106,(W(M),M=1,MK)
106   FORMAT(1H ,35X,E14.6,15X,E14.6,/)
246   ISWITC=1
      IF(KLING-2)93,95,95
98    PRINT 174
174   FORMAT(1H ,38X,38HFIELD CURVE AFTER 1ST ORDER CORRECTION,//)
      PRINT 105
      PRINT 106,(W(M),M=1,MK)
94    IF(KLYNG-1)62,62,63
62    PRINT 171
      PRINT 162
```

```
162 FORMAT(1H ,35X,23HCORRECTION OF 2ND ORDER,///)
    NSHIM1=NSHIM
    KRES1=K+2
    INC=0
    KL=1
    K=K+4
    KLYNG=KLYNG+1
    PRINT 156,KLYNG
    GO TO 66
63  K=K+2
66  KL=KL+1
    IF(KL-NSHIM1)67,67,60
67  N=NY(KL)
    NN=N+1
    MM=2*NN
68  IF(W(MM)-W(MM-2))40,40,69
69  MM=MM-2
    GO TO 68
40  IF(W(MM)+20.)41,41,42
41  NN=MM/2
    N=NN-1
    NSHIM=NSHIM+1
    PRINT 120,NSHIM
    NSH=2*NSHIM+2
    RRES=Y(NN)
    PRINT 151,RRES
    HL=W(MM)/2.
    IF(HL+100.)64,64,65
64  HL=-100.
65  PRINT 157,HL
157 FORMAT(1H ,3HHL=E15.7,/)
    KRES2=K
    A(K)=0.1
    A(K+1)=A(K)
    B(K)=1.
    B(K+1)=B(K)
    R(K)=RRES
    R(K+1)=R(K)
    G(K)=10.
    G(K+1)=-G(K)
    KLAC=1
    KLIC=0
    KLYC=0
    LG=0
    DELTAG=0.2
    GO TO 23
42  PRINT 160
160 FORMAT(1H ,41HIN THIS REGION NO CORRECTION IS NECESSARY,/)
    GO TO 66
61  PRINT 161
161 FORMAT(1H ,40HIN THIS REGION NO CORRECTION IS POSSIBLE,/)
    NSHIM=NSHIM-1
    GO TO 66
60  PRINT 171
    PRINT 170
170 FORMAT(1H  ,35X,28HMAGNETIC  CHANNEL PARAMETERS,///)
```

```
      DO 300 K=1,2
      PRINT 102,K A(K),K,B(K),K,R(K),K,G(K)
  300 CONTINUE
      K=1
      PRINT 171
      PRINT 172
  301 K=K+2
      PRINT 102,K,A(K),K,B(K),K,R(K),K,G(K)
      IF(K-KRES1)301,312,312
  312 PRINT 171
      PRINT 162
  313 K=K+2
      PRINT 102,K,A(K),K,B(K),K,R(K),K,G(K)
      IF(K-KRES2)313,302,302
  302 PRINT 175
  175 FORMAT(1H ,38X,38HFIELD CURVE AFTER 2ND ORDER CORRE TION,//)
      PRINT 105
      PRINT 106,(H(M),M=1,MK)
   99 STOP
      END
```

```
      SUBROUTINE CHAMP
      COMMON/BLOCK1/H(180),Y(180),A(40),B(40),R(40),G(40),
     1N,SIG,KLING,ISWITC,NSH
      IF(ISWITC-2)8,9,9
    8 IF(KLING-2)1,12,12
    1 J=1
      GO TO 14
   12 JB=N-1
      MB=N+2
   21 JB=JB+1
      IF(JB-MB)13,13,25
   13 J=JB
      GO TO 14
    9 JC=0
   10 JC=JC+1
      IF(JC-180)2,2,25
    2 J=JC
   14 H(J)=0
      I=0
   24 I=I+1
      MC=NSH
      IF(I-MC)23,23,20
   20 IF(ISWITC-2)7,10,10
    7 IF(KLING-2)25,21,21
   23 H(J)=H(J)+2.*SIG*(
     1-ATAN((Y(J)-R(I)-A(I))/(G(I)*B(I)))
     2+ATAN((Y(J)-R(I)+A(I))/(G(I)*B(I)))
     3+ATAN((Y(J)-R(I)-A(I))/(G(I)+B(I)))
     4-ATAN((Y(J)-R(I)+A(I))/(G(I)+B(I))))
      GO TO 24
   25 RETURN
      END
```

