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THE HEIDELBERG MP TANDEM VAN DE GRAAFF

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Properties and improvements of the Heidelberg MP tandem are reported. The upgrading to terminal voltages of 13 MV and the installation of new components are discussed in detail. The performance of the machine and projects in future such as the installation of a pelletron charging device and a nanosecond beam pulsing system are described.

1. Introduction

The Heidelberg MP tandem Van de Graaff was installed by the High Voltage Engineering Corporation in 1967 as MP No. 5. The final test of its guaranteed properties was performed in June of that year. Since then the machine has been operated for more than 45 000 h under mostly satisfying conditions. Longer lasting interruptions were only caused by changing the charging belt (in 1968, 1969 and 1972) and by the installation of a set of new accelerating tubes in 1970. In between some modifications of the system, especially on the column structure, have been carried out to improve the operation reliability.

Immediately after the installation the complete HVEC vacuum pumping system (Hg diffusion pumps) was replaced by a system of turbomolecular pumps similar to the one which had already proved to require much lower maintenance at the 6 MV EN tandem.

Within the first three years the most frequent failures of the machine were caused by potential rings opened by vibration or shock waves and by broken contact springs fallen down to the tank floor. These springs had been connecting the electrodes of the tubes with the formerly U-shaped, open ended equipotential planes of the column. After having mounted shorting bars between the open ends, no spring was damaged any more. To prevent potential rings from jumping off the supports have been improved. Additionally one third of the rings has been removed. Only every third potential plane now bears a potential ring.

To detect failures of column resistors six additional generating voltmeters were installed along the tank. Each instrument is compensated with the terminal voltmeter, thus drastic changes of the resistance within a section can be seen.

Some minor improvements were performed on systems which had caused some few interruptions. For example the dust catchers below the belt have been removed and an improved feedthrough for the belt charge cable was installed. The motor driving the stripper gas valve was mounted outside the tank.

Throughout the last years the growing interest in heavy ion induced reactions has caused a steadily increasing demand for heavy ion beams. In 1968 only 20% of the beam time was used to accelerate ions with $A \leqslant 6$ amu, in 1970 already 40%. In 1972 more than 80% of the effective beam time was spent on heavy ions. In the very beginning the ions were extracted from a HVEC diode ion source. In 1968 this source was replaced by a Penning source[1]). The exchange canal of the HVEC duoplasmatron was isolated, which allows the extraction of negative ions created inside[2]). Since 1973 an off-axis-duoplasmatron (General Ionex Corporation) is available which can be used alternatively.

The heavy-ion performance of the accelerator always was satisfying. Transmission through the machine exceeded in most cases 50%. Not satisfying, however, was the high voltage capability of the MP. Only within the first two years after the installation the machine could be run at 10 MV and even higher without a considerable loss of beam time by sparking. To extend the lifetime of the first set of tubes it was decided to limit the maximum terminal voltage to 9.5 MV. This limit was kept after the installation of a new set in 1970 until the accelerator was shut down for the upgrading in September 1973, because operation above 9.5 MV always showed to be troublesome.

2. Upgrading of the MP tandem

2.1. HIGH VOLTAGE TEST OF THE COLUMN STRUCTURE

In order to convert the MP tandem to guaranteed 13 MV terminal voltage it was decided to install the new Mark I stainless steel accelerating tubes and a set of spark-gap protected 400 MΩ 20 element-Welwyn resistors, offered by HVEC as an upgrading kit.

Upgrading started with the removal of the old tubes, the installation of the new resistor chain and a new

TABLE 1

Results of voltage conditioning of the MP column structure. The maximum terminal voltage limited by sparking is given for each SF_6 concentration and tank pressure.

SF_6 (Vol. %)	Pressure (kp/cm^2)	U_{term} (MV)
1.8%	10.9	11.7
≈ 10.0%	11.2	12.5
13.5%	11.8	14.0
20.0%	10.8	14.5
≈ 18.0%	12.5	14.6

belt. Because of recent negative experiences with the "tan" belt in Chalk River[3]) and Brookhaven[4]) it was decided to use the old type of black belt again.

As the accelerator tubes had been factory tested[5]) up to terminal voltages of 16 MV it was considered necessary to test the voltage holding ability of the Heidelberg MP column structure. In addition it should be checked whether for 13 MV operation a lower rate of SF_6 admixture to the insulating gas than specified by HVEC was admissible, which would be desirable because of the high costs and the damages caused by decomposition products of SF_6.

Therefore the SF_6 concentration in the insulating tank gas was increased stepwise. Table 1 shows the results of these tests. The maximum terminal voltage limited by sparking is given for each SF_6 concentration and tank pressure. Stable operation of the machine would have been possible about 0.2–0.4 MV below these voltages. These tests have been done using a 4 Ci ^{192}Ir radiation source.

It could be shown that 18% SF_6 at a slightly increased pressure of 12.5 kp/cm^2 is sufficient for operating the machine at 14.3 MV for more than 5 h without any sparking. The following breakdown occurred at 14.6 MV. These values were considered to give a reasonable margin of safety for normal operation at 13 MV.

