MPS/LIN/DW/nc

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UNDERSTANDING CLASL *)

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There are several useful references :

i) M. Martini, D. Warner "Numerical calculation of linear accelerator cavities", CERN 68-11 (enclosed).

ii) S. Kulinski, "Note on numerical calculations of linear accelerator cavities", NAL conference proceedings (1970), p. 353.

iii) A. Katz, "Numerical computation of field distributions", Ch. 1.1d, p.617 of "Linear accelerators" by Lapostolle and Septier.

iv) M. Sedlaček "Computer program for calculation of electrical parameters in cavity resonators with cylindrical symmetry", TRITA-EPP-71-06 (Report of Electron and Plasma Physics Institute, Stockholm, Sept. 1971).

References i) and ii) contain comprehensive details of the theory on which CLASL is based while iii) is a less specialised introduction with emphasis on methods used in CLAS. Sedlaček actually spent some days with us before taking CLAS to Stockholm and subsequently modifying it for an IBM 360 and "LASL" type cavities. Much of his report is thinly disguised "M&W" 68-11 but his accounts of the geometrical treatment of drift tube profiles and the logic of his (similar) program are good.

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*) The reader is assumed to have an up-to-date listing of program CLASL at his disposal.

SOME GENERAL COMMENTS ON CLASL

i) The influence in wording of comment cards, printed titles and variable names is predominantly French which could cause a slight problem e.g., in Britain or the USA.

ii) CLASL has been added to, modified, improved, etc. several times since 1968 so that some sections are only present for historical reasons. The fact that it works well (and a general lack of time), has discouraged us from doing a general tidy-up.

iii) A concept which shaped CLASL originally (see M&W, p.1) was that any convex profile of drift-tube should be calculable; hence, the logic of the so-called "geometrical treatment" including input data seems sometimes unnecessarily obscure when one is dealing with cylindrical drift tubes only.

iv) We have avoided the complication and handling costs involved in magnetic tape outputs recently, (see Sub. TAPEIT), but we incur the penalty of corresponding excess of paper. Computer time costs (ν 2o sec/cell) are not worrying. We punch cards of dynamics coefficients when necessary.

v) There are "C" cards which appear to be complete nonsense; they are often PRINT instructions turned over and left in for reference (FORMATS are generally left in regardless).

SUMMARY OF SUB-ROUTINES

Program CLASL

This main program generally organises the sequence of sub-routine calls but does some arithmetic necessary for choosing the mesh size on which one does the numerical calculation of the discrete values of $U = rH_{\phi}$. It is mostly devoted otherwise (i.e., between CLASL 113 and CLASL 277) to odd jobs arising from the "geometrical treatment" (Subs GRILLE, COMPIL, DUALE, etc.) such as rearrangement of tables of irregular points and tests of diagonal dominance and of values of iteration coefficients (which must be less than COEFMX). A new mesh is sought if the coefficients found initially are unsatisfactory. Contrary to the footnote in MeW, p.7, DY and DX (h,h') can differ by up to 5%, at least (without harm).

Sub. TAPEIT

General tape output procedure (not used now).

Sub. SETCOM

Sets labelled commons to zero.

Sub. GRILLE

This generally searches for and analyses the conditions around points on the normal grid network which are irregular (points) i.e., near the drift tube profile so that one or two of their neighbouring points are "missing" (M&W p.8 et seq.). A complicated logic was necessary (for the general profiles envisaged) to produce the tables of indices and coefficients in common /BLOC 3/ and /BLOC 4/. The rectangular areas "HP7", associated with irregular points near horizontal or vertical lines are also found.

Sub. COMPIL

Calculates iteration coefficients (often via IRCOE) and assigns a code number to irregular points.

Sub. IRCOE

Calculates auxilliary coefficients (M&W, p.9, Eq. (30) nearly applies except terms with "R" have been dropped).

Sub. DUALE

Treats the so-called "dual grid" which is displaced by DX/2, DY/2 from the normal grid and defines areas to be assigned to various (irregular) points. In many respects it is similar to GRILLE but defines (yet) another set of irregular points.

Sub. REDUCT

Calculates the irregular, non-rectangular areas for the future integrations of type $\int f(U)ds$.

Sub. PLACER

Determines points to which areas, calculated by REDUCT, should be assigned.

Subroutines GRILLE, COMPIL, IRCOE, DUALE, REDUCT and PLACER form the "geometrical treatment".

