RECENT OPERATION AND MODIFICATIONS ON THE CPS - 50 MeV LINAC (OLD LINAC)

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Summary

Mainly to satisfy the requirements of the Booster synchrotron substantial improvements have been achieved on the Linac since 1970. The pulse length was increased to 100 μs and modifications on the RF-system and on the pre-injector allowed the production of a stable beam without active feed-back. These and further changes to the equipment have had a very beneficial effect on the fault rate.

An emittance line providing one measurement per pulse and a spectrometer line furnishing ten spectra per pulse are important tools for beam adjustments. Without additional drastic changes to the machine beams of deuterons and alphas have been produced recently and successfully accelerated by the PS.

Introduction

With the approval of the second stage CPS improvement program (800 MeV Booster synchrotron)[1] a certain number of changes were accepted for the Linac. These changes were finished more or less by 1972. They caused certain problems because the installation had to be done on an operating machine accessible only during very short periods (1 or 2 days every 4 or 5 weeks and another 6 weeks per year) and with a very limited amount of observation and control possibilities. In addition the new requirements resulted in an increased stress for certain old components which were conceived for lower average power and less stringent requirements on beam quality. All this and the need to provide alternate pulses with different quality to two machines - to the CPS as the normal client and to the Booster synchrotron (PSB) for its running in - resulted in a fairly unstable beam, during the pulse as well as from pulse to pulse, and a rather high fault rate. In early 1973 therefore a few requirements were relaxed. The fastest repetition rate was fixed to one pulse per second. The idea of providing an additional pulse only for the measuring equipment in the PSB injection line[2] was abandoned as well as a fast beam chopper, placed after the 500 keV pre-injector, which was complementing the fast kicker magnet switching the Linac beam to the four PSB levels[3,4]. The buncher was temporarily not used, thus limiting the Linac output current to 60 mA. Additional modifications and improvements allowed us then to obtain rapidly a stable beam with good quality.

Modifications (till 1972) for running with the Booster

The main requirement for the Booster operation was the increase in pulse length to 100 μs. The changes on the ion source were fairly simple and mainly on the electronics side e.g. increased arc pulse length. The HT of the pre-injector on the other hand, which before had a programmed compensation (bouncer) with a spark gap, needed now a proper regulation with active feed-back to achieve the desired stability ($\approx 10^{-3}$) during the pulse[5]. The power supplies for the pulsed quadrupoles of tank 1 were producing a half sine wave which was no longer flat enough during 100 μs. They were modified by introducing a higher harmonic[6]. To accelerate the long beams the pulse length of the RF power amplifiers, used for beam load compensation, was lengthened too. To satisfy the Booster requirements ($\leq \pm$ 150 keV energy spread) a debuncher system was installed in the Booster injection line[2,7] and measuring lines were provided for emittance and energy measurements[8,9].

Modifications ($\approx$ 1973 onwards) to increase stability and reliability

In order to understand the stability problems that occurred when starting to operate with a 100 μs beam pulse one has to remember the basic structure of the RF system. There is a chain starting with a transmitter up to the so-called drive-amplifier giving a 300 μs pulse of about 2.5 MW. Afterwards there are three principal amplifiers for the three accelerating cavities and three compensation amplifiers to compensate for beam loading. All are fed from the drive-amplifier via fixed power dividers. The RF output power is controlled via the anode voltage of the tubes (FTH 470 and FTH 516) by adjusting the voltage of the modulators (delay-line type). Power for the debunchers and the buncher is also taken from the drive-amplifier but through variable power dividers.

The stability of the Linac beam depends clearly on the relative stability of the pre-injector beam and the RF system. Both needed some improvements.

The main reasons for instabilities on the ion source (duoplasmatron) were discharges between the extraction grid and the plasma expansion cup provoking variations in the extraction voltage and thus changes in emittance and intensity of the proton current.

