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FACTORS AFFECTING H^- BEAM PERFORMANCE IN THE FERMILAB LINAC

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Summary

Addition of an independently controlled heater and a grooved cathode to the magnetron ion source has signigicantly improved source lifetime and consistency of performance at the 50-mA beam level. Emittance measurements at 750 keV and 200 MeV are shown with comparisons between flat and grooved cathode sources and for variations of other conditions. The dramatic effect of beam space charge is shown in comparison with neutralized beams. Some variation of linac emittance with linac quadrupole tuning is explored.

Introduction

The Fermilab 200-MeV linac was converted to H^- operation in early 1978 with the installation of a second 750-keV preaccelerator and an H^- ion source. The reasons for this conversion were to provide charge-exchange injection into the booster accelerator and to accommodate the cancer therapy facility and electron cooling ring on a time-sharing basis. With the overall success of H^- ion versus proton operation the original proton preaccelerator was also converted to H^- operation. Initial operation of the linac with H^- ions required little change and stable operation of the linac occurred in a matter of hours.

The H^- magnetron source is now in use at several laboratories so that considerable experience and several improvements have occurred. With these improvements the source lifetime, stability and performance have improved dramatically.

Changes in the linac performance were observed recently. Studies of the problem areas have been initiated.

Ion Source

The H^- magnetron ion source as originally used at Fermilab was described in 1979[1] and 1980[2]. Operation and improvements of the source at other laboratories have been reported recently[3,4].

In 1981 a problem developed with one of the two Fermilab sources which prevented its normal operation after 8 to 12 hours from start-up. Normally in a good source, once cesium has entered, the source starts in a low plasma-current (few amps), high plasma-voltage (> 200 V) mode. After several hours the current rises to 140 Amps while the voltage decreases to 140-150 Volts as the cesium reaches optimum condition, the cathode becomes hot (400-500 C.) and the source hydrogen pressure is adjusted (decreased). A good source operates ~2 months at this level producing 40-50 mA of H^- ions after 12-24 hours of conditioning and careful adjustment of the source parameters. In the problem system the high current, low voltage mode would occur but soon after revert to a high voltage condition with a very unstable plasma. Maintaining even unstable operation required high gas pressure and resulted in very erratic low-current H^- ion beams making the source unusable. Fortunately, during this period sources continued to work well in the second preaccelerator system. For over a year the problem in the 'bad' system persisted even though magnetron assemblies from the good, bad and test bench systems were interchanged.

The cause of the source failures was suspected to be a contaminant in the vacuum system which poisoned the source surfaces after several hours of operation. Investigations of optical spectra of the plasma emissions, surface analysis of the source and system, and residual gas analysis produced no definitive results. The vacuum system was thoroughly dismantled and cleaned but still the failure persisted.

During this period, Witkover, at Brookhaven experienced a similar problem[5], possibly due to different causes, and at the suggestion of Sluyters[6], grooved the source cathode as a possible solution. The grooved cathode not only solved the problem but gave superior performance over earlier source operation. Meanwhile at Argonne, Stipp also used a grooved cathode to achieve improved source performance[7]. Following these successes a grooved cathode was installed in the Fermilab problem source. In addition to the grooved cathode, a resistive heater was placed around the source body (fig. 1). Both Brookhaven and Argonne maintained the temperature necessary for proper cesium condition by increasing the arc duty factor to compensate for the lower arc current used with the grooved cathode. At Brookhaven the pulse length was increased while at Argonne the repetition rate was increased to meet the needs of each facility. At Fermilab the resistive heater proved very useful in maintaining the source temperature without having to change the duty factor. With the independent heater the source can be started more quickly, the source temperature can be optimized independently of the arc parameters, the plasma condition can be changed to give different ion currents without significantly changing the source operation, and the lifetime can be maximized by keeping a low duty factor.