Sub. RELAX

Organises the iteration and analytical solution parts of the program and in particular calculates (continually) the best value for the "over-relaxation factor", BETA (see M&W, p.16, and Appendix IV). The various values of MARK correspond to progressive stages in the convergence of the vector UMAT.

Sub. ITRATE

This is the real core of the numerical (iteration) part of CLASL. In fact the vast majority of (regular) points are treated between ITRATE.33 and ITRATE.55 and the real iteration business is between 41 and 44. Other variables, e.g., GNORM, DMAX,etc., are necessary for assessing the convergence of the system.

Sub. CHARG1

This is very long and complicated as it contains the initial filling of UMAT (see M&W, p.19-20 and Appendix VI), the intermediate fillings above the Dirichlet line (M&W, p.20-21 and Appendix VII) and for convenience in availability of variables, the entry CALCK3, which calculates $k^2 = (2\pi/\lambda)^2$ by numerical integration (M&W, p.5, p.22 and Appendix VIII) and by analytical integration where possible (see Kulinski paper). The theory of the initial solution (filling) is treated thouroughly in M&W but the program does contain some redundant features. At CERN the Bessel functions J_0, J_1, Y_0, Y_1, I_0, I_1, K_0 and K_1 are in the program library under labels BESJ0, BESJ1, etc.

CHARG1 has been very reliable and is one of the key parts in the speed and accuracy of the program CLASL.

Sub. PLOTU

A rather trivial plotting routine displaying drift-tube and equipotentials after the initial filling of UMAT.

Subroutines RELAX, ITRATE, CHARG1 and PLOTU form the numerical calculation part of program, i.e., determine a converged set of UMAT($=rH_\phi$) at all grid points.

Sub. CALPAR

Organises the calculations for normalising the UMAT (so that $\frac{1}{2}\int E_z d = 1$ MV m^{-1} and for derived quantities such as Q, perturbation of stems, surface fields, dynamics coefficients. Also many of the entries in the output summary are printed here.

Sub.STORE

Calculates several integrals of interest concerning normalisation of UMAT and stored energy e.g., $\int U^2/r \, ds$, $\int U/r \, ds$ and $\int r \, ds$.

Sub.NORM

Calculates several integrals involving E_Z on the axis (r = 0) for values "sur l'axe" of T, DT, DDT, SL, DS and DDS (see output). An important indicator known as the "second normalisation factor" compares $\int E_Z dZ$, with $\omega \int B.ds$ (found in STORE) and is a measure of the goodness of the entire calculation, i.e., consistency of solution over the whole area of cavity section.

Sub.GEOM

Sets up a system of co-ordinates measuring along the surface of the drift tube profile, deriving S(J) and corresponding radial co-ordinates YS(J) and also lengths of arcs ARC(I).

Sub.POTUBE

This organises and does the majority of the calculation of surface field on drift tube (including prints). The apparent complication here was to avoid some defects in MESSYMESH. A surface potential FB(IB) is calculated from UMAT at every point where grid lines intersect the drift tube profile and the corresponding position SB(IB) found from table of S via Sub.RECHER. The electric field on the drift tube surface is finally calculated by Fourier synthesis and an appropriate differentiation using coefficients derived by Sub.LIFOU (M&W, p.28-29 covers subs POTUBE, LIPA and LIFOU).

Sub.LIPA

Is a parabolic smoothing of potentials "YT" (previously FB) taken 5 at a time to derive a set of potentials YPAR at equal intervals DX along the profile.

Sub.LIFOU

This does a Fourier analysis of the function YPAR calculating coefficients AFOU(L) which are then smoothed (higher harmonics regularly reduced) by Cesaro's Method (M&W p.29).

Sub.CALCQ

Calculates surface dissipations (perfect copper), and stored energies necessary to evaluate Q's for laboratory cavity and linac cavity (stems included later).

Sub.TRAFAC

Extends results of Sub.NORM by calculating various transit time factor type integrals off-axis. The axial values are often better defined by extrapolation from off-axis.

Sub.PERTUB

Calculates frequency perturbation due to drift tube support stems and post couplers and dissipations thereon.

The above routines CALPAR, STORE, NORM, GEOM, POTUBE, RECHER, LIPA, LIFOU, CALCQ, TRAFAC and PERTUB all deal with derived cavity parameters.

Sub.DISP

Routes the calls to contour subroutines CONTn.

Sub.INPUT

Input of cell dimensions with some preliminary geometric calculations as well.

Sub.CONTn (n = 1 to 6)

Describe the contours of the drift tube profile in a standard way so that calls from GRILLE and DUALE can obtain information independently of the type of curve described.

