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ADDENDUM TO PROGRAM TRACE

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I. INTRODUCTION

The interactive beam transport program - TRACE - has been modified warranting an addendum to the initial report [1]. The modifications are described in the order that they would have appeared in the initial report.

II. SPECIFICATION OF THE TRANSPORT SYSTEM

Two new elements, a harmonic buncher and an energy spread corrector, have been included, allowing a reasonable simulation of the transverse dynamic between the buncher and the linac. The change in the transverse emittance of the beam is also calculated when the beam passes through the buncher.

Harmonic buncher

The type code for the buncher is G (for "groupeur", B having already been used to indicate a bending magnet), and its parameters are as follows:

1. η : the bunching efficiency, in %;
2. $\Delta\phi$: the half phase spread of the fully bunched beam, in degrees;
3. D : the distance from the buncher, in mm, at which full bunching is achieved;
4. V_1 : the maximum energy gain of a particle, in keV, at the fundamental frequency gap;
5. V_2/V_1 : the ratio of the harmonic buncher voltage to the fundamental buncher voltage

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The last two parameters are only used in calculating the change in the transverse emittance when the beam passes through the buncher (see Appendix). The calculation of the emittance change also requires the buncher frequency, but, since only 5 parameters are allowed per element, the frequency is assumed to be that of the CERN buncher, 202.56 MHz.

The first three parameters specify that the portion of the beam within a phase spread of $\eta \times 360^{o}$ at the buncher, will be bunched to lie within a phase spread of $2 \times \Delta\phi$ after a distance D. At a distance, s, downstream of the buncher, where $0 \leq s \leq D$, the phase spread containing the fraction η of the beam, will be :

$$\phi(s) = \eta \times 360 + \frac{s}{D} (2 \times \Delta\phi - \eta \times 360)$$

For distance $s > D$, it is assumed that the beam starts debunching at the same rate as it was bunching, and the phase spread is calculated as above, except that s is replaced by

$$s' = 2D - s.$$

The transverse space charge forces on the bunching beam are simulated by multiplying the unbunched beam forces by the factor

$$F(s) = \eta \times 360^{o}/\phi(s)$$

$$= \frac{1}{1 + \frac{s}{D} \left(\frac{\Delta\phi}{\eta \times 180} - 1 \right)}$$

The force is that of a long, uniformly charged, cylinder whose effective current is F x I, where I is the current in the unbunched beam.

Because of the approximate way that the bunching effect is treated, there can be only one buncher in a transport system. If the transport system contains a buncher, then, anytime that the beam is downstream of the buncher, the "effective value" is used for the current; anytime that the beam is upstream of the buncher, the standard beam current (specified via button 6) is used.

It should be mentioned that there is no checking done by TRACE to insure that the bunching parameters are valid. For example, if the user desires, $\eta \times 180$ may be less than $\Delta\phi$, which would make the effective beam current decrease rather than increase. This feature has been used for simulating the debunching of the beam, due to its energy spread, at the exist of tank I.

Energy spread corrector

The "type code" for the energy spread corrector is G, and its only parameter is eVT, the maximum energy gain that a particle could receive in the gap. This element is treated as a thin lens, and the divergence of a particle after the gap is

$$x'_n = x' + kx,$$

$$y'_n = y' + ky,$$

with

$$k = \frac{\pi \, eVT}{2\beta\lambda \, W_s}$$

The value used for λ is one corresponding to the CERN linac frequency of 202.56 MHz.

III. CAPABILITIES

Graphical output

Several additions have been made to the storage scope output, an example of which is shown in Fig. 1. The profile display at the bottom has been enclosed and the elements have been labelled with their element numbers. Additional information has been written on the central part of the display. At the top appear the beam current, I, in mA, and the emittances in the 2 transverse planes, in mm-mrad. If the transport system contains a buncher, as does the one shown in Fig. 1, the "effective "current", F x I, at the end of element N2 is shown in addition to I, the unbunched beam current. Likewise, the final emittance values are also shown, indicating how they may have been changed by passing through the buncher.

Below the emittance values appear the values of the "variables", as defined via touch button 14, SPECIFY VARIABLES. The element number, NE, the parameter numbers, NP, and the value of the parameter are shown for each of the specified variables. The values shown are the standard TRACE values multiplied by conversion constants which are also specified via button 14. A conversion constant can of course be unity, in which case the value shown for a quad. gradient would be in T/m. But if one specifies a constant that converts the gradient, in T/m, to the current, in A, through the quad. power supply, then one obtains a more practical value.

The information mentioned above is written on the scope at the end of a calculation, and only if there is a fresh background.