During these tests more than 500 sparks were counted, 116 of them at voltages above 13 MV. As revealed by pictures taken with cameras through viewport on both baseplates most of them have been tank sparks in the terminal region downwards to the tank floor. No column sparks have been recognized. On occasion of inspections of the tank during the

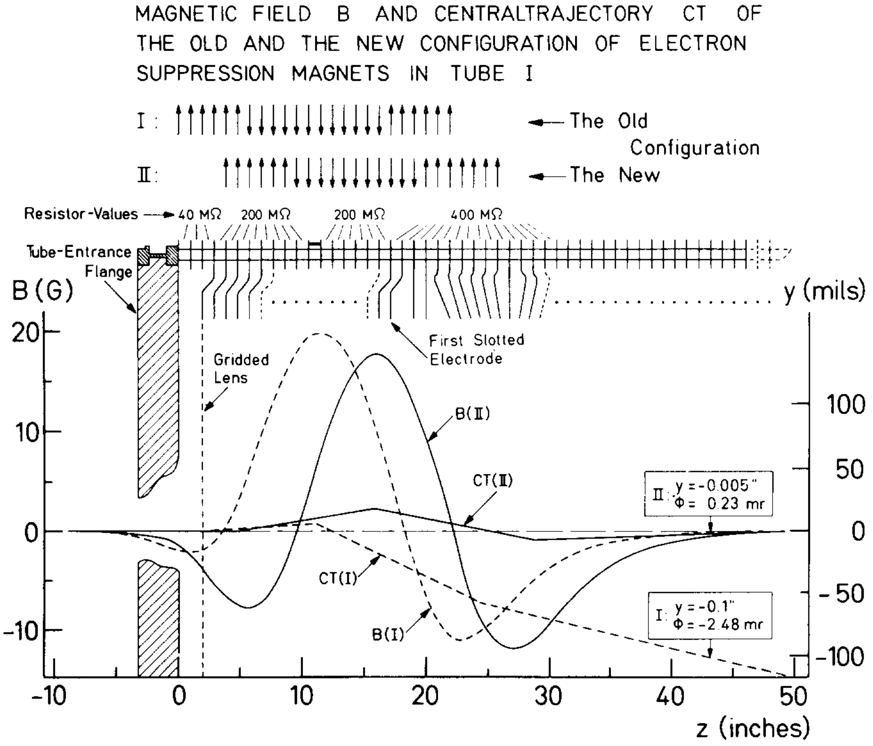

Fig. 1. Magnet arrangement at the first tube section. The new configuration provides minimum angular deflection and displacement for the incoming beam.

voltage tests no essential reasons for the limited voltage stability could be detected, except a remarkable amount of glue particles broken out of the column structure and some lint from filters in the recirculation system. The belt had been carefully dried and conditioned after its installation by evacuating the tank and running without belt charge for several days. It was in good condition after the test period and no indication of excessive mechanical wear as seen at Chalk River was encountered up to that time.

The installation of the new accelerating tubes started at the end of November 1973.

2.2. The accelerating tube

The new 14″ high gradient inclined field tubes are of the Mark I type already installed at Chalk River. Their main characteristics are grooved glass insulators. stainless steel electrodes and no straight section except in the injection region. The only difference is a small ion-optical modification in the transition between the straight and the inclined field region of the first tube section. The last dished electrode now has a slotted aperture which improves the beam focus within the stripper canal and seems to increase the transmission considerably.

Focussing is controlled by the "gridded lens" on electrode No. 4 of the first tube section. In order to avoid sparking the electrons produced by beam particles hitting the grid should not reach the end of the straight section. Therefore a magnet arrangement with alternating field direction for electron suppression was installed by HVEC as indicated in fig. 1, which also shows the resulting field distribution measured on the accelerator axis.

Though the factory tests of the tube have proved that the voltage stability of this system is sufficient, numerical integration of the motion of particles with different magnetic rigidity showed variations in angular deflection ($\Delta\varphi = -2.5$ mrad) and displacement ($\Delta y = -3.0$ mm). The main reason for the unbalancing of the system was the shunt action of the accelerator tube flange consisting of magnetic material, which drastically reduced the field of the first 6 permanent magnets. As the magnet arrangement should not cause any angular deflection or displacement for beams of different magnetic rigidity various magnet configurations were tested to obtain a more achromatic system. A downstream shift of the total assembly by five inches and an additional change of the polarity of the 18th magnet gave the best approximation. The residual