```
      PROGRAM TRIBAR
      DIMENSION DELTAH(6),YY(4),W(360),GG(500),NY(100)
      COMMON/BLOCK1/H(180),Y(180),A(60),B(60),R(60),G(60)
     1N,SIG,KLING,ISWITC,NSH
      COMMON/BLOCK2/H0(6)
       COMMON/BLOCK3/X(4)
      COMMON/BLOCK4/HT(6),F(6),NPOINT
5000  PRINT 3997
3997  FORMAT(1H ,15X,//////////)
      READ 3998,NPOINT
3998  FORMAT(I5)
      PRINT 3999,NPOINT
3999  FORMAT(1H ,40X,31HMAGNETIC CHANNEL CALCULATION IN ,I3,2x,6HPOINTS,/
     1////)
      IF(NPOINT-3)4000,4001,4002
4000  STOP
4001  NPAR=6
      PRINT 4003,NPAR
4003  FORMAT(1H ,24X,15HCALCULATION OF ,I3,2X,52HGEOMETRICAL PARAMETERS
     1OF A THREE.SLAB CONFIGURATION,/////)
      READ 3996,(H0(IC),IC=1,6)
3996  FORMAT(6E8.4)
      READ 3996,(X(MA),MA=1,3)
      PRINT 4004
4004  FORMAT(1H ,44X,32HFINAL CONDITIONS IN THREE POINTS,///)
      PRINT 4005
4005  FORMAT(1H ,8X,6X,16X,7HPOINT 1,16X,7HPOINT 2,16X,7HPOINT 3,//)
      PRINT 4006,(X(IF),IF=1,3)
4006  FORMAT(1H ,8X,6HRADIUS,13X,E13.5,10X,E13.5,10X,E13.5,/)
      PRINT 4007,(H0(JA),JA=1,3)
4007  FORMAT(1H ,9X,5HFIELD,13X,E13.5,10X,E13.5,10X,E13.5 /)
      PRINT 4008,(H0(JB),JB=4,6)
4008  FORMAT(1H ,6X,8HGRADIENT,13X,E13.5,10X,E13.5,10X,E13.5,///)
      GO TO 4020
4002  NPAR=4
      PRINT 4003,NPAR
      READ 3996,(H0(IIC),IIC=1,4)
      READ 3996,(X(MMA),MMA=1,4)
      PRINT 4009
4009  FORMAT(1H ,44X,31HFINAL CONDITIONS IN FOUR POINTS,///)
      PRINT 4010
4010  FORMAT(1H ,8X,6X,16X,7HPOINT 1,16X,7HPOINT 2,16X,7HPOINT 3,16X,7HP
     1OINT 4,//)
      PRINT 4011,(X(IAA),IAA=1,4)
4011  FORMAT(1H ,8X,6HRADIUS,13X,E13.5,10x,E13.5,10X,E13.5,10X,E13.5,/)
      PRINT 4012,(H0(IAB),IAB=1,4)
4012  FORMAT(1H ,9X,5HFIELD,13X,E13.5,10X,E13.5,10X,E13.5,10X,E13.5,///)
4020  PRINT 112
 112  FORMAT(1H ,8X,48HAUTOMATIC CORRECTION AT MIN DISTANCE OF THE SLAB,
     1/)
      PRINT 113
 113  FORMAT(1H ,8X,21HFIRST SHIM +.- 100 G.,/)
      PRINT 114
 114  FORMAT(1H ,8X,17H2ND SHIM +.- 25G.,/)
      PRINT 115
 115  FORMAT(1H ,8X,22H3RD SHIM -10G TO ZERO,/)
```

```
      PRINT 116
  116 FORMAT(1H ,8X,41HALL NEXT SHIMS OF 1ST ORDER =5G. TO ZERO,/)
      PRINT 117
  117 FORMAT(1H ,8X,59HTHE 2ND ORDER SHIMS REDUCE HALF OF THE LOCAL PERT
     1URBATION,//////
      INC=0
      IT=0
      ICOUNT=0
      ISWITC=1
      K=2
      NSH=3
      NSHIM=0
      HL=-5.
      DELTAY=0.5
      DELTAR=0.2
      PI=3.14159265
      SIG=21000./(4.*PI)
      DO 86 NC=1,NPAR
      DELTAH(NO)=ABS(0.1*H0(NO))
   86 CONTINUE
      Y(1)=0
      DO 3 II=2,180
      Y(II)=Y(II-1)+DELTAY
    3 CONTINUE
      PRINT 118
  118 FORMAT(1H ,43X,34HDETERMINATION OF THE CHANNEL FIELD,/)
      KLING=1
      PRINT 130,KLING
  130 FORMAT(1H ,6HKLING=I5,/)
      JANA=1
      PRINT 150,JANA
  150 FORMAT(1H ,5HJANA=I5,///)
      KLYNG=1
      PRINT 156,KLYNG
  156 FORMAT(1H ,6HKLYNG=I5,/)
      DO 21 NA=1,NPOINT
      YY(NA)=Y(NA)
   21 CONTINUE
      CALL ITER
      DO 225 NE=1,NPOINT
      Y(NE)=YY(NE)
  225 CONTINUE
      GO TO 15
   98 KLING=2
      PRINT 171
  171 FORMAT(1H , 5X,////)
      PRINT 172
  172 FORMAT(1H ,35X,23HCORRECTION OF 1ST ORDER,///)
      PRINT 130,KLING
   33 IF(W(MM)-0.)34,48,48
   34 MM=MM-2
      GO TO 33
   48 NM=MM/2
      NN=NM+3
      GO TO 51
   54 IF(Y(180)-RRES-20.)98,56,56
```

