EMITTANCE MEASUREMENT AT THE CERN PS LINAC WITH AN ON-LINE COMPUTER

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Summary

The emittance measurement equipment at the CERN PS Linac has been connected to an on-line computer (IBM 1800). Four digitalized parameter values, six limit numbers and a status word are fed over a fast multiplexer system 200 m to the computer. The advancement of the measurement gear is under control of the computer. A typewriter at the Linac gives a line by line print-out of elementary emittance currents giving by their positions on the print-out the shape of the phase space area and the current distribution inside it. Ten error conditions can at present be recognised by the computer program. Error messages are displayed on a TV-monitor or printed out on the typewriter. Advantages gained from the on-line operation with the computer are less operator fatigue and possibility to follow immediately the evolution of the measurement.

Introduction

As reported at the 1966 Linac Conference [1] an automatic analysing system has already been used for the Linac emittance measurements with an off-line computer. Raw data from a measurement were punched on a paper tape, later transferred to magnetic tape and processed by the CERN CDC 6600. The inevitable delay of one to two days between the measurement and access to the results turned out to be rather annoying, since any malfunctioning of the hardware was usually detected at too late a stage. The arrival in spring 1967 of the IBM 1800 computer, intended for control and monitoring of the CERN PS, opened the possibility of getting the Linac emittance measurements treated by an on-line computer. Although the smaller capacity of the process computer required simplifications in the data treatment as compared to the previous system, the advantage of immediate access to the data from the on-line operation is particularly useful, as one may use data from one run in choosing the conditions of the following run.

System Description

Our measurement method has been given earlier [1] : "After the Linac, a slit 2 mm wide defines a strip of the output proton beam in phase space at a constant vertical or horizontal position. This slice of beam passes through a focusing triplet, at the focal plane of which, and parallel to the first slit is another 2 mm wide slit defining a small range of angular divergence. The current passing through the two slits is measured with a transformer and by moving the slits systematically and recording the current at each elemental area (2 mm × 0.584 mrad), the emittance plane can be mapped".

Fig. 1 gives a view of the Linac computer terminal with typewriter, Nixie displays for control of parameter values and TV monitor for error messages. The PS control computer is placed in an extension to the main PS control room, requiring a cable length of about 200 m to our typewriter. Initially it was feared by IBM that this length might need an increase in transmission voltage, but tests with a normal multicore cable revealed no difficulties. The typewriter puts a restriction on the output format, and it was decided to map the phase plane with an array of maximum 20 × 20 measurement points. Before the measurement starts six limit values are set on thumb-wheel switches at the Linac :

ILILO

No advance order is given by the computer to the measurement gear and no values recorded until the Linac current equals or surpasses this limit. We preferred this solution rather than to normalize the elementary current with respect to the Linac current, since the relation between the two parameters is unknown and certainly not a linear function.

IJWLO

The program considers the elementary current to equal zero if below this limit. This feature is used to mask the unavoidable noise level on the beam current transformer - usually of the order of a few microamps. - and results in a more realistic presentation of the shape of the phase space area on the printout. By raising the limit value one can get the emittance and phase space plot of the higher density beam core.

JW1LO, JW1HI, JW2LO, JW2HI

These limits set the excursions of the measurement slits and can be used to speed up the measurement in the case when only the beam core is of interest.

Four parameter values are fed to the computer; two slit positions, the Linac current and the surviving or elementary current behind the slits. A sixteen bit status word is also transmitted with information on the direction of slit travel, condition of vacuum valves, etc.

A program request on the push button panel at the Linac terminal causes an interrupt in the computer main line program. If the interrupt is accepted the computer transfers the emittance program from its disc store into core memory. Although time sharing operation of the computer is foreseen, the present program does not make use of this facility. So far this has not caused any inconvenience. The measurement is destructive for the beam and therefore mainly used outside normal PS operation.

When the measurement is requested to start, the computer first checks if the positions of the slits correspond to the given lower limits and that they are in advance status. If not, an error message is printed out on the typewriter, otherwise the heading is typed. As can be seen on Fig. 2 the array values L, M are given below corresponding excursion limits.