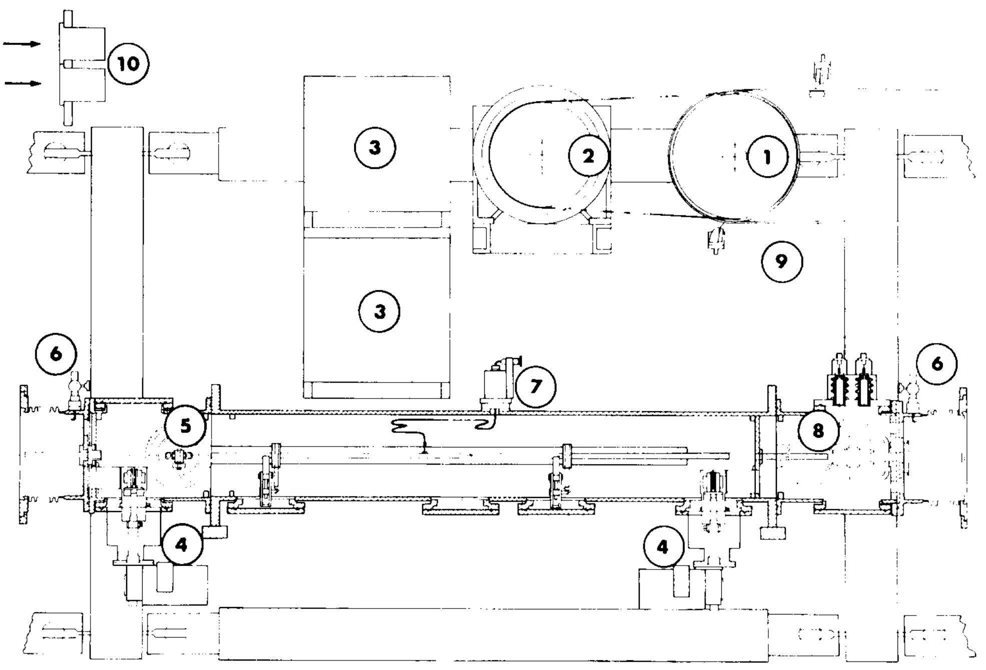

Fig. 2. Scheme of the new stripper housing assembly. The numbers denote the following components: (1) 400 Hz belt generator; (2) 60 Hz generator; (3) He-compressors for cryopumps; (4) cryocoolers and pumping heads; (5) foil changer; (6) quenching gas inlets; (7) insulated stripper gas feedthrough; (8) electrostatic terminal steerer; (9) downcharge spray screen; (10) terminal instrumentation.

variation of deflection angle is now $\Delta\varphi = -0.23$ mrad and of the displacement $\Delta y = -0.05$ mm for the worst case.

As suggested by HVEC the three last resistors on tube section No. 8 have been changed to 200 MΩ in order to reduce the field gradient at the tube exit and to avoid sparking due to secondary electrons from the beam line.

2.3. INSTALLATIONS WITHIN STRIPPER HOUSING

In addition to the installation of the Mark I tubes several new features were included which partly are mandatory for proper operation. Most of these components are located in the high voltage terminal of the MP.

In order to accommodate the additional components the stripper canal housing was partly rebuilt providing 6 extra flanges. Fig. 2 shows a schematic cross section of the stripper housing assembly, whose components (new stripper canal, steerer, terminal pumping and foil stripper) are described in more detail below.

2.3.1. *Stripper canal*

The gas canal, shortened to 126 cm, has been moved upstream. Together with the foil changer mounted in front of it the gas canal is positioned in a separate stripper chamber, terminated to the accelerator tubes on both ends by gas baffles of low conductance which now are separated from the canal. The gas canal including the gas inlet valve and the foil stripper assembly are electrically isolated from the terminal by ceramic material thus allowing to apply modulated high voltage in order to reduce the energy fluctuations of the beam[6]).

2.3.2. *Terminal steerer*

To verify the dispersion compression scheme necessary for Mark I tubes an electrostatic vertical steerer has been installed at the high energy end of the terminal (see fig. 2). The length of the plates is 10 cm with a separation of 3 cm. The steerer power supply contains two dc power packs. The relative voltage of the plates can be changed between −8 kV and +8 kV effectively.

At 13 MV terminal voltage an electric gradient of 2.5 kV/cm, which is well obtained within the limit of the steerer power supply, provides a deflection angle of one milliradian per charge state. Calculations have shown that this deflection is sufficient for a reasonable transmission through the high energy tube for heavy ions of all charge states expected after foil or gas stripping.

2.3.3. *Terminal pumping*

The low conductance of the Mark I accelerator tubes demands a pumping system in the terminal region at least if gas stripping is used for charge exchange of the ions. A reasonable stripper gas flow of 8×10^{-3} torr l/s, which is only externally pumped with a reduced speed of 8 l/s would deteriorate the vacuum in the terminal to 10^{-3} torr. But even when using the foil stripper terminal pumping is favourable because of outgasing and leak rates, which influence the transmission of highly charged heavy ions.

Because of their reliability and high pumping speed for all relevant gases two cryopump systems have been installed in the terminal[7]). They consist of two independent closed cycle helium refrigerators specially modified for operation in the terminal (General Ionex Corporation, type 3520), which are able to deliver 1 W of cooling power at 20 K. The helium compressors and refrigerators are powered by a 3.5 kW, 2-phase, 60 Hz generator driven by a tooth belt from the normal belt generator. The temperature and the suction pressure of both cryosystems are monitored by instruments within the terminal. Both cryosystems can be switched on separately.

In order to meet the geometrical requirements of the modified stripper canal housing and to yield maximum flexibility in the terminal gas handling new pumping heads for differential pumping were designed as shown

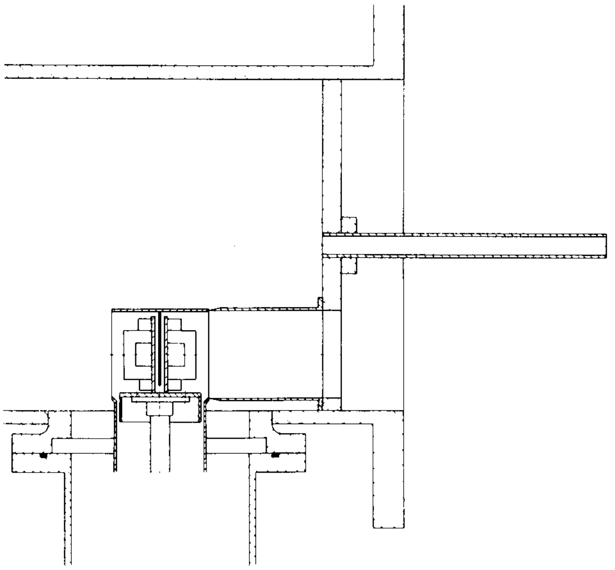

Fig. 3. Scheme of a cryopumping head, installed near the baffle which separates the center part of the stripper housing from the LE and HE accelerating tube, respectively (see text).

in fig. 2. The center part of the stripper housing is separated from the LE and HE accelerator tubes by two gas baffles of about 1 l/s conductance. Differential pumping is achieved by the special shape of the two cold heads pumping both sides of each gas baffle with separate parts of their surfaces. By virtue of a thin wall connected to the thermal shielding the pumping head forms an optically tight separation between both sides of the gas baffle (see fig. 3). Molecules can only pass from one side to the other if they were reflected several times from the surface. Because of the high sticking coefficient at 20 K the conductance is smaller than that of the tube baffles. Warmed up the conductance through the pumping head is about 20 l/s, thus there is nearly no reduction to the pumping speed of the external pumps.