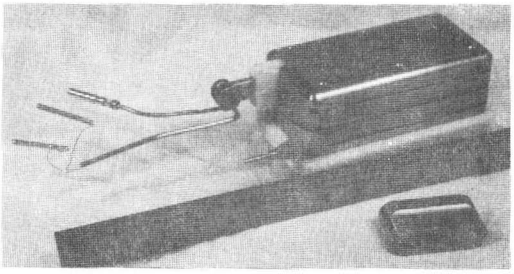

Fig. 1. H^- magnetron source showing resistive heating element around source body (anode). A grooved cathode from within the source is in front. Cathode electrical connection and thermocouple are on left side and anode beam aperture is on top.

The heated and grooved cathode source is now used successfully in both systems. The parameters for this source are given in table I and a 54-mA H^--beam pulse from the column at 750 keV is shown in figure 2. This source has been operating smoothly for six months. The previous source operated eight months before showing a slight decrease in beam.

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Table I. Ion source parameters

Repetition rate	15	Hz
Arc width	85	μsec
Arc voltage	140-150	V
Arc current	35	A
Source magnetic field	1-1.5	kG
Cathode temperature	400-500	°C
Anode temperature	250-300	°C
Cesium boiler temperature	130-140	°C
Cesium valve and feedtube temperature	>250	°C
Source chamber pressure	3×10^{-5}	Torr
Extraction voltage	18	kV

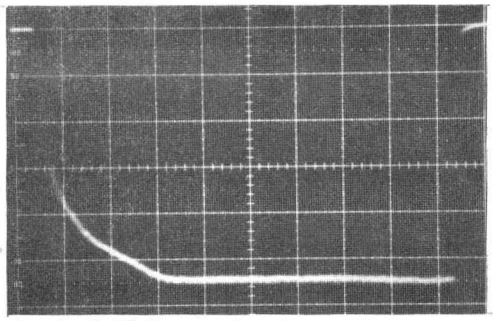


Fig. 2. Typical H^- beam pulse from 750-kV accelerating column. Vert: 10 mA/Div., Horz: 10 μsec/Div.

The notable changes in the source parameters which have led to the improved performance and lifetime are the lower arc current (150 down to 35 Amps) which has reduced sputtering and erosion of the cathode, and the lower cesium boiler temperature which results in a lower consumption and deposit of cesium outside the source. The beam pulse is stable to a few mA for many months with noise variations being less than a few percent. Careful comparison between the grooved and previously flat cathode sources has shown little if any change in the emittance following the 750-kV column. The normalized emittance for 90% of a 50-mA H^- beam from the preaccelerator at 750 keV, as measured by a slit scanner, is:

$E_{nh} = 1.0\ \pi$mm-mrad, $E_{nv} = 1.5\ \pi$mm-mrad.

