PERFORMANCE OF THE PS LINAC

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I. INTRODUCTION

With the exception of a recent increase of peak current to 75 mA the machine's characteristics remain much as reported at Dubna.[1] It has, however, revealed an appetite for deuterons.[2]

In these notes we shall mention briefly the minor changes which have taken place, describe some of the developments in the duoplasmatron and short column studies and in instrumentation, and conclude with some of the practical aspects of operation.

II. PREINJECTOR

1. RF Ion Source

Reductions in the height of the cathode protection brought increases in the source output current, with more than 300 mA observed in the laboratory. Further reductions however produced instability. A normal working current is 220 mA.

A miniature Faraday cup was used to scan the beam 30 mm from the source outlet and indicated a roughly triangular current density distribution.

2. Focusing and Beam Transport

The maximum current observed till now at the earth end of the column was 220 mA, but only 140 mA reached the input of the first tank.

The emittance "blow-up" factor of 2 to 3 in the lens and column is largely responsible for this loss, and is believed to be due in part to a time dependence. Recently we rearranged the column electrodes for greater acceleration at the source end with the object of reducing the lens strength required and hence of increasing the minimum particle velocity in the lens. This only reduced the 500 keV emittance by 10% for the same current.

It is believed that aperture limitation in the first triplet also contributes to the beam loss, and so the triplet diameter will shortly be increased from 40 to 50 mm. The increase in peak current to 75 mA followed the widening of the second triplet aperture from 40 to 50 mm and the buncher aperture from 30 to 40 mm.

3. High Tension

New control circuits were installed towards the end of last year to permit:

(i) Automatic formation of the column, 0-500 kV in 3 hours, advisable after extended work on the column at atmospheric pressure.

(ii) Manual formation to 250 kV and automatic to 500 kV in 2 hours.

(iii) Fast automatic voltage rise 0-500 kV in 3 minutes.

Other items of interest are:

(a) An automatic restart circuit, which tries twice to reapply full H. T. after breakdowns and then shuts down the H. T. set. The breakdown rate averaged over 2-week runs varies between 1 and 3 per day.

(b) A multi-channel pen recorder for the continuous monitoring of voltage, column current and vacuum pressure simultaneously. A fourth channel is available for other parameters as required.

As a routine check on the state of the H. T. set, power factor is measured twice a month, and a precision measurement at the column divider resistor chain is made monthly in order to detect any incipient fault in this component. The present chain has been in operation for 2 years without trouble.

III. ADDITIONAL 500 KEV ELEMENTS

1. Harmonic Buncher

A second harmonic cavity has been added to the 200 Mc/s buncher cavity but awaits completion of the 400 Mc/s generator.

2. Chopper

An electrostatic deflector and power supply has been built to permit chopping of the 500 keV beam at the P.S. injection frequency (3 Mc/s) with variable mark to space ratio. This should relieve the linac rf system of charge which would lie between the synchrotron rf buckets and would be lost anyway. This will be installed and tested shortly.

IV. DUOPLASMATRON AND SHORT COLUMN DEVELOPMENTS

Following the plasma expansion cup developments in Leningrad, we have made some tests on different cup and extraction geometries. These were encouraging and the best beam for which we have complete figures was 450 mA at 100 kV in a phase volume of 0.59 cm mrad, giving a brightness of 130 mA cm^{-2} $sterad^{-1}$.

Assuming that high gradients are useful in controlling beam blow-up along the accelerating column, we have also been exploring the behaviour of different electrode materials in a re-entrant column arrangement. Use of a conventional column for these tests (13 - 40 kV sections) enables us to put aside the air breakdown aspect of a short column for the time being while profiting from the range of potentials available for supplying intermediate electrodes.

The test setup consisted of the column within which two electrodes of the new material, carefully cleaned and polished, could be separated by a known gap. Cathode current, anode current, anode temperature, radiation level and voltage were monitored. The best materials were found to be low carbon stainless steel and titanium alloy as used for supersonic aircraft. At a pressure of 2×10^{-6} mm Hg provided by a mercury pump and liquid nitrogen baffle, we could hold 500 kV over a 10 cm gap.

Preparations are being made for testing the combination of duoplasmatron and high gradient gap in the laboratory. If successful, we plan to install it on the linac early in 1965.

V. INSTRUMENTATION

For emittance measurements the aperture-lens-aperture method is used where quick checks are required or where time dependence is suspected. Formerly it held another advantage in that it also yielded density distribution across the phase space, but the photographic emulsion method has now been developed to the point where the emulsion can be calibrated and made to supply contours as well as envelopes. These developments are described in references 3, 4.