The surface of the pumping head is enlarged by several concentric cylinders soldered to the opposite sides of two parallel plates. The geometry was designed in order to achieve a nearly uniform coating of frozen nitrogen on the cold surface. A thin nickel film is electroplated on the copper cryo-tip to avoid the oxidation as it is warmed up. Each side of one pumping head has a pumping speed for nitrogen of 300 l/s. Therefore the stripper gas in the center terminal housing is pumped by both cryopumps with a total speed of 600 l/s which results in a pressure of 1.2×10^{-5} torr. Hence the gas flow through the baffle is in the order of 10^{-5} torr l/s and the base vacuum in the terminal end of the tube pumped with an effective pumping speed of 140 l/s will deteriorate only slightly.

The cool-down time of the system is about 50 min. Though the cold head is only partially shielded the radiation heat load is less than 0.06 W assuming an absorptivity of 0.03 [8]) for the 50 cm^2 pumping apertures. The heat load increases with the thickness of the nitrogen coating due to the change in emissivity which increases significantly for a thickness of several wave lengths. For a surface condensate of 80 torr l/cm^2 the emissivity increases to 0.8 [9]). Most of the differentially pumped gas will condensate on the terminal side of the cryohead. Thus, the total radiant load is about 0.8 W, which is well within the performance of the 1 W refrigerator. The accumulated amount of gas mentioned above corresponds to a pumping time of 18 d for the effective 80 cm^2 area at normal stripper gas flow rates. The load caused by the enthalpy change of the nitrogen gas having a temperature of 290 K is 0.55 J/torr l. The resulting load to each pump of 0.003 W is small compared to the radiant load.

Normally the pumps have to be recycled once a week by switching off the compressors. Within less than a minute the cold heads warm up and start to evaporate the frozen nitrogen. As the base end vacuum readings increase to values higher than 10^{-3} torr, even the belt must be stopped in order to prevent glow discharges from the self charge of the running belt. The main quantity of nitrogen is sublimated within 30 min, but major quantities of CO_2 and H_2O can be detected in the mass spectrum of the residual gas analyzer even 2 hours later. There is no evidence for greater amounts of organic vapors collected on the cold heads from the polyvinylacetate-glue of the tubes.

According to experience the voltage stability of the machine at high terminal voltages can be improved by using a small amount of gas loading to quench discharges in the tubes. The use of normal stripper gas would be unfavourable, because in the case of gas stripping the cryopumps do not allow a sufficient flow

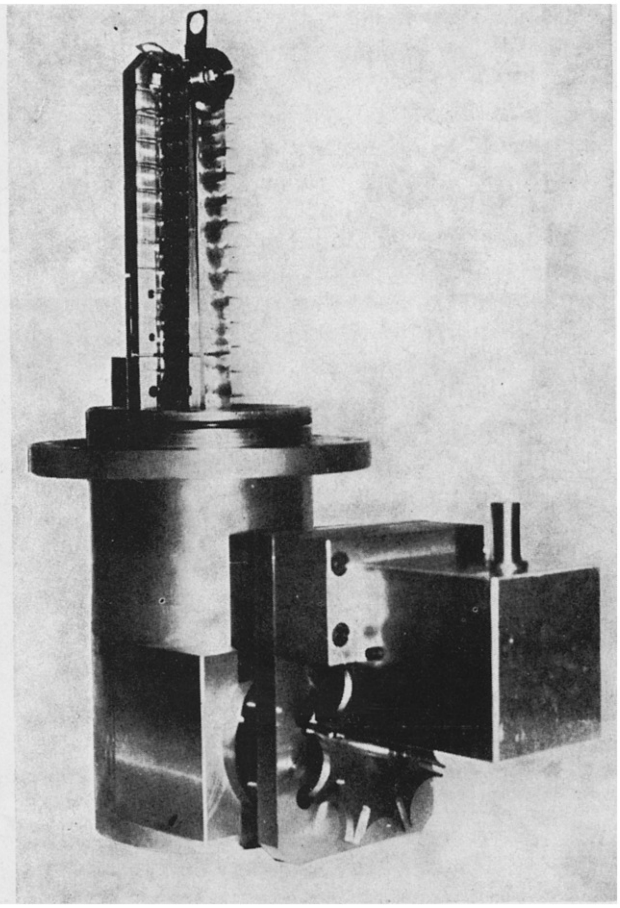

Fig. 4. The foil stripper assembly. 58 foils are mounted on an endless tape, which is driven by means of a Geneva mechanism (lower part).

rate down the tube without excessive pressure in the stripper canal and in case of foil stripping with the pumps shut off the high gas density in the gas canal reduces the yield of highly charged ions by charge exchange. For this reason two additional gas inlets outside the stripper housing allow to deteriorate the vacuum in the tubes in the terminal region independent of the stripper gas conditions and to raise the base vacuum at the ends of the machine from 2×10^{-7} to 5×10^{-7} torr. The quenching gas valve is driven separately by a lucite rod.

2.3.4. *Foil stripper*

The carbon foil changer is of the same type used already in the EN tandem. It contains 58 foils (4–8 μg/cm^2) mounted on an endless tape of steel (fig. 4). The stripping foil is positioned in front of the gas stripper which therefore acts as a collimator.