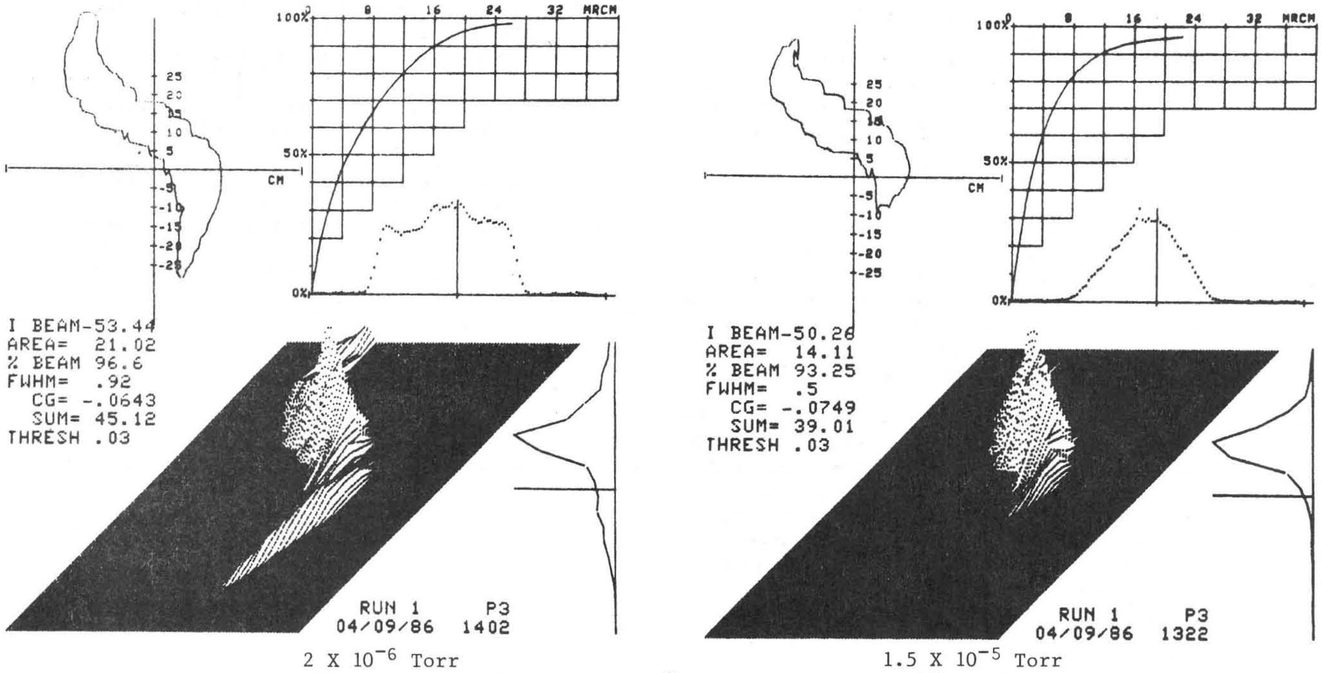
Beam Transport and Linac

Following switchover to the new micro-processor control system in 1982, the linac was without a beam-emittance measuring facility until D. Bogert and R. Goodwin reconstructed the required computer programs in September of 1985. Emittance measurements after this date showed the 200-MeV emittance to be higher than the best running values of the 1978-82 period by approximately 50%. During the next several months occasional attempts to understand this difference were made at times when adjustment of linac and source parameters would not disturb the programs of the booster, antiproton source and cancer therapy facility.

To test their effect on beam emittance, several changes were tried. These included different quadrupole strength distributions in the first linac tank and in the two preaccelerator 750-keV transport lines (4 meters and 10 meters in length)[8], variation of the ion source parameters and use of both grooved and flat cathode sources. Some of these changes (excluding ion source changes) independently lowered the 200-MeV emittance to values 25% over the 1978 values in the current range of 30-35 mA. Combining these beneficial changes gave no further improvement.

Table II shows some of the better operating emittance values throughout the linac for the two time periods. One notes the rather typical emittance growth of roughly a factor of two in the 750-keV transport line and in tank 1 of linac.[9] Exceptional cases have shown growth in the remainder of the linac.

When the grooved cathode source was used the transport line pressure decreased due to lower source gas consumption while the beam typically exceeded 50 mA. Under these conditions, possibly combined with the line tuning, severe distortions of the emittance area at the linac entrance has been observed for both lines due to space charge forces. Raising the hydrogen background pressure from 2 to 15 microtorr (equivalent nitrogen pressure) by throttling the pumps at the beginning of each line increases the neutralization by background ions and the distortions are significantly reduced or eliminated (fig. 3). The higher pressure causes a small loss in intensity (2-5%) but appreciably



2×10^{-6} Torr

1.5×10^{-5} Torr

Fig. 3. Emittance plots at linac entrance for ($2 \times 2\ 10^{-6}$) and high (1.5×10^{-5} Torr) pressure.

reduces the effective emittance and under favorable conditions has reduced the linac output emittance by 20%. Allison has made a detailed study of beam neutralization in a background gas[10].

Table II. Emittances for H^- beams.