```
56   IF(W(MM)-W(MM-2))57,57,58
57   IF(W(MM)+10.)59,59,98
58   MM=MM-2
     GO TO 56
59   IF(NSHIM-2)53,47,47
47   K=K+2
53   NN=MM/2
5    N=NN-1
     RRES=Y(NN)
     JANA=2
     K=K+2
     NSHIM=NSHIM+1
     PRINT 120,NSHIM
120  FORMAT(1H ,I2,14H PAIR OF SHIMS,///)
     NSH=2*NSHIM+3
     NY(NSHIM)=N
     PRINT 155,N,Y(N)
155  FORMAT(1H ,2HY(,I3,2H)=E15.7,//)
     PRINT 151,RRES
151  FORMAT(1H ,5HRRES=E15.7,//)
37   A(K)=0.2
     A(K+1)=A(K)
     B(K)=1.
     B(K+1)=B(K)
     R(K)=RRES
     R(K+1)=R(K)
     G(K)=5.
     G(K+1)=-G(K)
     ENTREF=R(K)+2.1
     KLAC=1
     KLIC=0
     KLYK=0
     LG=0
     DELTAP=0.05
     DELTAG=0.2
23   CALL CHAMP
     IF(KLAC-1)12,12,55
12   PRINT 102,K,A(K),K,B(K),K,R(K),K,G(K)
102  FORMAT(1H ,2HA(,I2,2H)=E12.4,4X,2HB(,I2,2H)=E12.4,
    1 4X,2HR(,I2,2H)=E12.4,4X,2HG(,I2,2H)=E12.4,/)
     NP=N+1
     NQ=N+2
     PRINT 101,N,H(N),NP,H(NP),NQ,H(NQ)
101  FORMAT(1H ,2HH(,I3,2H)=E15.7,3X,2HH(,I3,2H)=E15.7,
    1 3X,2HH(,I3,2H)=E15.7,///)
     KLAC=2
55   DO 35 NU=1,3
     NV=N+NU-1
     IF(NSHIM-5)90,27,27
90   GO TO(24,2,9,17),NSHIM
2    IF(JANA-1)24,24,25
9    IF(JANA-1)25,25,26
17   IF(JANA-1)26,26,27
24   IF(ABS(H(NV))-100.)35,35,22
25   IF(ABS(H(NV))-25.)35,35,22
26   IF(H(NV)-0.)91,91,22
```

```
91    IF(H(NV)+10.)22,22,35
27    IF(H(NV)-0.)92,92,22
92    IF(H(NV)-HL)22,22,35
35    CONTINUE
      IF(NSHIM-1)11,11,15
11    PRINT 102,K,A(K),K,B(K),K,R(K),K,G(K)
      NP=N+1
      NQ=N+2
      PRINT 101,N,H(N),NP,H(NP),NQ,H(NQ)
      GO TO 80
22    IF(H(NV)-0.)28,15,29
28    IF(C(K)-ENTREF)70,70,36
36    G(K)=G(K)-DELTAG
      GO TO 71
29    G(K)=G(K)+DELTAG
71    G(K+1)=-G(K)
      LG=LG+1
      GG(LG)=G(K)
      IF(LG-5)23,72,72
72    DIFG=G(K)-GG(LG-2)
      IF(ABS(DIFG)-0.005)73,73,23
73    DELTAG=DELTAG/2.
      IF(DELTAG-0.01)70,70,23
70    IF(KLIC-10)76,77,77
76    IF(H(N)-H(N+2))18,15,79
18    IF(KLYNG-1)78,78,89
78    IF(R(K)-A(K)-R(K-1)-A(K-1)-DELTAR)31,31,89
89    R(K)=R(K)-DELTAP
      GO TO 43
79    R(K)=R(K)+DELTAP
43    R(K+1)=R(K)
      KLIC=KLIC+1
      GO TO 44
77    IF(KLYK-10)19,19,31
19    IF(KLYNG-1)30,30,75
30    IF(R(K)-A(K)-R(K-1)-A(K-1)-DELTAR)31,31,75
75    A(K)=A(K)+DELTAP
      A(K+1)=A(K)
      G(K)=5.
      G(K+1)=-G(K)
      KLYK=KLYK+1
44    DELTAG=0.2
      GO TO 23
31    IF(KLYNG-1)32,32,61
32    NN=NN+1
      N=NN-1
      NY(NSHIM)=N
      PRINT 155,N,Y(N)
      RRES=Y(NN)
      PRINT 151,RRES
      INC=INC+1
      GO TO 37
80    KLING=1
      JAN =1
      IF( T-1)38,39,39
38    PRINT 130,KLING
```