The mechanism of the foil changer consists of a magnetic vacuum coupling and a Geneva mechanism which allows positioning of the foil insensitive to the exact stopping position of the driving motor outside the tank. Each carbon foil can be selected remotely from the control desk. Since the foils are very sensitive to mechanical stress, an electronic device was constructed to insert the desired foil on the shortest way possible. The number of motor turns, that is the number of foil changes, is monitored by a magnetic sensor and stored in an electronic register. At the beginning of operation or after a line breakdown a second sensor generates a pulse for a synchronisation procedure between the register and the actual tape position.

2.4. IMPROVEMENTS OF ENERGY STABILIZATION

The fluctuations of the terminal voltage without any regulation system are of the order of ±5 kV at 12 MV and mainly depend on the belt tension, condition of the charging screens, etc. Using the most common combination of slit stabilization and corona regulation the short term stability (ripple) can be improved to ±1 kV. The basic frequency of the disturbances is that of the charging belt, probably induced by local surface effects causing inhomogeneities of the charge distribution on the belt. Other sources of ripple may come from flutter and slipping of the belt and charge losses at spacers.

The efficiency of the corona regulation is limited to low frequencies^{6}). For the present MP operating conditions the response of the terminal to signals applied to the grid of the corona tube decreases by a factor of two for a frequency of 8 Hz, and is phase shifted by almost 180° for frequencies above 12 Hz.

As the new generation of magnet spectrometers, e.g. the Heidelberg Q3D, demands for higher beam quality, provisions have been made to improve the energy stability. New logarithmic FET preamplifiers for frequencies up to several kHz with an improved sensitivity have been built. To reduce the influence of the belt a downcharge system has been developed which allows a more uniform charging of the terminal. This unit consists of a current regulated stabilized 20 kV power supply mounted in the terminal. It can deliver up to 1 mA of negative belt charge using separate screens in the terminal and at ground potential for charge transfer and pickup. The system is completely decoupled from the usual upcharge device and can be used alone or in conjunction with the old system. Setting of the downcharge current is done via a lucite rod. In addition the current can be modulated with frequencies up to 1 kHz, sent via the light link from the ground to the terminal.

The use of the downcharge system first of all should reduce the charge density on the belt by a factor of two thus improving the lifetime of the belt by preventing burn marks and discharges along the belt. A noticeable effect on the terminal ripple can be seen because current regulating the charging of the belt in the terminal is smoother than pick-up of charges from the belt. However, the removal of fast components of the ripple is impossible. Though the belt only has to move 65 cm from the charging screen to the end of the terminal corresponding to a time of 23 ms, the modulation of the downcharge current only is effective for frequencies below 10 Hz, as observed from a voltage change of the terminal using the capacitive pick up plate. Though the charge transport is faster by a factor of 5 for the downcharge than for the corona the frequency dependence of the corresponding terminal voltage change is nearly identical for both regulation systems. This behaviour is easily understandable because using in both cases a modulated current of constant amplitude to charge the terminal capacity clearly results in a decreasing ac voltage across that capacitor with increasing frequency.

For the higher frequency components of the energy fluctuations a terminal wobbler system has been installed^{6}). The isolated gas stripper canal and the foil stripper which normally are on terminal potential now are isolated and connected to a high voltage amplifier giving ac voltages of max. 7 $\mathrm{kV_{pp}}$ in the frequency range from 3 to 300 Hz. Thus it is possible to change the effective terminal voltage seen by the particles by up to ±3.5 kV according to the error signal derived from the slit amplifiers and fed to the terminal via the light link connection. Qualitatively a considerable increase in beam energy stability is observed which can be noticed from the increase of beam transmission through the image slits, and from the decrease of the error signal derived from the slit amplifier. The improvement of energy resolution has at this time not yet been checked.

2.5. Terminal connections to ground

In order to control and operate the additional equipment installed in the machine several connections to the terminal have been provided.

Direct reading of meters and gauges in the terminal has been established by a television camera mounted on the low energy baseplate, viewing in beam direction between the upper horizontal gradient bars and the potential hoops to the terminal. The operation of the cryopumps, the two generator voltages, steerer voltage, downcharge current and several indicator lamps and a decimal display are monitored.

For analog signals to and from the high voltage terminal two different light links have been built in, using light emitting diodes and monofibric light pipes for the transmission.

The system transmitting from ground to terminal uses a frequency modulated 100 kHz square wave oscillator and a power amplifier to drive the light emitting diode. The terminal receiver consists of a red sensitive photomultiplier, a limiter stage and a 100 kHz FM demodulator, all built from vacuum tubes to reduce the sensitivity to electrical surges. The bandwidth of this system is about 1.3 kHz using ± 10 kHz modulation. The output can be switched either to the terminal wobbler or to the downcharge unit.

The inverse system for analog signals from terminal to ground uses a voltage to frequency converter in the transmitter stage and a phototransistor for receiving the signals, all built from integrated solid state devices. The main purpose of the latter system is to study the reliability of solid state units in the hostile environment of the terminal. It is presently used to monitor the downcharge current.

Though the transmission of the small diameter light pipe is less than 2% the signal level is sufficiently high for proper demodulation. Compared to a direct optical connection these systems have the following advantages:

1) no careful alignment necessary, arbitrary orientation of transmitter and receiver,
2) insensitivity to vibrations,
3) no cross-talk, even if transmitters and receivers are closely neighboured.