Touch panel options

The touch panel display shown in reference 1 is incorrect. The correct display is shown in Fig. 2. The following touch panel commands have been modified as defined below :

BUTTON 10. ENTER MATCHING CRITERIA

One additional matching option has been provided. It calculates the α's and β's required at the input to the limiting section of LEBT [2]. The user selects this option by specifying a "5" for the matching type. The message

CALCULATE ALPHA AND BETA FOR LIMITING SECTION

then appears on the screen.

This matching option is unlike the others in that a solution is sought for the input beam ellipse parameters rather than for transport system parameters. However, TRACE is structured to accept only transport system parameters as variables. One gets around this problem by specifying as the 2 variables, via button 14, two unused parameters in the transport system, and then, using button 15, supplying the initial guesses for α and β in these variables.

For example, if the transport system contains less than 50 elements (the maximum number), then one may specify that the first and second parameters of element 50 are the variables, each with a conversion constant of unity. In the unlikely event that there are 50 elements, then one could use 2 of the unused parameters in any of the drift spaces, for instance.

BUTTON 12. DROP

When TRACE is "dropped" via this button, the storage scope is automatically erased to protect the display surface.

BUTTON 14. SPECIFY VARIABLES

In addition to specifying the element number and parameter number, the user must also supply a conversion constant for each variable. The purpose of this conversion constant is to allow the user to work with more practical units for the variables. The practical unit is obtained by multiplying the internal TRACE value by the conversion constant. For example, since the user actually sets a quad. gradient by specifying a current, in A, through the quad. power supply, it is more practical for him to specify quad. currents to TRACE rather than using quad. gradients, in T/m, which is the internal TRACE unit. The practical units will be seen on the graphical display and when one modifies the variables via button 15. The internal TRACE units will still be seen when one prints the transport system via button 3, and when one uses button 13 to modify any element. There is, of course, nothing to prevent the conversion constant from being unity, in which case the practical unit and the internal unit are the same.

IV. OPERATING PROCEDURE

One starts TRACE running by using the system touch panel ; the sequence is :

Home page →	Beam quality selection page →	LEBT application programs
BEAM QUALITY	LEBT APPLIC. PROGRAMS	TRANSPORT PROGRAM "TRACE"

This causes TRACE to be installed and run with a low priority (10) and to be "checkpointable", capable of being interrupted and restarted, if necessary.

Since the MAXI consoles have been reassigned numbers 3 and 4, one must specify either 3 or 4 when asked by TRACE for the console numbers.

ACKNOWLEDGEMENT

Most of these modifications were made after discussions with M. Weiss on how TRACE could be made more useful in the on-line tuning of LEBT.

REFERENCES

1) K. Crandall, "TRACE - An interactive beam transport program for unbunched beams", PS/LIN/Note 77-3.

2) B. Bru and M. Weiss, "Evolution in the LEBT design (3rd version) : Choice of quadrupole triplets", MPS/LIN/Note 74-4.

3) M. Weiss, "Bunching of intense proton beams with six-dimensional matching to the Linac acceptance", CERN/MPS/LI 73-2.

Distribution

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A P P E N D I X

CHANGE IN TRANSVERSE EMITTANCE AT HARMONIC NUMBER GAP

Following Weiss [3], the increase in the transverse emittance of a cylindrical beam as it passes through a double drift harmonic buncher is calculated as follows : Considering that all the bunching action takes place at the harmonic buncher gap (thin lens), the divergence of a particle leaving the gap can be expressed in terms of the buncher parameters and the particle's displacement and divergence at the entrance to the gap

$$x'_n = x' + x(k_1 \cos\phi - k_2 \cos 2\phi)$$

where ϕ is the phase of the particle in the gap with respect to the fundamental bunching frequency, and k_i the transverse force constant of each of the bunchers

$$k_i = \frac{\pi\, e\, V_i\, T_i}{2\beta\, \lambda\, W_s}\ , \qquad i = 1, 2.$$

The output displacement of a particle is the same as its input displacement

$$x_n = x\ .$$

The new emittance is found by calculating the new second momenta $\overline{x_n^{\,2}}$, $\overline{x'^2_n}$, and $\overline{(xx')_n}$. If the bunching efficiency is η, then one is usually interested only in the emittance of that portion of the beam having a phase spread at the buncher in the range $-\eta\pi \le \phi \le \eta\pi$. Therefore, the averages are taken over this interval, with the average defined as

$$\overline{f(\eta)} \equiv \frac{1}{2\eta\pi}\int_{-\eta\pi}^{\eta\pi} f(\phi)\, d\phi .$$

The second momenta of the output beam may be expressed as follows :

$$\overline{x_n^2} = \overline{x^2}$$

$$\overline{x'^2_n} = \overline{x'^2} + \overline{2xx'(k_1 \cos\phi - k_2 \cos 2\phi)} + \overline{x^2(k_1 \cos\phi - k_2 \cos 2\phi)^2};$$

$$\overline{(xx')_n} = \overline{xx'} + \overline{x^2(k_1 \cos\phi - k_2 \cos 2\phi)}.$$