```
      PRINT 150,JANA
39    IT=IT+1
      PRINT 153,IT
153   FORMAT(1H ,3HIT=I5,/)
      DO 81 NF=1,NPOINT
      YY(NF)=Y(NF)
81    CONTINUE
      PRINT 122
122   FORMAT(1H ,10HCALL CHAMP,/)
      CALL CHAMP
      IF(NPOINT-3)99,232,231
231   PRINT 4010
      PRINT 4012,(HT(JP),JP=1,4)
      GO TO 233
232   PRINT 4005
      PRINT 4007,(HT(JR),JR=1,3)
      PRINT 4008,(HT(JS),JS=4,6)
233   DO 83 NH=1,NPAR
      IF(ABS(HT(NH)-H0(NH))-DELTAH(NH))83,83,84
83    CONTINUE
      GO TO 85
84    IF(NSHIM-2)202,203,203
202   ICOUNT=ICOUNT+1
      PRINT 123,ICOUNT
123   FORMAT(1H ,7HICOUNT=I5,/)
203   PRINT 124
124   FORMAT(1H ,9HCALL ITER,/)
      CALL ITER
      DO 82 NG=1,NPOINT
      Y(NG)=YY(NG)
82    CONTINUE
85    IF(NSHIM-2)204,88,88
204   IF(ICOUNT-1)88,87,87
87    ICOUNT=0
      KLING=2
      CALL CHAMP
      NP=N+1
      NQ=N+2
      PRINT 101,N,H(N),NP,H(NP),NQ,H(NQ)
      IF(IT-10)23,32,32
88    PRINT 131
131   FORMAT(1H ,37HTHE CHANNEL FIELD HAS A CORRECT VALUE ///)
      KRES=K
      DO 303 K=1,2
      PRINT 102,K,A(K),K,B(K),K,R(K),K,G(K)
303   CONTINUE
      K=KRES
      IF(NPOINT-3)99,228,229
229   PRINT 4010
      PRINT 4012,(HT(JF),JF=1,4)
      GO TO 230
228   PRINT 4005
      PRINT 4007,(HT(JG),JG=1,3)
      PRINT 4008,(HT(JH),JH=4,6)
230   KLING=2
      PRINT 130,KLING
```

```
      IF(NSHIM-2)206,97,97
206   PRINT 154
154   FORMAT(1H ,22HPARAMETERS OF 1ST SHIM,//)
      GO TO 49
50    K=K-2
      JANA=1
      KLAC=1
      KLIC=0
      NCORR=NSHIM-1
      PRINT 121,NCORR
121   FORMAT(1H ,19HCORRECTION OF SHIM ,I2,///)
      N=NY(NCORR)
      GO TO 23
15    IF(KLING-2)96,49,49
96    DO 304 K=1,2
      PRINT 102,K,A(K),K,B(K),K,R(K)$K,G(K)
304   CONTINUE
      K=2
      IF(NPOINT-3)99,226,227
227   PRINT 4010
      PRINT 4012,(HT(JC),JC=1,4)
      GO TO 97
226   PRINT 4005
      PRINT 4007,(HT(JD),JD=1,3)
      PRINT 4008,(HT(JE),JE=4,6)
      GO TO 97
49    PRINT 102,K,A(K),K,B(K),K,R(K)$K,G(K)
      NP=N+1
      NQ=N+2
      PRINT 101,N,H(N),NP,H(NP),NQ,H(NQ)
      IF(JANA-1)207,207,50
207   IF(NSHIM-2)97,208,208
208   IF(NSHIM-8)80,8,8
8     IF(KLYNG-1)97,97,52
52    IF(NSHIM-NSHIM1-7)80,97,97
97    ISWITC=2
      CALL CHAMP
      DO 16 NJ=1,180
      M=2*NJ-1
      W(M)=Y(NJ)
      W(M+1)=H(NJ)
16    CONTINUE
      MM=M+1
      MK=MM
      IF(NSHIM-1)245,246,246
245   PRINT 101
      PRINT 103
103   FORMAT(1H ,42X,30HFIELD CURVE WITHOUT CORRECTION,//)
      PRINT 105
105   FORMAT(1H ,43X,1HY,26X,1HH,//)
      PRINT 106,(W(M),M=1,MK)
106   FORMAT(1H ,35X,E14.6,15X,E14.6/)
246   ISWITC=[illegible]
      IF(KLING-2)93,95,95
95    IF(KLYNG-1)54,54,94
93    PRINT 104
```