The use of VCO- or FM-coded signals for transmission

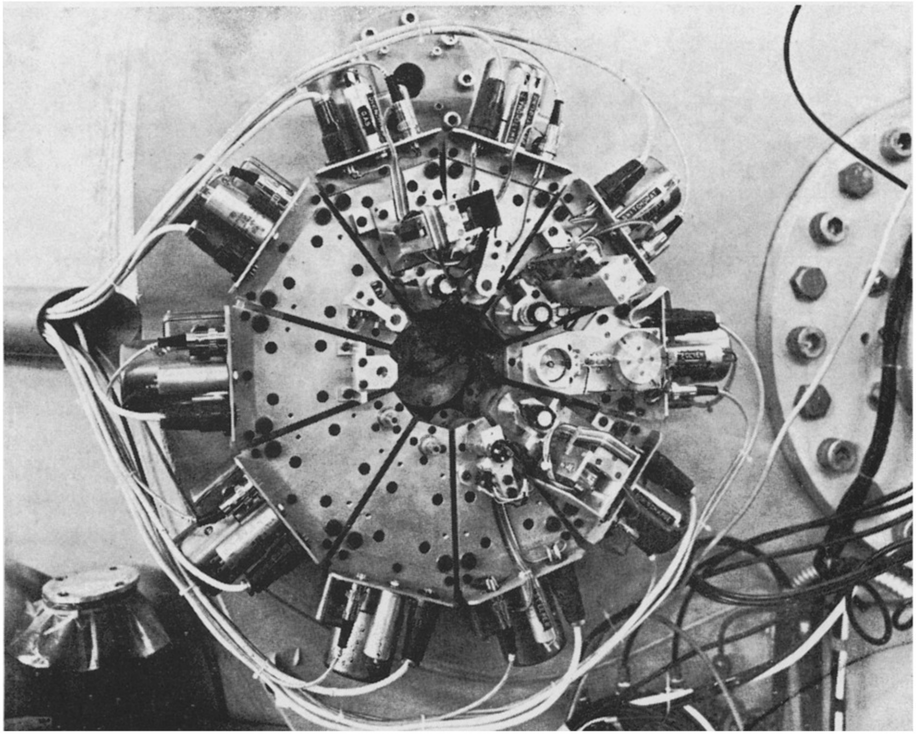

Fig. 5. Motor assembly for the lucite rods of the terminal connections mounted outside the LE baseplate.

removes the influence of an eventual colouration due to aging or radiation damage of the plastic light pipe, belt dust, density fluctuation of the tank gas and external light sources including sparks in the machine. For mechanical reasons the light pipes are supported by lucite rods near the bottom edge of the column structure. Former trials using lucite pipes for guidance failed.

For direct manual operation of terminal power supplies, switches, and circuit breakers a set of up to ten steering rods are installed along the low energy column, six of which is actually in use. The insulating sections consist of 25 mm diameter lucite rods, supported in the dead sections by ball bearings. Quick disconnect couplings as reported from Brookhaven[10]) facilitate the access to the column.

As there have been several failures of internally mounted driving motors due to sparks, the driving motors of the new system are installed outside the pressure vessel (see fig. 5). Ten high pressure mechanical feedthroughs, each sealed by two O-rings are mounted on a 20 cm diameter flange. The 4.5 rpm ac motors are controlled by servo systems.

2.6. SURGE PROTECTION

All electrical components in the terminal are enclosed by singly shielded metal housings, internally grounded to one point only. All interconnecting wiring is shielded by solid copper tubing. The ends of these lines, which should be movable, e.g. at connectors, are made from bellows, soldered to the tubing. Wherever possible, input-, output- and power lines are protected by sealed gasfilled or open spark gaps.

All electrical units are protected by automatic circuit breakers which can be activated and reset from ground. For this purpose a mechanical multiplexer has been designed, capable of handling a number of 15 circuit breakers and switches. For operating this unit, only two lucite rods are necessary, one for positioning the movable activator, the other for the switching procedure. Selection and activation is done by pushbuttons from the control desk via a servo system.

The whole terminal assembly including lucite rods and cable shielding is to be seen in fig. 6.

2.7. CONDITIONING OF THE TUBES

The conditioning of the machine was started middle of February 1974, when the installation of the tubes and the additional equipment was finished. In comparison to the previously used aluminium tubes the new stainless steel accelerating tubes are conditioning much faster. A terminal voltage of 10 MV was reached