Advancement of the slits is under computer control; the position slit starts by moving in steps until the limit JW1HI is reached. After this point has been measured, the angular slit is moved one step and the status of the position slit is flipped to return. A printout is not given at each measured point since that would require the typewriter to step backward for each second line in synchronism with the position slit. Instead the data are stored until the line is completed, when they are printed in proper sequence, followed by the sum of elementary currents on this line and the average Linac current of accepted machine pulses. The position of the elementary currents on the printout gives the shape of the measured phase space area. A comparison of Figs. 2 and 3 gives an example of how this shape can vary for different machine conditions. When the angular slit reaches its higher limit JW2HI, the measurement is terminated, and the computer prints out the average Linac current for all measured points, the ratio between the sum of all elementary currents and this average, the number of measured points where the elementary current was above or equal to the limit IJWLO and the emittance of the phase space area. The latter is simply obtained by multiplying the number of points with a constant deducted from the known size of each elementary phase space area. It makes use of the fact that we never have observed holes inside the 50 MeV phase space area.

Software

The present size of core memory is 8 K of 16 bit words, but due to the necessary programs for running the computer less than half of the memory is available for user programs. This restriction excluded the use of the curve fitting routine for finding equi current lines in the phase plane as was done in the earlier program. Even so, the first attempt with a simpler program in Fortran caused memory overflow. The program was therefore rewritten in Assembler language, which being closer to the machine language is more economical in memory space. By storing not more than one measurement line at any time, and by transferring each subroutine from disc store into core only at the time it is required in the program, it became just possible to get the program accepted. The present program therefore contains very little treatment of the data and consists mainly of logical checks so that the program can cope with different possible hardware troubles and warn the operator with an error message on the TV screen. If after a certain number of machine pulses the trouble persists, the measurement is automatically stopped.

The core size will shortly be increased to 16 K giving more possibilities for refined data treatment. Another possibility, as yet not explored, is to punch the measurement data on cards for for further treatment by the previous program on the CDC 6600.

Hardware

The measurement gear was already fitted with digitalized position indicators [2]. These use the same type of A/D converters [3] as the beam transformers. The analog signal is gated during 2 μs and charges a capacitor which subsequently is discharged by a linear run down. The resulting time interval is filled with 4 MHz clock pulses which afterwards are divided by 4 to decrease the jitter due to the fact that the clock pulses and the time interval are not synchronized. A pulse burst of 1000 pulses corresponds to an input voltage of 1 V with a precision of ± 1 pulse per 10°C ambient temperature.

The computer data acquisition is not synchronized to the Linac timing, and 10 or 16 bit scalers built with integrated TTL circuits are therefore used as local buffer memories [4] (Fig. 4). The parallel outputs of all scalers go through individual gates to a common 16 wire bus bar. The scalers are addressed and read by the computer over a fast multiplexing system known as - STAR*- which was developed by the PS Controls Group for data acquisition in the PS area.

Nixie displays and preset pulse burst generators [4] for system tests have also been realized with integrated circuits and resulted in substantial savings over the cost for similar commercial units. The reliability of these units has been very good.

Conclusion

Our present measurement system, which takes about 10 minutes for a run, might seem slow compared to single pulse emittance presentations used elsewhere. We feel, however, that the increased accuracy and the more detailed information are of particular value for the long term development of our Linac. Our system is mainly used for machine studies and for control of the initial set-up of the Linac, rather than for operational checks

during the run of the PS. Long measurement series for studies of different machine conditions are therefore usual practice and the present system has practically removed operator fatigue as a cause for limiting the number of measurements that can be performed.

Acknowledgements

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References

[1] C.S. Taylor, D.J. Warner, F. Block and P. Têtu "Progress Report on the CERN-PS Linac" Oct. 1966 Linear Accelerator Conference.

[2] U. Kracht "A Converter for Automatic Recording of Mechanical Position". Electronic Engineering April 1967 (England).

[3] U. Kracht "Some Parameter Conversion Units used for Data Acquisition on the Linear Accelerator and the CPS". CERN MPS/Int. LIN 68-2, 1968.

[4] A. van der Schueren "Modules a Circuits Intégrés Digitaux pour l'Acquisition des Données de l'Accélérateur Linéaire et du PS". MPS/LIN Note 68-2, April 1968.

Footnote

* STAR : Système de Transmission Adressée Rapide
Total capacity : 16384 addresses permitting a transmission of 16 bit words at a maximum speed of 400.000 words/sec (Limited by IBM 1800 to 70.000 words/sec). Max. distance about 2000m.

