K500 CYCLOTRON OPERATION

CYCLOTRON OPERATION SUMMARY

P. Miller, D. Poe and N. Anantaraman

1. Operating statistics

The graph in Fig. 1 of the ion source hours of operation in each week is equivalent to the pattern of beam production by the K500 cyclotron. Following the first period of running nuclear science experiments a series of machine and ion source development tests were made in July 1983. Some beam properties (emittance, timing) were studied, and solid feed beams of lithium and boron were run. A thesis experiment employing a "long arc" special ion source was also carried out. The rf system was operated at several frequencies to calibrate the tuning controls and the dee voltmeters. Coupling power from the transmission lines into the resonators with loops, a possible alternative to the capacitive couplers, was tried but was not a good option. A shutdown period began in August for repairs and upgrading some systems. Below is a list of the main jobs done.

1. Modification of the liquid nitrogen shields on two of the cryopumps (B and C).
2. Repair of a leak in the C cryopump helium circuit.
3. Replacement of C-seals on dee stem insulators with indium seals.
4. Installation and debugging of the fast field mapper; mapping of the cyclotron magnetic field imperfection harmonics.
5. Test fitting and adjustment of two new electrostatic deflectors.
6. Assembly of new PIG ion sources.
7. Positioning and adjustment of the dees.
8. Installation of voltage taps on the trim coils for ground sensing.
9. Installation of controls for the new ion source power supply.
10. Repair of leaks in the ion source gas system.
11. Replacement of the main probe head with one having 3 fingers (vertical current sensing) and a thin wire differential element.
12. Installation of a safety system for controlling access to restricted radiation areas; also hazardous gas alarms in the experimental vaults.
13. Rearrangement of the beamline control console in response to users' suggestions.
14. Changes in beamlines and experimental equipment. A water line freeze inside the dees and dee stems added a month to the shut down. External beam was obtained on December 20, 1983, and the program of nuclear science experiments was resumed.

As of December 31,1984, 28 experiments were completed and 4 were partly done and awaiting scheduling of the remaining time allocated by the Program Advisory Committees (PAC). These runs are summarized in Table 1. A total of 43 experiments were granted accelerator time, 24 by PAC2 and 19 by PAC3.

Since September 1984 we have recorded the distribution of accelerator time to one of six categories: research, development, overhead, maintenance, breakdowns and scheduled off time. The first two are considered the useful beam time. Overhead includes such activities as changing the beam energy, tuning the beamline and replacing ion sources. Table 2 gives the hours devoted to three groupings of these categories.

The beams required most often were ^{14}N, ^{12}C and ^{6}Li in the energy range 20 to 35 MeV/u. We have produced energy as low as 8 MeV/u (^{6}Li) and as high as 45 MeV/u ^{14}N 5+ and 53 MeV/u ^{4}He^{2+}. Experiments have also been carried out with ^{22}Ne and ^{18}O beams. The development of more beams at energies above 40 MeV/u has been postponed until modifications to improve the cooling to the dee stems are complete. The maximum voltage held by the electrostatic deflectors will also need to be increased. Both of these improvement programs will benefit the