Subroutines DISP, INPUT and CONTn were a special feature of CLASL enabling very general contours to be treated by the same program merely by altering the input data (Sub INPUT) and the short subroutines CONTn describing the profiles.

NOTES ON INPUT DATA

Card No	READ AT	Variables, Name	Notes
1	CLASL.19	JOBNUM	6 digit identifying number
		NITEMX	Integer ≤ 9 allowing finer variations in choice of a (non-square) mesh size.
		COEFMX	Maximum allowable value for iteration coefficients (≈ 1.25) but varied according to difficulty of cell if necessary.
2 3 4	CLASL.25	NUMREC IXREC( )	Concern record lengths if one wants to put results on magnetic tape.
5	INPUT.4	EL	Cell length (cm)
		R	Cavity radius (cm)
		G	Gap (cm)
		A	Drift tube hole radius (cm)
		B	Hole corner radius (cm)
		D	Drift tube body diameter (cm)
		AX2	Drift tube upper profile radius (cm)
		AX1	Spare
6	INPUT.4	DX	Proposed horizontal mesh size (cm) — If = 0
		DY	Proposed vertical mesh size (cm) — see NPIA
7	INPUT.4	STEM	Stem diameter in metres (a value must be given)
8	INPUT.4	NPIA	Proposed starting number of mesh points (applies if DY=DX=0 above)
		NCOURB	Number of distinct parts of drift tube profile e.g., horizontal line, lower radius, vertical line, upper radius and upper horizontal line (NCOURB = 5).

9	RELAX.19	BFINAL	Preset value for over-relaxation factor - if 0 then BFINAL is automatically calculated in the program.
		EWANT	Error on potentials at which calculation stops (see theory in M&W, p.24-25 before changing it.
		INDEX	Not now used
		NITMAX	Default number of iterations if program has not converged cf. EWANT (rarely applies).
		CK2	Starting value for $k^2 = (2\pi/\lambda)^2$, λ in cm. Precise value not necessary but 0 would give an error.
10	RELAX.19	FATNOR	Normalisation factor, now redundant but not worth eliminating.
11	PLOTU.9	SYMBOL	Alphabetic symbols used on PLOTU graph
		RLIMIT	Radial limit (cm) for PLOTU.
		NEQUIP	Number of equipotentials plotted
		ITEST	If=0 prints out initial values of UMAT
12	CLASL.19	JOBNUM	If=0 then program STOP, otherwise next case.

RESULTS AND OUTPUT FORMATS

i) Geometrical treatment

Results are between headings "Geometrical Data for Cavity" and "Coefficient Maximum = ". Dimensions in cm unless otherwise indicated.

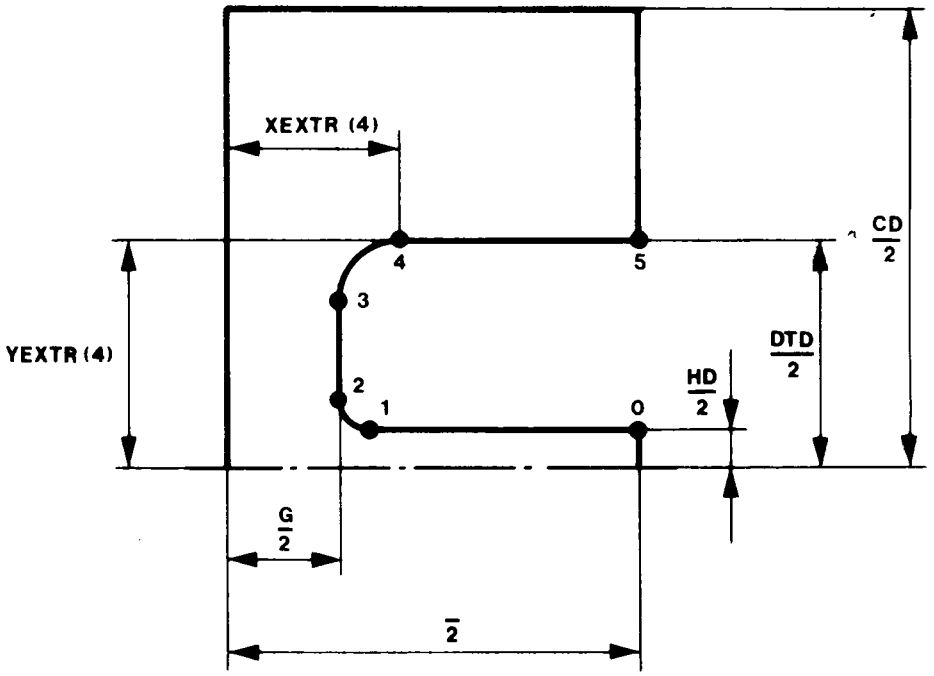

FIG. 1: Symbols for cavity dimensions and profile coordinates

XEXTR, YEXTR are co-ordinates of the ends of the curves forming the drift tube profile as shown in Fig. 1.