```
174 FORMAT(1H ,38X,38HFIELD CURVE AFTER 1ST ORDER CORRECTION,//)
    PRINT 195
    PRINT 196,(W(M),M=1,MK)
94  IF(KLYNG-1)62,62,63
62  PRINT 171
    PRINT 162
162 FORMAT(1H ,35X,23HCORRECTION OF 2ND ORDER,///)
    NSHIM1=NSHIM
    KRES1=K+2
    KL=1
    K=K+4
    KLYNG=KLYNG+1
    PRINT 156,KLYNG
    GO TO 66
63  K=K+2
66  KL=KL+1
    IF(KL-NSHIM1)67,67,60
67  N=NY(KL)
    NN=N+1
    MM=2*NN
68  IF(W(MM)-W(MM-2))40,42,69
69  MM=MM-2
    GO TO 68
40  IF(W(MM)+20.)41,41,42
41  NN=MM/2
    N=NN-1
    NSHIM=NSHIM+1
    PRINT 120,NSHIM
    NSH=2*NSHIM+3
    RRES=Y(NN)
    PRINT 151,RRES
    HL=W(MM)/2.
    IF(HL+100.)64,64,65
64  HL=-100.
65  PRINT 157,HL
157 FORMAT(1H ,3HHL=E15.7,/)
    KRES2=K
    A(K)=0.1
    A(K+1)=A(K)
    B(K)=1.
    B(K+1)=B(K)
    R(K)=RRES
    R(K+1)=R(K)
    G(K)=10.
    G(K+1)=-G(K)
    KLAC=1
    KLIC=0
    KLYC=0
    LG=
    DELTAG=0.2
    GO TO 23
42  PRINT 160
160 FORMAT(1H ,41HIN THIS REGION NO CORRECTION IS NECESSARY,/)
    GO TO 66
61  PRINT 161
161 FORMAT(1H ,40HIN THIS REGION NO CORRECTION IS POSSIBLE,/)
```

```
      NSHIM=NSHIM-1
      GO TO 66
60    PRINT 171
      PRINT 170
170   FORMAT(1H  ,35X,28HMAGNETIC  CHANNEL PARAMETERS,///)
      DO 300 K=1,2
      PRINT 102,K,A(K),K,B(K),K,R(K);K,G(K)
300   CONTINUE
      K=2
      PRINT 171
      PRINT 172
301   K=K+2
      PRINT 102,K,A(K),K,B(K),K,R(K);K,G(K)
      IF(K-KRES1)301,312,312
312   PRINT 171
      PRINT 162
313   K=K+2
      PRINT 102,K,A(K),K,B(K),K,R(K);K,G(K)
      IF(K-KRES2)313,302,302
302   PRINT 171
      PRINT 175
175   FORMAT(1H ,38X,38HFIELD CURVE AFTER 2ND ORDER CORRECTION,//)
      PRINT 105
      PRINT 106,(H(M),M=1,MK)
99    STOP
      END


       SUBROUTINE CHAMP
       DIMENSION GRAI(180)
       COMMON/BLOCK1/H(180),Y(180),A(60),B(60),R(60),G(60)
      1N,SIG,KLING,ISWITC,NSH
        COMMON/BLOCK3/X(4)
       COMMON/BLOCK4/HT(6),P(6),NPOINT
       IF(ISWITC-2)8,9,9
 8     IF(KLING-2)1,12,12
 1     A(1)=P(1)
       B(1)=P(2)
       A(2)=P(3)
       A(3)=A(2)
       B(2)=P(4)
       B(3)=B(2)
       R(1)=-A(1)
       R(2)=P(5)
       R(3)=R(2)
       G(1)=0
       G(2)=P(6)
       G(3)=-G(2)
       DO 52 NA=1,NPOINT
       Y(NA)=X(NA)
 52    CONTINUE
       JA=0
 10    JA=JA+1
       IF(JA-NPOINT)11,11,55
```

```
11    J=JA
      GO TO 14
12    JB=N-1
      MB=N+2
21    JB=JB+1
      IF(JB-MB)13,13,25
13    J=JB
      GO TO 14
9     JC=0
10    JC=JC+1
      IF(JC-180)2,2,25
2     J=JC
14    H(J)=0
      GRAD(J)=0
      I=0
24    I=I+1
      MC=NSH
      IF(I-MC)23,23,25
20    IF(ISWITC-2)7,12,10
7     IF(KLING-2)19,21,21
23    H(J)=H(J)+2.*SIG*(
     1-ATAN((Y(J)-R(I)-A(I))/(G(I)*H(I)))
     2+ATAN((Y(J)-R(I)+A(I))/(G(I)*H(I)))
     3+ATAN((Y(J)-R(I)-A(I))/(G(I)*H(I)))
     4-ATAN((Y(J)-R(I)+A(I))/(G(I)*H(I))))
      IF(NPCINT-3)57,26,24
26    GRAD(J)=GRAD(J)+2.*SIG*(
     1-(G(I)-B(I))/((Y(J)-R(I)-A(I))**2+(G(I)-B(I))**2)
     2+(G(I)-B(I))/((Y(J)-R(I)+A(I))**2+(G(I)-B(I))**2)
     3+(G(I)+B(I))/((Y(J)-R(I)-A(I))**2+(G(I)+B(I))**2)