The cure was simple and consisted in removing the extraction grid with its special power supply and using the HT of the accelerating column not only for acceleration but also for extraction of the protons. The replacement of the old tube-regulated arc current pulser by a delay line with series resistor as a very stiff current source also helped the stability and increased the useful life of the oxide cathode from two months to more than a year. In addition the output current was lowered to 330 mA (from original 600 mA) without affecting the Linac output current but reducing the hydrogen consumption by almost a factor ten. This pushed the operating pressure after the accelerating column from a few x 10^{-4} Torr down to a few x 10^{-5} Torr. The result was that pressure variations after the pre-injector, which are frequent due to the presence of mercury diffusion pumps, do not cause changes anymore in beam focussing due to a variation of space charge neutralisation. These modifications[10] were supplemented by some changes on the buncher (profiting from the experience with the 3 MeV Linac[11]) and a better matching between pre-injector beam and RF compensation (moment of starting and rise time). This meant abandoning - as mentioned above - any beam chopping at the 500 keV level and increasing the power to trigger the modulator ignitrons for the RF compensation amplifiers by an order of magnitude. The firing jitter was reduced from several microseconds to about 0.2 μs. As a 1 μs variation when firing the RF compensation already causes (with no feed-back!) almost 1% amplitude variation in the accelerating cavities, one can understand the importance of correct timing when working with a long beam.

Clearly, suggestions were made to introduce fast feed-back for RF levels and phases, but to incorporate them would have needed a very big effort[12]. Instead the stability of the whole RF system was improved.

The servo tuner system for the cavities was speeded up to cope correctly with fast temperature variations. The modulator stability was improved to 10^{-3}. The three output coupling loops of the amplifiers were replaced by one only - giving a higher output power- and connected to 6" rigid lines, replacing the cables which joined the old loops together. The introduction of a variable line length between amplifier and accelerating cavity made proper matching possible, i.e. fulfilled three conditions:

- rapid rise of cavity RF level
- no sparking inside the amplifier, especially during the filling period of the cavities
- minimised interaction between principal and compensation amplifier before and during the beam pulse.

The replacement of cables on the input side of the RF amplifiers by rigid lines helped again to gain some power. The final set-up of the RF system now gives sufficient field levels in the three accelerating cavities without pushing the anode voltages on the amplifiers to levels where sparking is likely to occur.

Another improvement to the stability was the introduction of circulators before the debunchers in order to avoid undesired feed-back to the output of the drive amplifier which mainly influenced the RF level and phase for the first accelerating cavity (due to the distribution of power dividers). Now the passage of a high current beam - even at non zero phase - or detuning of the debunchers in order to keep the phase stable during the passage of the beam (there is no compensation amplifier to compensate for beam loading) has no effect on the incoming beam anymore.

In general it is now possible to set up the Linac in a standard way and identical settings reproduce the same beam characteristics. This is naturally helped by the introduction of many more monitor signals notably from the modulator currents and from the RF phases in the cavities during the passage of the beam. The use of transient recorders to compare (superimposed on the same scope screen) old signals and updated signals facilitates adjustments.

Reliability

The modifications described above and another one on the vacuum system for the acclerating cavities - the replacement of mercury diffusion pumps and a special refrigeration system by turbomolecular pumps - had a very good effect not only on the beam quality but also on the down time of the Linac (Fig. 1). The big impact with the introduction of intermediate pulses for the Booster together with the increased pulse length in 1972 is clearly marked. The result of the changes in 1973 and afterwards is also visible. Not shown on this statistic is the number of missing or bad pulses which - on the whole - have been frequently as bad as the ordinary down time. Today missing or bad pulses are of no real concern anymore. It is interesting to mention that almost half of the downtime of 1.53% in 1975 is explained by a single fault of one system only (pulsed quadrupole supply for the first cavity): 40 hours out of 94.8 hours total down time. It is clear that with fault rates of ≈ 1% a single catastrophe can change the situation drastically. In addition it must be stressed that the reduction in down time can only partially be explained by improving the equipment. The care with which work is carried out during maintenance periods or during repairs plays also an important role. Naturally better care is taken if it can be checked with some monitoring system afterwards. One should mention also that the life-time of the FTH tubes in the RF amplifiers has been increasing from about 5000 hours to about 7000 hours, explained by better servicing, better parameter control and lower anode voltage than in the past.

Beam measuring systems

The typical 80 mA (only quite recently 90 ... 100 mA) delivered to the Booster are very near the lower limit of what is needed to provide 10^{13} protons per pulse in the PS. The quality of the beam is therefore of utmost importance. To check this two measuring lines are installed,[8,9] to measure either emittance or energy spread. Today normal operation is: one out of two pulses goes to the Booster, the second goes to a measuring line. The emittance can be measured in one plane during one pulse. A sample of 10 μs is swept across a slit (radial position corresponds to the timing moment) and the angular distribution is measured with a set of Faraday cups located behind. The emittance can be adjusted manually to a standard shape acceptable by the Booster. The spectrometer uses a secondary