The method was recently adopted for measurements of the first turn in the P.S., one wavelength downstream from the point of injection. A series of 24 exposures was made for different injection conditions, permitting estimates to be made of aberrations in the first P.S. wavelength, the acceptance of this section, and the matching achieved.

VI. OPERATION

1. Machine Reliability

The scheduled P.S. time which is lost due to linac faults remains at around 2% in spite of a fairly serious breakdown in May when 48 hours were lost in stripping down on FTH cavity and replacing the input loop which had flashed across at a metal-epoxy joint.

The FTH 470 tubes themselves have averaged 7000 hours, with one lasting for 11,000 hours.

2. Machine Stability

The pulse-to-pulse stability remains good but the P.S. is rather sensitive to mains voltage variations. The linac contribution to this seems to come from the modulators which are at present not regulating very efficiently.

There are certain major items of equipment which one expects to run without much attention, for example, the mercury vacuum pumps, the FTH cavities, the high-power phase shifters and power dividers, and the refrigerator compressors. After five years' running, however, we are finding that the pumps take longer to pull a tank down, and that breakdown occurs occasionally in the phase shifters and power dividers, provoking flash-over elsewhere in the rf system and reducing the range of adjustment, making the whole chain more critical of adjustment. We have also had the complete failure of an FTH cavity already mentioned, and recently the failure of a compressor.

We are therefore turning our attention to the overhaul of these items, one by one; this has involved for the mercury pumps the construction of a separate ventilated lab for cleaning and speed measurements on a dummy tank.

3. Setting-Up

The present rhythm of P.S. operation allows us from Sunday through Tuesday twice a month for maintenance and repairs, source changes and measurements, with machine start-up on Wednesday. In the absence of faults it is sufficient to take standard values for source, rf and focusing, and trim around these values by successive approximation, progressing along the machine. The final criteria are intensity and pulse shape at the point of injection into the synchrotron, and 50 MeV emittance and energy spread. The emittance at 500 keV is also measured as a routine procedure.

4. Running

When the beam is handed over to the P.S. Main Control Room for injection, certain controls are also transferred and the linac control position is abandoned. A linac operator remains "on call" for fault repairs and readjustment, but otherwise works normally within reach of a telephone in his laboratory or office during the day, or sleeps in the operators' dormitory at night.

The controls transferred include the bending magnets, triplets and the vertical steering coils in the inflector region, variable apertures and the tank levels. The transfer of tank level controls and indications is questionable in principle, but the retouching of tank levels by the M.C.R. operators seems justified with the present stability of the modulators.

VAN STEENBERGEN: When you saw an increase of current, did you see increase in emittance?

TAYLOR: It didn't make a great deal of difference; the 50 MeV emittance is always around about 3 cm milliradians and it did not change very much.

HUBBARD: These standard operating values that you use to start up after shutdown, are they a set of values that do not change over a long period of time or are they just the ones you used when you turned it off before?

TAYLOR: Actually, by the control position we have a little piece of paper with them all marked down; this has been around for a year or so, and it is still the one we use.

WROE: You mentioned right at the beginning that you had reduced the height of the cathode shield. Could you say how much you reduced it by and what difference it made?

TAYLOR: I can't give you the exact figures, but it was the order of 1 or 2 mm. This pushed us up to the 300 mA from the source. We had been previously in the 200's.

WROE: We tried it at one time and it did not make any difference.

BLEWETT: Do you have any evidence of x-ray emission?

TAYLOR: No.

NORDBY: I was wondering about the 3 Mc chopper. Do you have any information on its operation?

TAYLOR: It is a couple of parallel plates with about 10 kV across them. We haven't used it yet. We had some trouble getting sufficient power in the driver stage.

NORDBY: Also on that photograph method, do you have any trouble with the surface building up potential and giving you erroneous readings?

TAYLOR: No.

OHNUMA: You mentioned about the routine measurement of the beam shape in the transverse direction. To what extent can you use the results of those measurements for adjusting the focusing system between the preinjector and the linac?

TAYLOR: It is almost entirely an empirical type adjustment. We do it rather as a check on the performance of the preinjector.

OHNUMA: Is it something you could probably control by, say, on-line computers or anything like that?

TAYLOR: We have got for the normal method at 50 MeV this arrangement of the slit, lens and a slit. This defines in the phase plane of the first slit a strip like this, which is swung around through 90° by the lens and drift system to the second slit where we further limit to a small rectangle in the phase plane. Now what we have done recently is to make up a new set of slits from which we can take digital information, with the object of feeding this to a computer eventually.