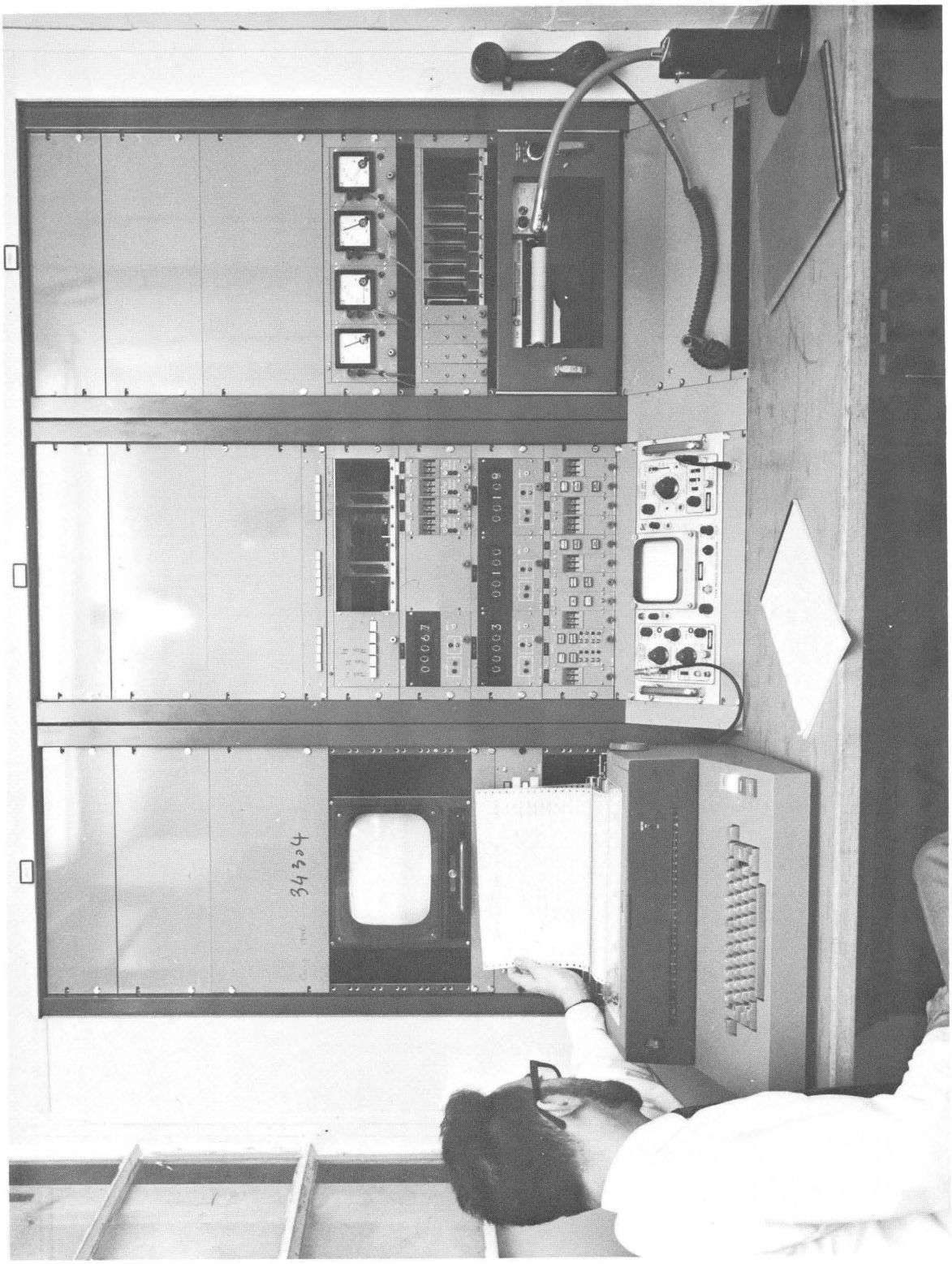

Fig. 1 The Linac Computer Terminal.

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                L I N A C   E M I T T A N C E   M E A S U R E M E N T   I N   T H E   Y - P L A N E

                ELEMENTARY CURRENTS ARE GIVEN IN TENS OF MICROAMPS.
                LIMITS=  ILILO=  60  IJWLO=   5  JW1LO=  80  JW1HI= 240  JW2LO= 100  JW2HI= 240                $IJAW  ILINAVE
                                                 MLOW=   2  MHIGH=  18   LLOW=   4  LHIGH=  18                X10UA    MA

      M20  M19  M18  M17  M16  M15  M14  M13  M12  M11  M10  M9   M8   M7   M6   M5   M4   M3   M2   M1
L  4.......................................................................................................      0    68.8

L  5.......................................................................6....7...10....5....5.................   33    69.6

L  6.......................................................7...15...20...16...17...15...11.................  101    69.4

L  7.......................................................9...29...41...39...31...23...21...13.................  206    69.0