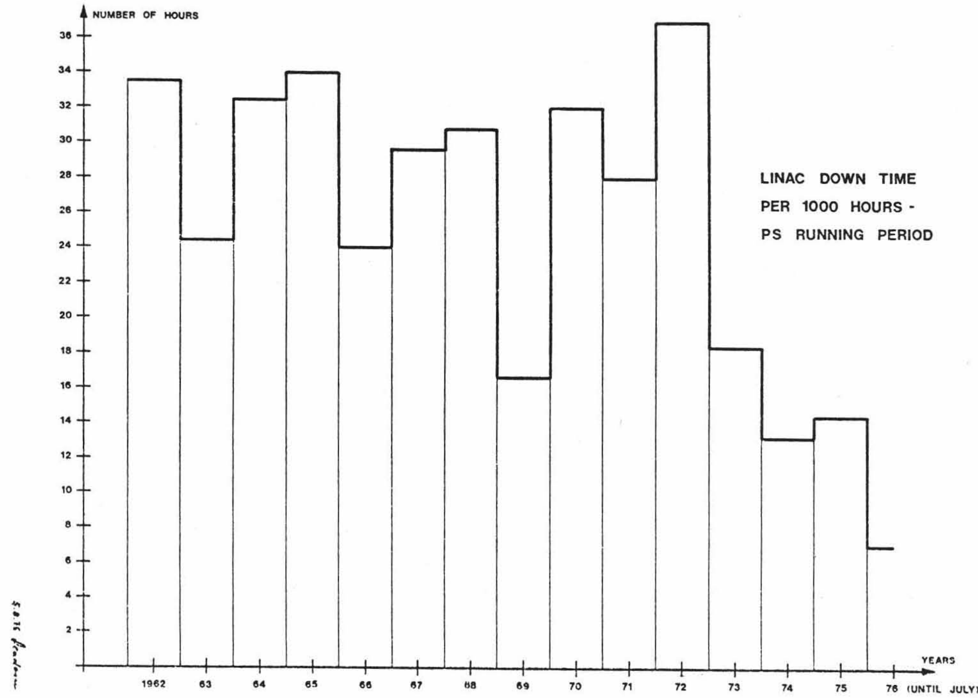

Figure 1.

emission detector and can normally produce one dispersion curve at a certain moment per pulse (Fig. 2)

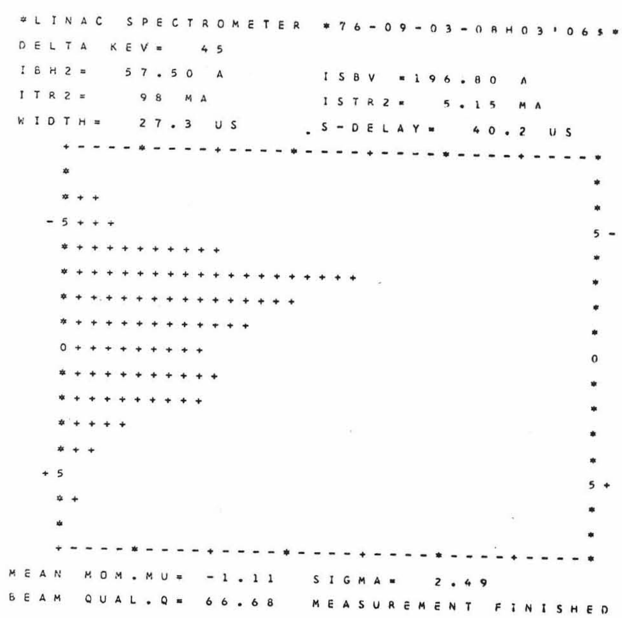

Figure 2.

Whereas the emittance is practically not changed during the pulse, the energy spread and the mean energy can show rather large variations. In order to facilitate adjustments of the RF an additional device has been developed. In front of the spectrometer detector a fast magnet is excited with a 50 kHz sine wave. The centre of the detector is thus looking at different portions of the spectrum at different times. This signal is, together with the deflection angle, used to provide a mountain range display of effectively 10 energy spread curves per pulse (10 measurements in 100 μs). This display and an emittance measurement as displayed by the computer are shown in Figs. 3, 4a and 4b.