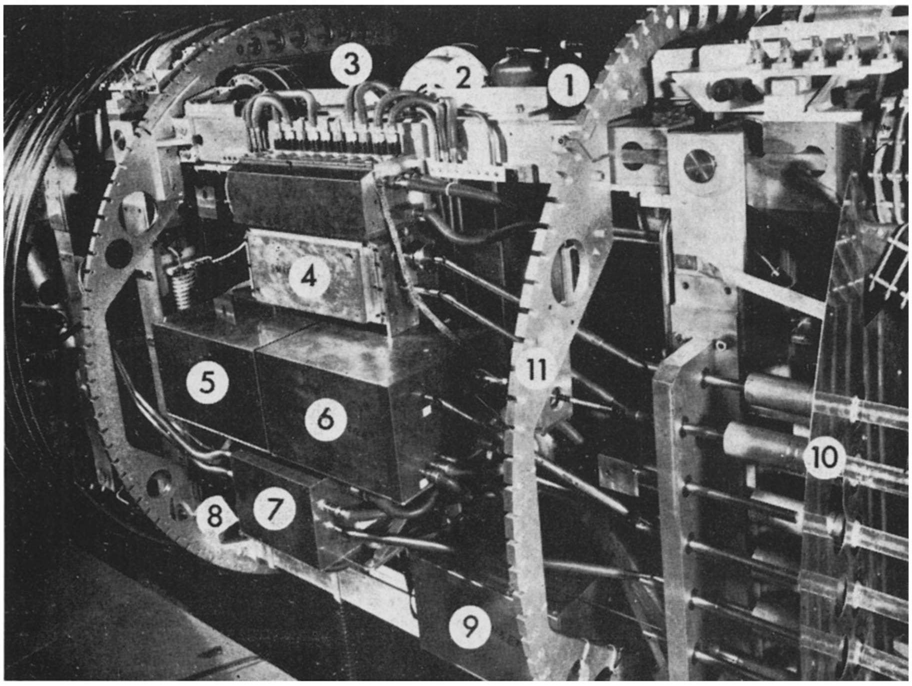

Fig. 6. View at the terminal assembly: (1) He-compressor for cryopumps; (2) 60 Hz generator; (3) 400 Hz generator; (4) driving mechanism for switches and breakers; (5) terminal wobbler; (6) downcharge unit; (7) terminal steerer power supply; (8) telemetry transmitter; (9) telemetry receiver; (10) lucite steering rods; (11) quenching gas leak valve.

after five days and it took only additional five days to raise the conditioning level to 13.5 MV.

Different methods of monitoring the conditioning process have been applied. The LE- and HE-vacuum gauges are observed with a fast recorder. Small increases of the base vacuum accompanied by short bursts of gas obviously from minor discharges in the tube give a very sensitive indication of the progress in conditioning. The vacuum activity drops when the conditioning process is finished.

A NaI(Tl) crystal mounted outside the tank wall is used to monitor the bremsstrahlung produced inside the tube. A single channel analyzer set to energies below 300 keV and connected to a ratemeter gives an audible report on the status of the conditioning process even in the presence of the strong γ-background from the radiation sources.

By steadily pushing the machine and keeping the metered activities at a constant level the conditioning time can be effectively reduced. For voltages above 10 MV radiation sources of 2 Ci has been used and rather dry insulating gas was necessary. Most of the sparks that occurred were tank sparks, while the number of tube sparks normally accompanied by a distinct deterioration of the tube vacuum was almost negligible. However, quite frequent upward spikes in the column current especially on the high energy side with occasional minor drops of the terminal voltage demonstrate the presence of smaller discharges in the tube. As they do not cause catastrophic break downs of the terminal voltage the different inclined field regions of the accelerating tube seem to be effectively decoupled.

2.8. PERFORMANCE OF THE UPGRADED MACHINE

By some minor mechanical failures which caused several openings of the accelerator tank the final acceptance tests were delayed to the end of March 1974. The performance specifications for the new tubes which only refer to protons were easily surpassed. Proton currents of 5.5 μA at 3 MV, 11 μA at 7.5 MV and 5–7 μA at 13 MV terminal voltage were accelerated for more than two hours. These tests were performed using a standard charge exchange duoplasmatron source or the off-axis-duoplasmatron, with the foil stripper in the MP terminal and with the terminal pumps shut off. For the 26 MeV run a slight flow of nitrogen was introduced in the terminal increasing the pressure at the base ends from 2×10^{-7} to 6×10^{-7} torr in order to quench tube loading and to stabilize the machine.

The transmission through the machine is excellent. For proton beams from the off-axis-duoplasmatron transmission rates of up to 85% have been measured, and normally are better than 60% depending slightly on terminal voltage and beam intensity. The transmission for helium beams is worse by a factor of two due to the emittance of the Li-exchange source but values of 40 and 50% are achievable for foil stripper and gas stripper respectively.

With reference to measured equilibrium charge state distributions in carbon foils[11]) the measured transmission rates for oxygen are 68% ($Q=6^+$) at 13 MV and for sulfur 60% ($Q=8^+$) at 12 MV terminal voltage. There are some indications that the transmission rates decrease with increasing charge state and increasing terminal voltage. The heavy ion measurements have been done with terminal pumps in operation which increase the yield by 5–10% and without use of quenching gas. A slight flow of quenching gas already deteriorates the yield for higher charge states and reduces the beam intensity nearly to the same level as found for gas stripping.

The stability of the beam is quite remarkable. Neither horizontal nor vertical motions of the analyzed beam caused by energy or gradient fluctuations have been observed so far. However, for optimum transmission the beam does not leave the accelerator tube on axis. The first quadrupole lens behind the accelerator which has been magnetically aligned to the accelerator axis is passed with a horizontal displacement of about 1.3 cm and somewhat less in vertical direction. This causes a splitting of different charge states of heavy ions by the quadrupole as observed with the beam scanner near the object point of the analyzing magnet and a considerable steering action of the lens which is quite annoying when focussing the beam to the experimental area. Therefore additional magnetic steerers[3,12]) have been installed inside the tank in the high energy dead section in order to correct the displacements before entering the first focussing lens. Criteria used for setting the steerer currents are the compression of the different charge states at the beam scanner and minimum steering action by the quadrupole lens.

The new accelerator tube seems to be more sensitive to the injection conditions with respect to transmission and beam loading as has been the previous one. An unstable ion beam with fast energy or intensity fluctuation from the source is no more tolerable. A "speedobeam" monitor[13]) which is connected permanently to the modified aperture at the injection point of the MP has been found to be an extremely useful instrument for the diagnosis of the source conditions. Though a badly focussed beam does not cause immediate sparking the terminal voltage gets unstable and the amount of belt charge for a given voltage increases drastically.