     4-(G(I)+B(I))/((Y(J)-R(I)+A(I))**2+(G(I)+B(I))**2))
      GO TO 24
55    IF(NPCINT-3)57,59,58
57    STOP
58    DO 56 NB=1,4
      HT(NB)=H(NB)
56    CONTINUE
      GO TO 25
59    DO 60 NC=1,6
      IF(NC-3)61,61,62
61    ND=NC
      HT(NC)=H(ND)
      GO TO 60
62    NE=NC-3
      HT(NC)=GRAD(NE)
60    CONTINUE
25    RETURN
      END
```

```
      SUBROUTINE ITER
      DIMENSION HP(40),HPP(200),HRES(6),C(4,5),INDEX(4),F(6),D(6,7),
     1INDE(6)
      COMMON/BLOCK2/HO(6)
       COMMON/BLOCK3/X(4)
      COMMON/BLOCK4/HT(6),P(6),NPOINT
      AQRACY=0.1
      DLTAH1=ABS(0.05*HO(1))
      DLTAH3=ABS(0.2*HO(3))
      DLTAH4=ABS(0.2*HO(4))
      DELTAP=0.00
      DH=0.02
      DPTITA=0.02
      DGRANA=0.02
      HEIGHT=2.
      IF(NPOINT-3)4040,17,18
 17   N=6
      GO TO 423
 18   N=4
 423  HEIGHT=HEIGHT+0.2
      IF(HEIGHT-3.)424,424,425
 425  PRINT 180
 180  FORMAT(1H ,39HTHE PARAMETERS HAVE EXCEEDED THE LIMITS,/)
      PRINT 2,(P(JA),JA=1,6)
 2    FORMAT(1H ,5HA(1)=E13.5,2X,5HB(1)=E13.5,2X,5HA(2)=E13.5,
     12X,5HB(2)=E13.5,2X,5HR(2)=E13.5,2X,5HG(2)=E13.5,//)
      IF(N-4)20,227,226
 227  PRINT 4012,(HT(JD),JD=1,4)
4012  FORMAT(1H ,9X,5HFIELD,13X,E13.5,10X,E13.5,10X,E13.5 10X,E13,5,///)
      GO TO 20
 226  PRINT 4007,(HT(J)),JD=1,3)
4007  FORMAT(1H ,9X,5HFIELD,13X,E13.5,10X,E13.5,10X,E13.5 /)
      PRINT 4008,(HT(JE),JE=4,6)
4008  FORMAT(1H ,6X,8HGRADIENT,13X,E13.5,10X,E13.5,10X,E13,5,///)
 20   STOP
424   GAP=2.
421   GAP=GAP+0.5
      IF(GAP-3.)422,422,423
422   DIST=0.6
29    DIST=DIST+0.2
      IF(DIST-1.)420,420,421
420   P(1)=0.8
      P(2)=HEIGHT
      P(3)=0.4
      P(4)=3.
      P(5)=DIST+P(3)
      P(6)=GAP+P(4)
499   P(3)=P(3)+DGRANA
      P(5)=DIST+P(3)
      LB=0
      IF(P(3)-2.)497,497,29
497   ICOUNT=0
500   ICOUNT=ICOUNT+1
      IF(ICOUNT-3 )498,498,499
498   CALL CHAMP
      HP(ICOUNT)=HT(1)
```

```
      IF(ICOUNT-3)701,702,702
 702  DIFHT=HP(ICOUNT)-HP(ICOUNT-2)
      IF(ABS(DIFHT)-0.005)703,703,701
 703  P(2)=P(2)+DPTITA
      IF(P(2)-3.)497,497,499
701   IF(HT(1)-H0(1))501,501,504
501   IF(ABS(HT(1)-H0(1))-DLTAH1)520,520,503
503   P(1)=P(1)-DPTITA
      GO TO 500
504   IF(ABS(HT(1)-H0(1))-DLTAH1)505,505,506
505   GO TO 520
506   P(1)=P(1)+DPTITA
      GO TO 500
 520  LB=LB+1
      IF(N-4)4025,4026,4027
4025   STOP
4026  HPP(LB)=HT(4)
      IF(LB-3)704,705,705
 705  DIFHT4=HPP(LB)-HPP(LB-2)
      IF(ABS(DIFHT4)-0.005)499,499,704
 704  IF(HT(4)-H0(4))521,521,524
521   IF(ABS(HT(4)-H0(4))-DLTAH4)530,530,523
 523  IF(P(4)-6.)708,708,499
 708  P(4)=P(4)+DH
      P(6)=GAP+P(4)
      GO TO 500
524   IF(ABS(HT(4)-H0(4))-DLTAH4)530,530,526
526   P(4)=P(4)-DH
      P(6)=GAP+P(4)
      GO TO 500
4027  HPP(LB)=HT(3)
      IF(LB-3)706,707,707
 707  DIFHT3=HPP(LB)-HPP(LB-2)
      IF(ABS(DIFHT3)-0.005)499,499,706
 706  IF(HT(3)-H0(3))4028,4028,4029
4028  IF(ABS(HT(3)-H0(3))-DLTAH3)530,530,523
4029  IF(ABS(HT(3)-H0(3))-DLTAH3)530,530,526
530   PRINT 4034
4034  FORMAT(1H ,43X,35HROUGH APPROXIMATION OF THE SOLUTION,//)
      IF(N-4)4035,4036,4037
4035  STOP
4036  PRINT 2,(P(JO),JO=1,6)
      PRINT 4038
4038  FORMAT(1H ,10X,//)
      PRINT 4010
4010  FORMAT(1H ,8X,6X,16X,7HPOINT 1,16X,7HPOINT 2,16X,7HPOINT 3,16X,7HP
     1OINT 4,//)
      PRINT 4012,(HT(JP),JP=1,4)
      GO TO 4039
4037  PRINT 2,(P(JQ),JQ=1,6)
      PRINT 4038
      PRINT 4005
4005  FORMAT(1H ,8X,6X,16X,7HPOINT 1,16X,7HPOINT 2,16X,7HPOINT 3,//)
      PRINT 4007,(HT(JR),JR=1,3)
      PRINT 4008,(HT(JS),JS=4,6)
4039  IT=0
```