	PREACC OUT	LINAC IN	TANK 1 OUT	LINAC OUT
ENERGY	750 keV	750 keV	10 MeV	200 MeV
CURRENT	∿50 mA	∿50 mA	∿35 mA	∿35 mA
1978-1982:				
E_{nh} =	.9-1.0π	2.1π		3.7-4.2π
E_{nv} =	1.5π	2.3-2.6π		3.9-4.6π
1985-1986:				
E_{nh} =	1.0π	1.8-2.3π	5.0π	5.0π
E_{nv} =	1.5π	2.3-2.6π	5.3π	5.3π

E_n = (90% AREA) X $\beta\gamma$ mm-mrad.

The quad settings in tank 1 which gave less emittance growth had a relatively smoother distribution of gradients (both high and low) than the present operating quads. The higher gradient settings from the years 1969 and 1980 gave somewhat more improvement than the lower gradient settings of 1971.

Further changes reduced the accelerated beam current through the linac. These included reduction of ion source beam current, reduction of tank 1 or buncher gradient, change of buncher phase and even mistuning of the transport line and reduction of preaccelerator beam energy. The emittance at 200 MeV as a function of beam current is shown in figure 4 for all these maneuvers. Although not labeled on the plot, the trend of reduced emittance at lower current is still true for those cases when full source current (and full emittance) enter the linac but beam capture is reduced by rf adjustments to the buncher and the first linac tank. The beam property common to all methods of beam reduction is less space charge in the linace (at least after the first few cells) and therefore the opportunity for weaker non-linear forces. In addition, in several but not all cases there is less longitudinal emittance area created by the bunching rf fields with the attendant potential for coupling with the transverse motion.

Investigations are presently underway in another area which should have only minor connection with the emittance problem. The linac has not been realigned since its installation in 1970. Beam position analysis shows evidence for misalignment of the 200-MeV beam-diagnostic line with the linac and some further misalignment of tanks and a few individual quads as well. Measurements of beam position changes at scanning wires in the 200-MeV line as each quad or pair of quads is excited to 20% over nominal gives a picture of coherent betatron oscillations of varying amplitude and sudden phase shift throughout the linac. The motion is more pronounced in the horizontal than the vertical plane. Recent optical surveys have shown tilts in some of the tanks and offsets of a few quads by ∿0.025 in, which are in the process of being corrected. Possible tank movements have yet to be decided.

Resolution of the emittance problem is not yet complete. Our belief is that the enlarged linac emittance is real and that it can be lowered to its former value through a combination of selecting appropriate quadrupole fields in tanks 1 and 2, and careful adjustment of the 750-keV line. Operation with improved quad settings has not been possible because of insufficient time to reestablish the match to the 66-MeV cancer therapy line. Additional time will be required to fine tune the 750-keV line to minimize emittance growth and reduce the effective area presented to the linac.

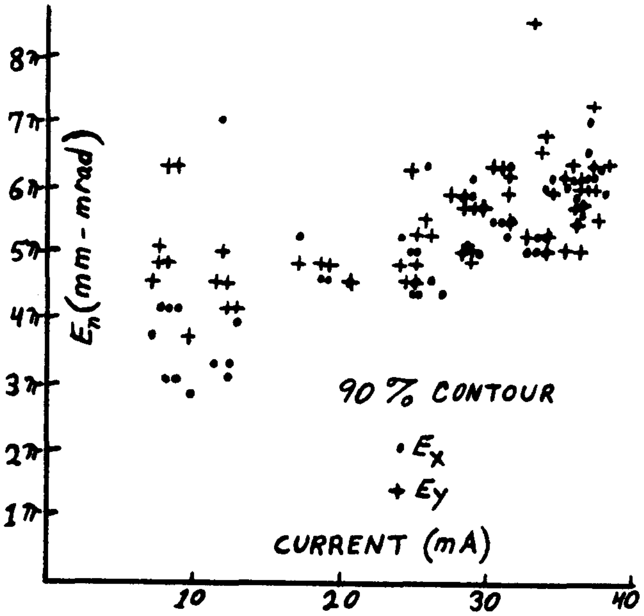


Fig. 4. 200-MeV linac output emittance versus beam current for various tuning conditions.

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