L  8.......................................17...48...77...92...79...59...36...24...13.................  445    69.8

L  9.................................7...25...59..120..163..155..102...51...32...24...12.................  750    69.7

L 10.................................18...59..137..249..281..182...91...34...24...21...11.................  1107   70.0

L 11.......................6...10...32..116..253..412..242..127...58...26...19...18.....................  1319   69.6

L 12..............8....7...11...25...61..155..292..293..136...66...28...19...16...15.....................  1132   70.0

L 13.............10...12...18...42...83..142..171..140...73...34...13....7....8....8.....................  761    70.5

L 14..............9...13...23...50...70...85...91...62...37...19....5....5...10.........................  479    69.9

L 15..............8...13...19...27...41...50...43...28...15.................6.........................  250    70.2

L 16..............7...10...14...23...25...24...19...11.........................................................  133    70.7

L 17.......................7....5....8....6.........................................................  26    70.4

L 18.......................................................................................................      0    71.1

THE AVERAGE LINAC CURRENT DURING THE RUN WAS =     69.9 MA.
THE EMITTANCE PLOT FOR L BETWEEN  4 TO   18 AND M BETWEEN   2 TO   18 INCLUDES   67.42. MA INSIDE.
THE CURRENT COLLECTION RATIO WAS THUS =0.96
JAW CURRENT WAS MEASURED IN   126 POINTS.
TOTAL MEASURED EMITTANCE AT 50 MEV WAS THUS = PI* 46.62 MM*MRAD, OR NORMALIZED = PI*  15.37 MM*MRAD.
JOB FINISHED.

COMPUTER READY FOR MEASUREMENT
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Fig. 2 A typical emittance measurement.

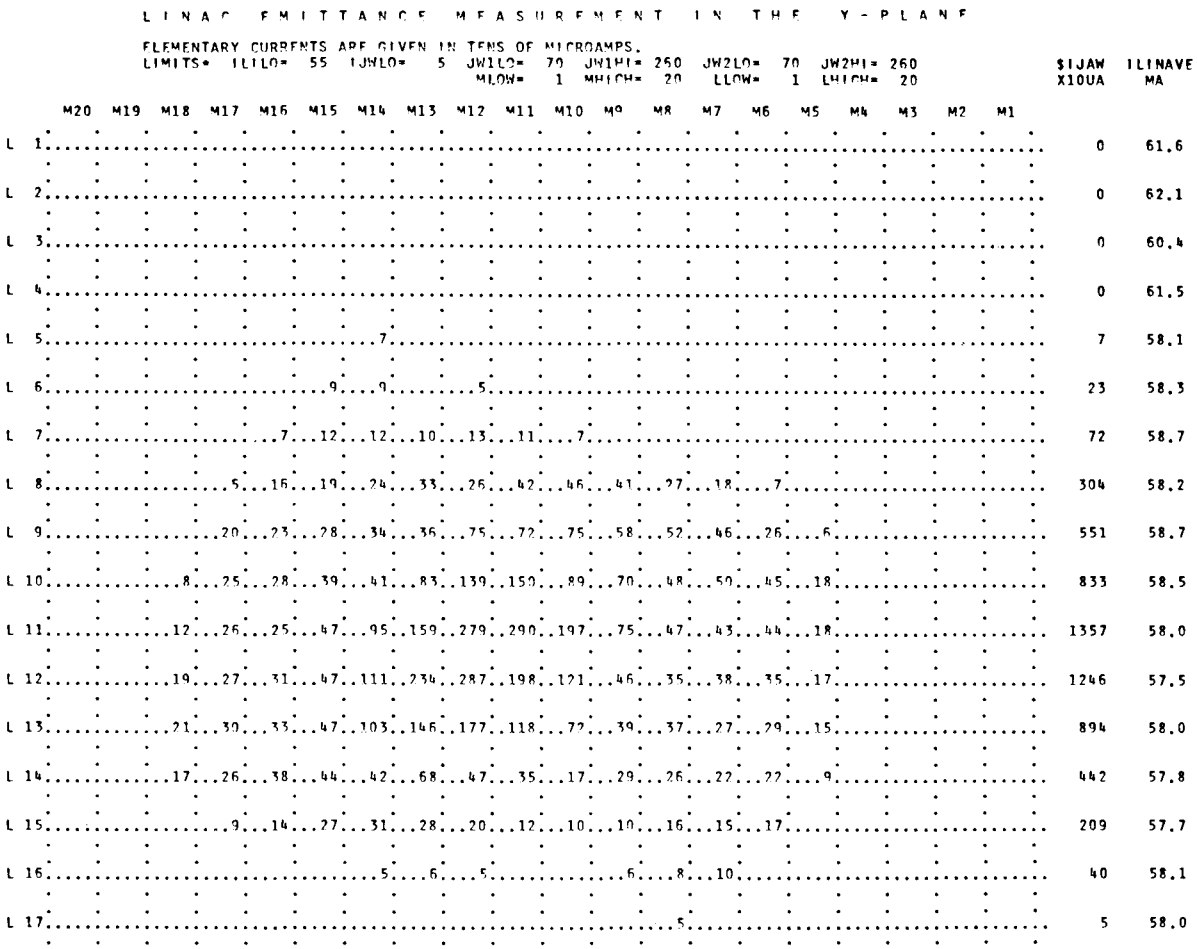

Fig. 3 An example of change in shape of the phase space area due to misadjustment of the RF of the Linac.