Cavity dimensions printed should be consistent with XEXTR( ), YEXTR( ) of course. "Precise" and "Approx.Areas" should be equal to within ±0.1 otherwise frequency error may arise.

The output of PLOTU shows equipotentials of UMAT (starting solution).

ii) Numerical/Iteration part of CLASL

Concerns outputs up to heading "UMAT MAXIMUM = ".

Every 25 iterations, one has a set of results reviewing the progress of the calculation. "Nouvelle Methode --" Kulinski integration and "Ancienne Méthode --" numerical integration over whole cell. The values of UMAT along the "Fourier Line" are compared with values re-calculated by Fourier Analysis/Synthesis. Other results which commence with the number of iteration cycle generally give no trouble but are worth studying if one suspects a bad convergence. The second or third from last cycle of iterations is generally done for the region of drift tube aperture only, when 100 cycles ensure good convergence of potentials which will be used for calculating dynamics coefficients.

Set of results between "UMAT MAXIMUM = ' and "PERTUB----" are values of UMAT (normalised to 1.00 maximum) for the two horizontal mesh lines immediately above the drift-tube.

iii) Results of Derived Quantities (CALPAR et seq.)

EFOU, XFOU and RFOU are surface electric fields (MVm^{-1}), co-ordinates measured along profile (cm) and corresponding radial distances from cavity axis (cm), respectively.

"Distribution de la Dissipation" and results which follow are useful if one requires the distribution of r.f. dissipation on drift tube surfaces (cooling calculations).

"Paramètres electriques des cavités" (~ two pages of output) as shown on Figs. 2 and 3, are the summary tables rather analogous to MESSYMESH outputs but more comprehensive.

NB. "Energie" corresponds to $\beta\lambda = L$ unless β is specially set at CALPAR.22. (Generally in the case of a buncher cavity). For linac cavities, one normally has $\beta\lambda = L$ and the energy defined is used as the reference energy for the dynamics coefficients.

We use two simple algorithms for finding the "correct" length or "correct" gap corresponding to the desired frequency (202.56 MHz).

The "Deuxième Normalisation" is an important criterion for the goodness and homogeneity of the potentials UMAT (see Sub.NORM). It is generally slightly more than 1.00 and for cells of normal geometry we require $1.015 > FN2 \geq 0.985$. For cells at beginning of Tank I or bunchers we have (reluctantly) accepted values between 0.97 and 1.03. FN2 outside these limits does not necessarily imply poor results and in particular the frequency may be within ±20 kHz of ideal case result.

"Energie Totale" is stored energy for the "cavité du Labo" i.e., for half a normal unit cell.

"Cavité du Linac" consists of outer tank cylinder and drift tube only.

"Collected Buncher Parameters" assume a standard unit cell (two half drift-tubes).

Note that all dissipations and fields correspond to a mean axial field of $E_o = 1MV\ m^{-1}$.

Dynamics coefficients given as results come from NORM and TRAFAC and the headings are self explanatory. (Use of these coefficients is described by Martini and Promé in "Particle Accelerators", 1971, Vol. 2 pp. 289-299).

Distribution

Linac Design Committee
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PARAMETRES ELECTRIQUES DES CAVITES

CAVITE NO.674101 16/12/75

FREQUENCE = 202,5804 MHZ ENERGIE = ,776 MEV

STEM FREQUENCY PERTURBATION ,394232 MHZ FOR DIAMETER = ,0280 M

COUPLER FREQUENCY PERTURBATION ,317544 MHZ FOR DIAMETER = ,0250 M AND FOR GAP = ,0500 M

FREQUENCY = STEM FREQUENCY PERTURBATION + COUPLER FREQUENCY PERTURBATION = 201,8686 MHZ
REQUESTED GAP = 1,327331 CM FOR FREQUENCY = 202,56MHZ B = 1,000646
REQUESTED LENGTH = 6,018030 CM
OLD GAP = 1,328000 CM OLD LENGTH = 6,015000 CM