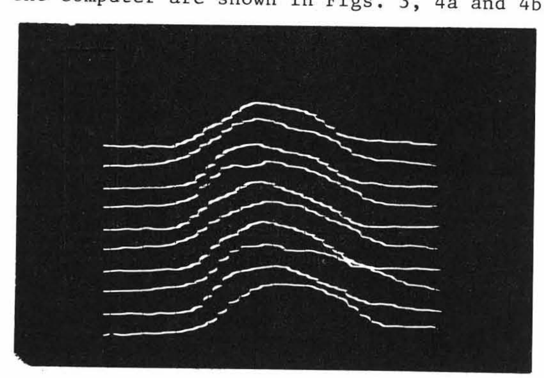

Figure 3.

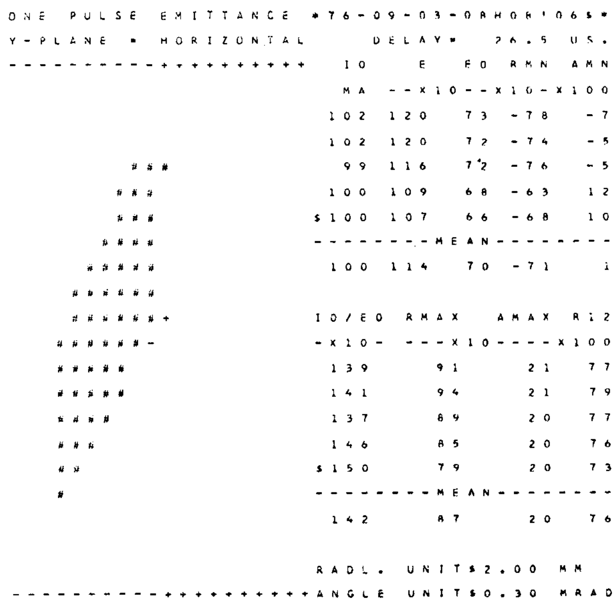

Figure 4a.

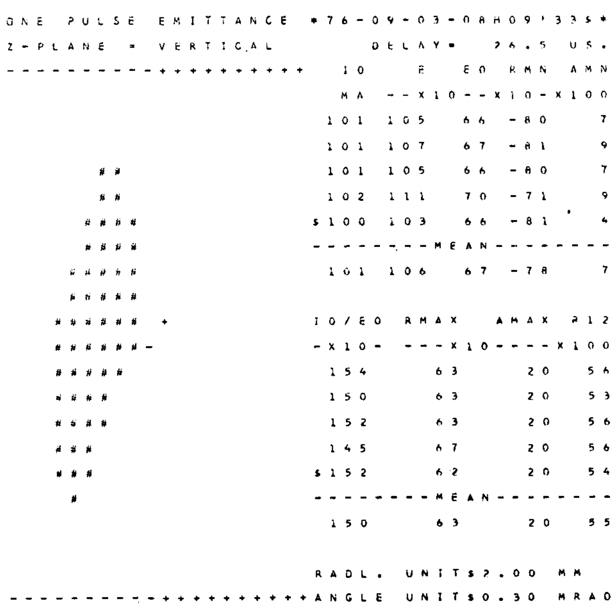

Figure 4b.

Acceleration of deuterons and alphas

The acceleration of deuterons has been tried because there was some interest from high energy physicists especially at the ISR. Already in 1964 T. Sluyters achieved 7 mA with a short pulse (10 μs). This year we were able to accelerate 13 mA with 100 μs pulse length[16] – already too much for the PS (space charge limit). Recently a test was made with alphas which gave 2 mA. Acceleration had been tried already successfully in the PS with only 1.2 mA from the Linac. The main difference to normal operation is the adjustment of quadrupoles and the RF tilt in the first cavity. Acceleration is done in the 2 $\beta\lambda$ mode, keeping the momentum of d's or α's the same as for protons. In the case of deuterium, source adjustments are similar to hydrogen, whereas when running with helium the arc current is raised from 80 A to 130 A and the gas pressure is lowered. This yields about 20% He^{2+} in the beam.

The current out of the Linac compared to the current into the first cavity is for protons 50%; for deuterons 20% was achieved. For He^{2+} the ratio is probably the same, but was not measured because of the high percentage of He^{1+} in the beam entering the first cavity.

Acknowledgements

It is clear that the good performance of the Linac today could not have been achieved without the active help of many old and new members of the Linac Group. Special thanks are certainly due to P. Rasmussen for his help to increase the stability of the RF modulators, to W. Pirkl, who provided a comfortable level of RF power, to P.H. Standley for his tremendous support – morally as well as practically – and last but not least to the present Operation crew for their good spirit in difficult situations, for their careful preventive maintenance and for their competence during repairs.

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