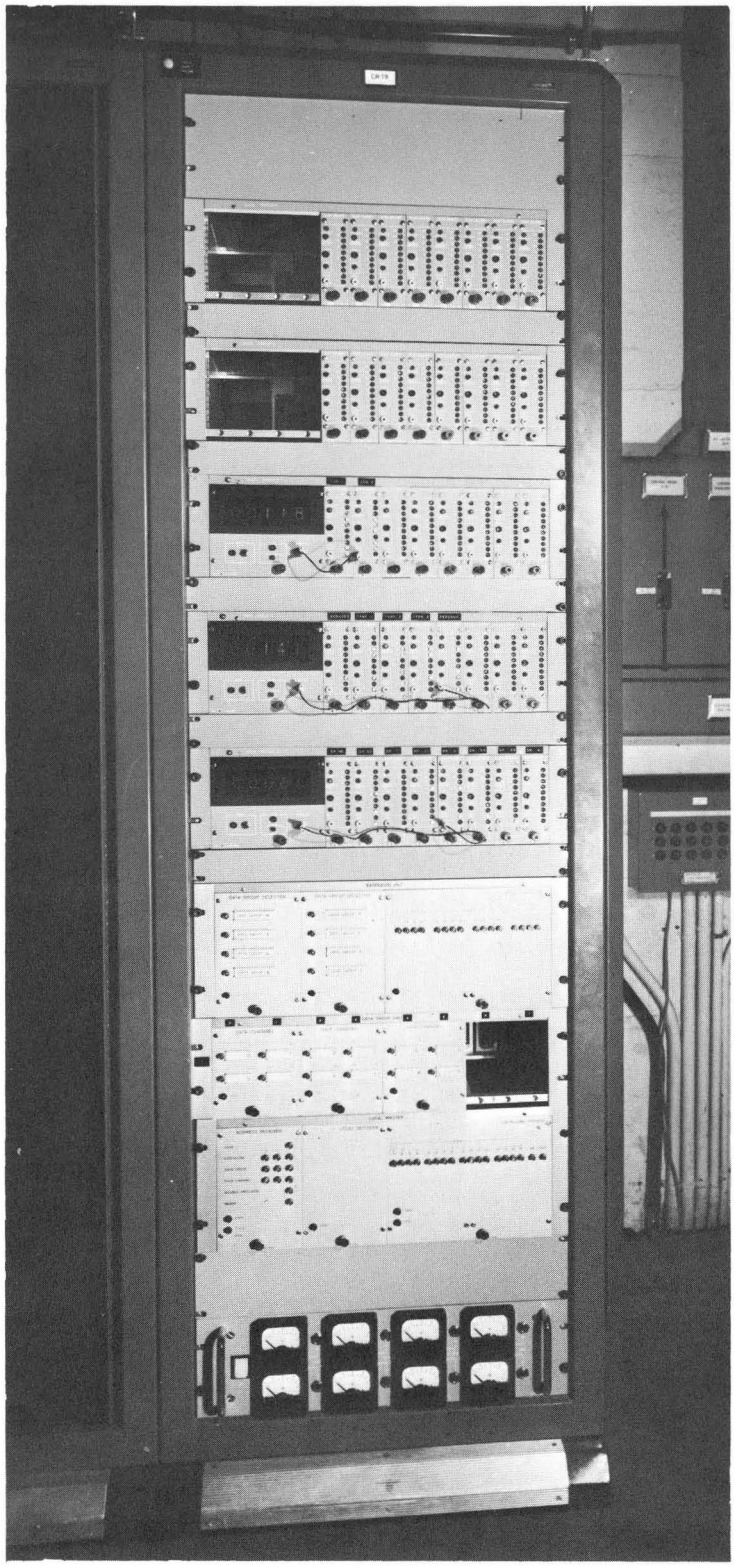

Fig. 4 Upper Part : 10 bit data acquisition scalers serving as buffer memories for forty Linac parameters.
Lower Part : local units of the "STAR" multiplexing system.