GET TRANSPORT FILE	GET TRACE RECORD	PRINT TRANSPORT SYSTEM	SAVE TRACE RECORD
ENTER PARAMETER SET 1	ENTER PARAMETER SET 2	--------- ERASE ---------	DO NOT --------- ERASE
INPUT BEAM ELLIPSE	ENTER MATCHING CRITERIA	--------- GO ---------	--------- DROP ---------
MODIFY ANY ELEMENT	SPECIFY VARIABLES	MODIFY VARIABLES	START -STOP MATCHING

FIGURE 2 : TOUCH PANEL DISPLAY
(USER'S TOUCH PANEL)

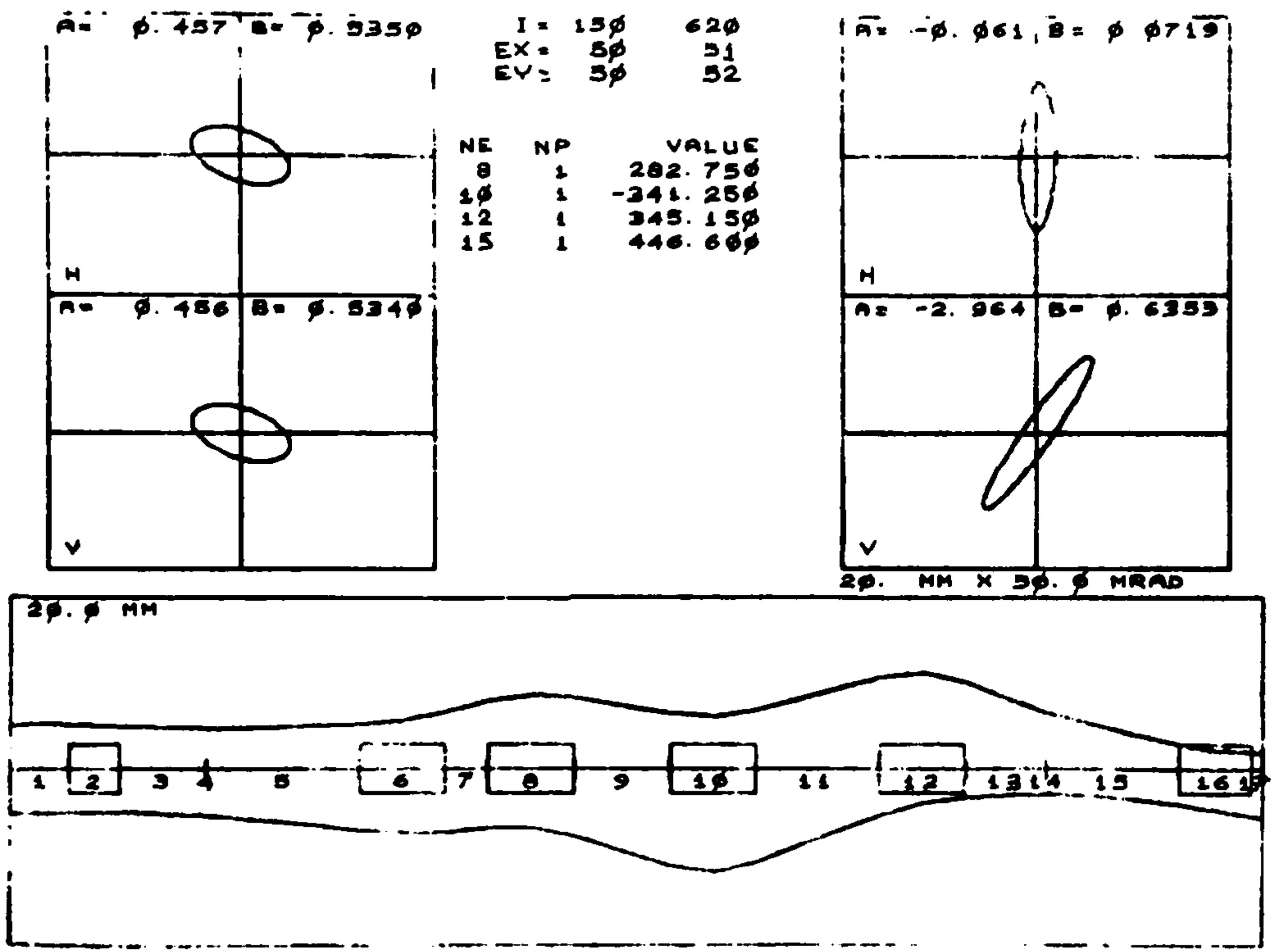

FIGURE 1 : EXAMPLE OF STORAGE SCOPE DISPLAY