FACTEUR DE NORMALISATION = 473,99
DEUXIEME NORMALISATION = 1,01409

CHAMP MOYEN SUR L AXE E0 = 1,000 MV/METRE

ENERGIE EMMAGASINEE W/V= 1,43103 JOULES/METRE CUBE

ENERGIE TOTALE W = ,02909 JOULES

FACTEUR DE SURTENSION

CAVITE DE LINAC Q1 = 82879,9

CAVITE DE LABO Q2 = 5926,4

IMPEDANCE SHUNT

CAVITE DE LINAC Z81 = 67,32 MEGOHMS/METRE

CAVITE DE LABO Z82 = 4,81 MEGOHMS/METRE

PUISSANCE DISSIPEE

SUR LA PAROI EXTERNE PW1 = 826,13 WATTS

SUR LA PAROI TERMINALE PW2 = 2951,09 WATTS

SUR LA PAROI COTE TUBE PW3 = 2850,24 WATTS

SUR LE DRIFT TUBE PW4 = 367,42 WATTS

STEM POWER DISSIPATION 309,27 WATTS Q FACTOR WITH STEM 61693,5

COUPLER POWER DISSIPATION 225,50 WATTS

PEAK ELECTRIC FIELD = ,55436E+01 MV/M IS LOCATED AT ,12249E+01 CMS FROM THE AXIS

COLLECTED BUNCHER PARAMETERS

POWER DISSN = 6594,03 Q = 11830,9 SHUNT IMPEDANCE = 9,12 MEGOHMS/M

PEAK ENERGY MODULATION FOR ABOVE POWER DISSN = 41,08 KEV

FIG.2 / Summary tables (frequency, perturbations, normalisation, power dissipation).

FACTEUR DE TEMPS DE TRANSIT T = ,68297

COEFFICIENT DE COUPLAGE S = ,0811

DYNAMIQUE DES PARTICULES

1) SUR L AXE

T = ,6830
DT = -,8096
DDT = -,0851
SL = ,5347
DS = ,2673
DDS = -,6211

FIG 3 Summary Table (continued) (Dynamics coefficients axial electric field).

2) HORS DE L AXE
INTEGRALES SUR EZ

R	T	DT	DDT	SL	DS	DDS
,0009	,682313	-,509822	-,080482	,534854	,265775	-,621577
,0017	,686820	-,503986	-,085115	,532232	,266459	-,610937
,0026	,693884	-,494782	-,092159	,528073	,272578	-,594246
,0034	,703649	-,481951	-,101482	,522229	,276105	-,571143

3) VALEURS EXTRAPOLEES SUR L AXE

0,0000	,680743	-,511849	-,078645	,535762	,264631	-,625283

DATA GENLIN S1 = -1211,84559 KDS1 = 1242,61143 K2DS1 = 4920,71501 MARTINI

DATA GENLIN S1 = -1248,35784 KDS1 = 1298,05108 K2DS1 = 5093,21976 WARNER

4) INTEGRALES SUR ER

,0009	,017345	-,035724	,000097	,030235	,006723	-,049266
,0017	,035196	-,071456	-,000478	,060709	,017936	-,098168
,0026	,053643	-,107194	-,002105	,091559	,027920	-,146485
,0034	,073674	-,142927	-,005288	,122963	,039055	-,193901

DATA GENLIN S = -20,66862 -S = 41,88487 =S = ,32965 MARTINI

DATA GENLIN S = -20,33416 -S = 41,88019 =S = -,11409 WARNER

DONNEES PERFOREES POUR GENLIN

,6807 -,5118 -,0788 ,5358-1248,3578 ,2648 1298,0511 ,060150
,013280 -20,3342 41,8802 -,1141 -,6253 5093,2198

FIRST POTENTIAL ON OUTER WALL = 591,20437 AMPS
LAST POTENTIAL ON OUTER WALL = 591,20437 AMPS
POTENTIAL ON DRIFT TUBE = 195,25608 AMPS

ELECTRIC FIELD ON THE AXIS (MV/M)

2,862 2,848 2,804 2,731 2,631 2,504 2,353 2,182 1,995 1,798 1,597 1,400 1,212 1,036 ,878
,737 ,614 ,509 ,420 ,345 ,282 ,231 ,189 ,154 ,126 ,103 ,084 ,070 ,058 ,049
,042 ,037 ,033 ,031 0,000

CELLULE NO 6741 TEMPS DE CALCUL 16,6660 SECONDES