```
 828 CALL CHAMP
     IF(N-4)4040,4041,4042
4040 STOP
4041 DO 4043 JP4=1,4
     C(JP4,5)=H0(JP4)-HT(JP4)
     F(JP4)=ABS(C(JP4,5)/H0(JP4))
4043 CONTINUE
     DO 4044 JY4=1,4
     IF(F(JY4)-AQRACY)4044,4044,60
4044 CONTINUE
     GO TO 73
4042 DO 4053 JP6=1,6
     D(JP6,7)=H0(JP6)-HT(JP6)
     F(JP6)=ABS(D(JP6,7)/H0(JP6))
4053 CONTINUE
     DO 4054 JY6=1,6
     IF(F(JY6)-AQRACY)4054,4054,60
4054 CONTINUE
     GO TO 73
60   IT=IT+1
     IF(IT-20)458,458,29
 458 DO 8 IG=1,N
     HRES(IG)=HT(IG)
8    CONTINUE
     K=0
9    K=K+1
     IF(K-N)80,80,12
 80  IF(N-4)4040,910,913
 910 IF(K-3)913,914,914
 914 P(K+2)=P(K+2)+DELTAP
 913 P(K)=P(K)+DELTAP
     CALL CHAMP
     JI=0
10   JI=JI+1
     IF(JI-N)83,83,11
 83  IF(N-4)4040,81,82
81   C(JI,K)=(HT(JI)-HRES(JI))/DELTAP
     GO TO 10
 82  D(JI,K)=(HT(JI)-HRES(JI))/DELTAP
     GO TO 10
 11  IF(N-4)4040,911,915
 911 IF(K-3)915,916,916
 916 P(K+2)=P(K+2)-DELTAP
 915 P(K)=P(K)-DELTAP
     DO 16 JO=1,N
     HT(JO)=HRES(JO)
16   CONTINUE
     GO TO 9
 12  IF(N-4)4040,4045,4055
4045 CALL INVERS(C,4,4,5,1,INDEX,NERROR,DETERM)
     KLOC=0
4046 DO 4047 JM4=1,N
     CORECT=C(JM4,5)
     IF(F(JM4)-ABS(CORECT))4048,4048,4047
4048 KLOC=1
4047 CONTINUE
```

```
      IF(KLOC-1)4049,4050,4050
4050  DO 4051 JZ4=1,N
      C(JZ4,5)=C(JZ4,5)/2.
4051  CONTINUE
      KLOC=0
      GO TO 4046
4049  DO 4052 JU4=1,N
      P(JU4)=P(JU4)+C(JU4,5)/10.
4052  CONTINUE
      P(5)=DIST+P(3)
      P(6)=GAP+P(4)
      GO TO 828
4055  CALL INVERS(D,6,6,7,1,INDE,NERRO,DETER)
      KLOC=0
4056  DO 4057 JM6=1,N
      CORR=D(JM6,7)
      IF(P(JM6)-ABS(CORR))4058,4058,4057
4058  KLOC=1
4057  CONTINUE
      IF(KLOC-1)4059,4060,4060
4060  DO 4061 JZ6=1,N
      D(JZ6,7)=D(JZ6,7)/2.
4061  CONTINUE
      KLOC=0
      GO TO 4056
4059  DO 4062 JU6=1,N
      P(JU6)=P(JU6)+D(JU6,7)/10.
4062  CONTINUE
      GO TO 828
73    PRINT 15
15    FORMAT(1H ,45X,23HSOLUTION OF THE PROBLEM,///)
      PERCEN=100.*AQRACY
      PRINT 4070,PERCEN
4070  FORMAT(1H ,48X,10HACCURACY =F6.2,1X,8HPER CENT,///)
      RETURN
      END
```