At 13 MV terminal voltage 200 μA of additional belt charge current are necessary to accelerate an injected beam of 1 μA of ^{4}He or 0.5 μA of ^{16}O which are well focussed and show good transmission. This current does not show up in the column currents which in fact are decreasing by up to 15%. This current being of the same order of magnitude as the resistor currents presumably is removed via ionization of the tank gas to the tank wall bypassing the resistor chain and the corona. Under these conditions X-ray levels of 100–200 mRem/h have been observed at different positions at the tank wall. The ionizing radiation obviously supports the effect of the radiation sources and may explain the fact that the machine can be brought up to voltage more easily with an accelerated beam than without. The X-ray levels and the additional amount of belt charge are noticeably reduced when the vacuum in the tubes is deteriorated by the introduction of stripper- or quenching gas.

As the factory test of the accelerating tubes up to 16.5 MV had already demonstrated, the voltage holding ability of the new tubes is not the limiting factor for the upgraded MP. This also can be realized from the fact that almost no tube sparks have been observed for terminal voltages up to 13.5 MV. Limits of the performance are tank sparks eventually caused by belt dust or by the unfavourable shape of the accelerator tank. At highest voltages the performance of the machine also seems to be limited by the maximum ion current to be injected. Though the injection of 10 μA of protons at 13 MV was demonstrated to be possible, the present experience shows that not more than 1.2 μA of ^{4}He or about 0.8 μA of ^{16}O should be injected into the machine for stable operation. These currents can be accelerated with 500–550 μA of total belt charge current.

3. Future projects

As experience at other "upgraded" MP-tandems has shown, the conventional belt type charging system is a main limiting factor to reliably obtain terminal voltages in excess of 12 MV for longer periods of operation. However, as both the structure and the new tubes of the Heidelberg MP have been tested at voltages well above 14 MV, a pelletron charging system similar to that now in operation at the Yale MP has been ordered. It is guaranteed to deliver 600 μA of charging current up to a terminal voltage of 14 MV and will be installed later this year, whenever belt problems will make this necessary.

Furthermore a beam pulsing system will soon be operational at the MP. This system[14]), which consists of four different components, is similar to other installations[15–17]). A low energy two gap buncher and prechopper combination operates at 6.78 MHz and 3.39 MHz, respectively. Variable lengths of the buncher drift tubes permit the bunching of ions in a wide range of masses at high injection energies. A digitally controlled diverter selects single buncher pulses to operate with lowered

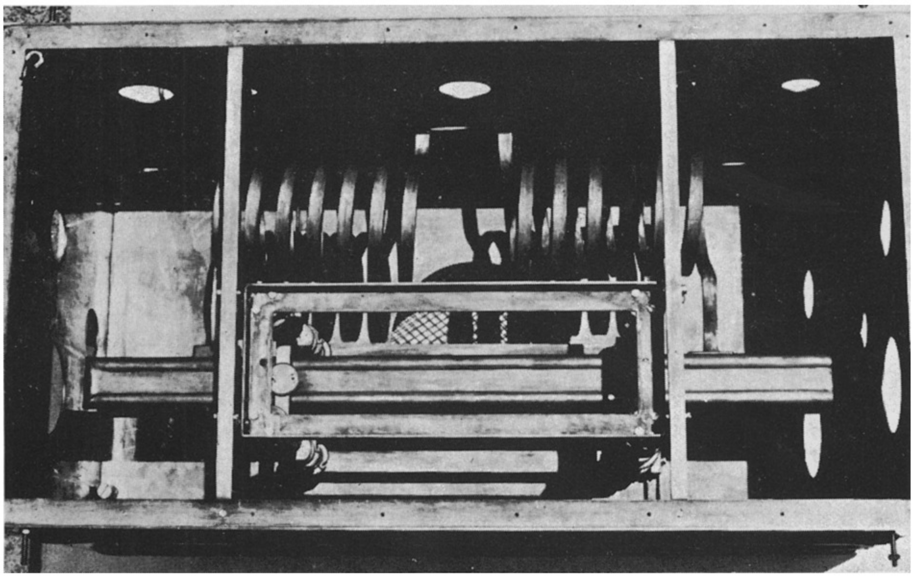

Fig. 7. Top view of the resonator circuit for the high-energy beam chopper.

pulse repetition frequencies. The main component of the fast beam chopper which is installed at the high energy end of the machine to trim the bunched pulses, is a high Q ($Q = 2200$) resonance circuit at 13.56 MHz. Fig. 7 shows the resonator before installation in its vacuum tank. The direction of deflection is perpendicular to the plane of the 90° analyzing magnet; the chopper slits are situated near the object slits of the analyzer. Writing speeds in excess of 10 mm/ns can be obtained for 26 MeV deuterons. Buncher to chopper phasing is controlled as usual by a slit regulation system[15]).

One of the major projects of the institute for the next years is the construction and testing of rf-accelerating structures to be used as elements of a post-accelerator for heavy ions behind the upgraded MP. These resonators – superconducting and "normal" ones – will be prototype-tested with a heavy ion beam in 1975. A magnet system for these experiments is now under construction. It was designed to maintain the time microstructure of the pulsed beam as well as to provide the dispersion necessary to stabilize the terminal voltage of the MP and to select special charge states behind a second foil stripper in the system. Also other experiments having need of good time structure will be located at this magnet system. The ultimate aim of these activities is to gain the necessary experimental experience to finally construct the postacceleration linear accelerator capable of delivering ions up to mass 80 with an energy of 5–6 MeV/amu.

The successful conversion of the machine would not have been possible without the collaboration of a great number of technicians and physicists from various departments of the institute, the results of their efforts being reported in this paper.

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