VAN STEENBERGEN: Have you noticed at those high currents any beam intensity modulations? Have you noticed with the duoplasmatron source, any plasma boundary instabilities?

TAYLOR: No, not yet.

VAN STEENBERGEN: At the high currents, with the duoplasmatron source, one finds that the beam extracted from the ion source shows hash or intensity variations. Does this exist with the rf source?

TAYLOR: Apparently not. The pulse shapes are always very clean. In the early days we found in the synchrotron a 60 Mc component and it looked as though it was beating between the rf frequency of the source, which is 140 Mc, and the tank which is 200 Mc. But as far as hash is concerned, we have not observed any problem.

NORDBY: We found some hash in the Argonne duoplasmatron source and we got rid of it by putting a small capacitor on the extractor supply.

FEATHERSTONE: I wonder if you know approximately what proportion of the beam current you quoted from the source is protons?

TAYLOR: Yes, it is between 90 and 95%.

FEATHERSTONE: Excellent. Also, have you a feeling as to the kind of electron current that flows up the column to produce unwanted x rays at the top? In other words, if this is the actual proton or positive current going down the column, the person who designs the bouncer to maintain stability on your Cockroft-Walton system has to contend with the electron loading as well. And I haven't seen figures quoted on what this amount is on typical installations.

TAYLOR: We said a little in the Dubna report. We've got a fairly big capacitor across the generator. And I gave some results, I believe typically 4 kV drop during the pulse. Measurements over a long period show that normally we have about equal electron and proton currents, occasionally rising to electron currents twice the proton current.

VAN STEENBERGEN: I would like to add to this question of Featherstone's. At High Voltage Engineering they mentioned that they normally take a factor of 2 into account. If you take 100 mA proton beam down one way, you count on a 100 mA of electrons the other way. May I ask at the same time, with the duoplasmatron source and the expanded plasma, are there any figures existent yet on proton percentages?

ANSWER: No.

VAN STEENBERGEN: One might worry here that the proton percentage might be drastically down from the conventional duoplasmatron source.

GUILBAUD: Could I offer a comment that we made such a duoplasmatron in our laboratory with expanded cup and at 40 kV we measured about 300 mA but these were protons. We had a magnetic focusing which took only protons on the target. I think I remember the proton percentage was estimated to be somewhere around 75%, but I am not sure.

WADDELL: The other day when you were talking about the machine, you described there that the phase between the first and the third cavities was zero and that the second cavity turned out to have a phase difference. You indicated at that time that you got a sharper beam, less spread at the end, and I was wondering if you were tuned for maximum current, whether you arrived at a similar condition without looking for the sharper energy spread.

ANSWER: The current in fact is determined by the level of Tank one and the focusing and matching, and thereafter it stays pretty well constant through the machine. You have to move the tank level a long way to drop the current and by then you would have a completely unacceptable beam.

QUESTION: The other day you indicated that the second tank had a different phase than the others and that at that time you got better energy spread operating in that mode. Is this reflected in the overall current acceptance?

TAYLOR: If you put the tanks in phase, you get about the same sort of current, but worse energy spread.

FEATHERSTONE: I am also interested in your high voltage experiment at 500 kV. When you say you were holding this across 10 cm, would it represent a voltage reached after a succession of conditioning sparks had been permitted to occur, or would this system be something that just never sparked at all?

TAYLOR: This is something which you form watching the sparking. You bring the voltage up gently, and reach a level where you get a low frequency of sparking.

FEATHERSTONE: So the sparking rate essentially drops off exponentially and after a time it becomes a negligible matter.

TAYLOR: Yes.

MORGAN: I believe you mentioned that you had about 220 mA of current out of the source and about 200 mA at the 500 kV level. Do you have any idea what happens to this 20 mA difference?

TAYLOR: We've got 300 mA maximum coming from the source and 220 mA maximum at the bottom of the column, and we think that the difference is scraped off by the aperture limitation at the end of the column. We have our first focusing triplet actually integral with the first accelerating electrode of the column.

MORGAN: I believe you extracted the high current at 28 kV; have you tried extracting it at higher gradients or higher potential levels?

TAYLOR: Yes, but that is about the limit of stable operation.

HUBBARD: I would like to ask Van Steenbergen about the electron drain number he quoted from High Voltage Engineering. Is that with one of their new inclined gradient columns or is that with the old-fashioned kind?

VAN STEENBERGEN: I couldn't tell.

REFERENCES

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4. C. Bovet and M. Regler. "Etalonnage d'emulsions pour les mesures d'emittance." MPS/Int. LIN 64-2.