```
      SUBROUTINE INVERS (A,DIM1,N1,DIM2,N2,INDEX,NERROR,DETERM)
C
C     MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS.
      TYPE INTEGER DIM1,DIM2,DIM,EMAT,PIVCOL,PIVCOL1,PIVCOL2
      DIMENSION A(DIM1),INDEX(DIM1)
      DATA(LGUNIT=2)
      DETER=1.0
      N=N1
      EMAT=N+N2
      DIM=DIM1
      NMIN1=N-1
C     THE ROUTINE DOES ITS OWN EVALUATION FOR DOUBLE SUBSCRIPTING OF
C     ARRAY A.
      PIVCOL=1-DIM
C     MAIN LOOP TO INVERT THE MATRIX
      DO 11 MAIN=1,N
      PIVOT=0.0
      PIVCOL=PIVCOL+DIM
C     SEARCH FOR NEXT PIVOT IN COLUMN MAIN.
      PIVCOL1=PIVCOL+MAIN-1
      PIVCOL2=PIVCOL +NMIN1
      DO 2 I=PIVCOL1,PIVCOL2
      IF(ABS(A(I))-ABS(PIVOT)) 2,2,1
    1 PIVOT=A(I)
      LPIV=I
    2 CONTINUE
C     IS PIVOT DIFFERENT FROM ZERO
      IF(PIVOT) 3,15,3
C     GET THE PIVOT-LINE INDICATOR AND SWAP LINES IF NECESSARY
    3 ICOL=LPIV-PIVCOL+1
      INDEX(MAIN)=ICOL
      IF(ICOL-MAIN) 6,6,4
C     COMPLEMENT THE DETERMINANT
    4 DETER=-DETER
C     POINTER TO LINE PIVOT FOUND
      ICOL=ICOL-DIM
C     POINTER TO EXACT PIVOT LINE
      I3=MAIN-DIM
      DO 5 I=1,EMAT
      ICOL=ICOL+DIM
      I3=I3+DIM
      SWAP=A(I3)
      A(I3)=A(ICOL)
    5 A(ICOL)=SWAP
C     COMPUTE DETERMINANT
    6 DETER=DETER*PIVOT
      PIVOT=1./PIVOT
C     TRANSFORM PIVOT COLUMN
      I3=PIVCOL+NMIN1
      DO 7 I=PIVCOL,I3
    7 A(I)=-A(I)*PIVOT
      A(PIVCOL1)=PIVOT
C     PIVOT ELEMENT TRANSFORMED
C
C     NOW CONVERT REST OF THE MATRIX
      I1=MAIN-DIM
```

```
C     POINTER TO PIVOT LINE ELEMENTS                                    F1000560
      ICOL=1-DIM                                                        F1000570
C     GENERAL COLUMN POINTER                                            F1000580
      DO 10 I=1,EMAT                                                    F1000590
      ICOL=ICOL+DIM                                                     F1000600
      I1=I1+DIM                                                         F1000610
C     POINTERS MOVED                                                    F1000620
      IF(I-MAIN) 8,10,8                                                 F1000630
C     PIVOT COLUMN EXCLUDED                                             F1000640
    8 JCOL=ICOL+NMIN1                                                   F1000650
      SWAP=A(I1)                                                        F1000660
      I3=PIVCOL-1                                                       F1000670
      DO 9 I2=ICOL,JCOL                                                 F1000680
      I3=I3+1                                                           F1000690
    9 A(I2)=A(I2)+SWAP*A(I3)                                            F1000700
      A(I1)=SWAP*PIVOT                                                  F1000710
   10 CONTINUE                                                          F1000720
   11 CONTINUE                                                          F1000730
C     NOW REARRANGE THE MATRIX TO GET RIGHT INVERS                      F1000740
      DO 14 I1=1,N                                                      F1000750
      MAIN=N+1-I1                                                       F1000760
      LPIV=INDEX(MAIN)                                                  F1000770
      IF(LPIV-MAIN) 12,14,12                                            F1000780
   12 ICOL=(LPIV-1)*DIM+1                                               F1000790
      JCOL=ICOL+NMIN1                                                   F1000800
      PIVCOL=(MAIN-1)*DIM+1-ICOL                                        F1000810
      DO 13 I2=ICOL,JCOL                                                F1000820
      I3=I2+PIVCOL                                                      F1000830
      SWAP=A(I2)                                                        F1000840
      A(I2)=A(I3)                                                       F1000850
   13 A(I3)=SWAP                                                        F1000860
   14 CONTINUE                                                          F1000870
      DETERM=DETER                                                      F1000880
      NERROR=0                                                          F1000890
      RETURN                                                            F1000900
   15 NERROR=-1                                                         F1000910
      DETERM=DETER                                                      F1000920
      WRITE(LGUNIT,100) MAIN,MAIN                                       F1000930
      RETURN                                                            F1000940
  100 FORMAT(18H MATIN1 ...., THE ,I10,50H. COLUMN OF THE MATRIX CONTAINF1000950
     1S ONLY ZEROS AT THE ,I10,19H, ELEMINATIONSSTEP. )                  F1000960
      END                                                               F1000970
```