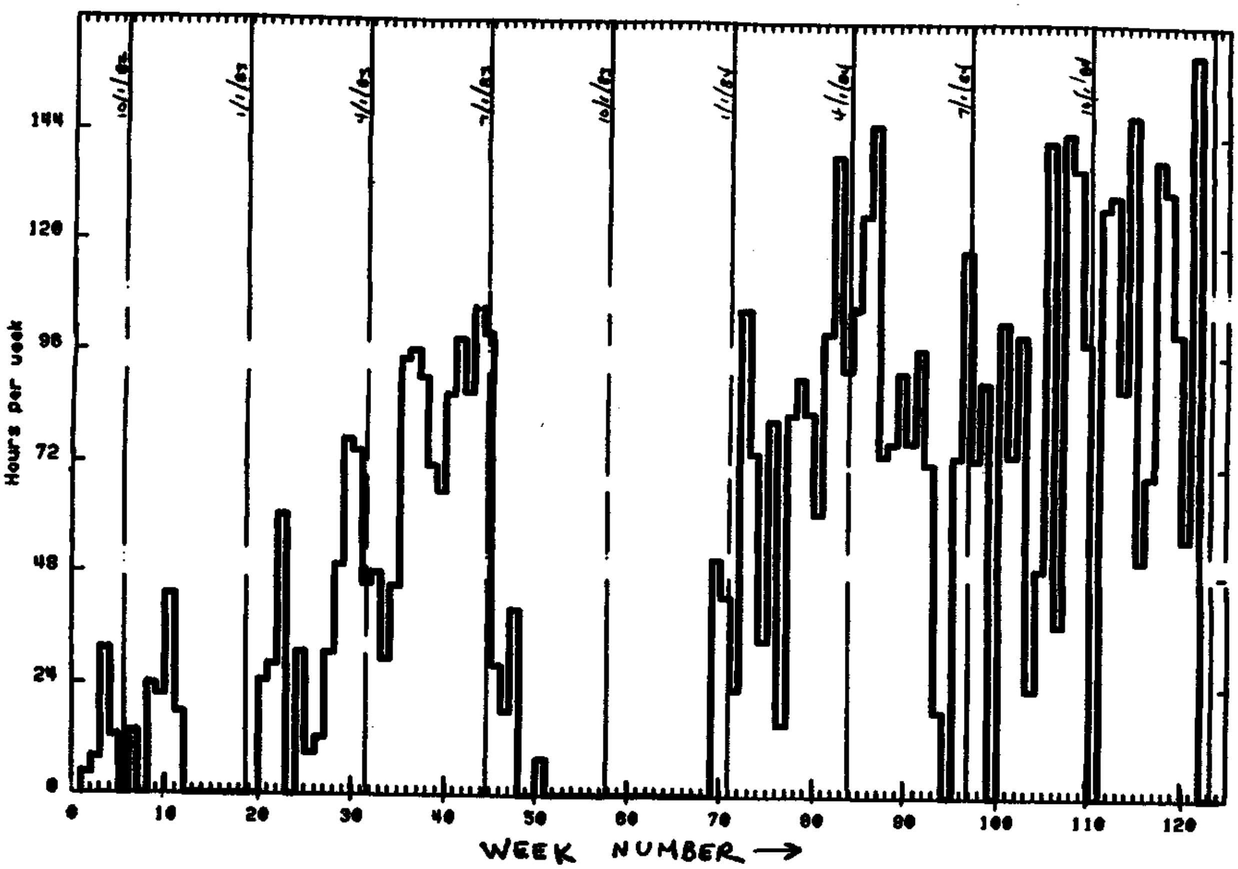

Fig. 1 Hours per week of production of beam from the K500 cyclotron, Sept. 1982-Dec. 1984

K800 cyclotron now under construction.

3. Instrumentation

The main beam probe was completed by installing the permanent drive mechanism. It is equipped with a vacuum lock so the probe can be retracted and inserted for modification or repair of the head without venting the cyclotron. The beam-damaged section of track was also replaced, which allows full radial scans to be made.

The planned ion source changer mechanism was completed. Insertion and retraction of the source were accomplished in two phases involving a hydraulic piston for part of the travel and an air piston for the rest. The hydraulic part was abandoned because the required mechanical tolerances were too severe, and damage to the source was likely to occur. The sources are now mounted into the air lock by hand and are then inserted by use of the air piston.

A scintillation detector to measure the macroscopic time structure of the beam was installed at the cyclotron. Its main use is to monitor the structure that results from pulsing the ion source arc current and to allow adjustments to be made to achieve uniform beam intensity during the pulse.

Table 2 - K500 Cyclotron Hours Distribution - Sept.-Dec. 1984

Total	Research + Development	Overhead	Maintenance + Breakdown + Off
2736 hr.	1338 hr.	404 hr.	994 hr.
Percent of total:	48.9%	14.8%	36.3%

Table 1 - NSCL Experiment Run Summary for 1-7-83/12-31-84

Spokesperson	Time Allotted (hrs.)	Station	Beam	Energy (MeV/nucleon)	Start Date	Hours Run	Run #
Parkinson	6	S-320	^{14}N	35	10-17-84	6	1
Utsunomiya	91	Users	^{14}N	20	07-10-84	1	1
Seaborg	24	M-1	^{12}C	35	05-01-84	8	1
					05-03-84	16	2
Porile	24	M-1	^{12}C	35	07-04-84	8	1
Crawley	72	S-320	^{4}He	25	05-04-84	24	1
					07-30-84	48	2
Koenig	150	SC	^{12}C	15,30	03-19-84	159	1
Sherrill	104	S-320	^{7}Li	25	03-13-84	104	1
Morrissey	72	Users	^{14}N	35	01-16-84	67	1
Braun-Munzinger	250	Users	^{14}N	35	04-04-84	156	1
Becchetti	48	S-320	^{6}Li	25	05-21-84	~6	1
van der Plicht	48	S-320	^{6}Li	35	02-16-84	48	1
Tiedje	48	M-1	^{14}N	35	01-30-84	16	1
			^{14}N	35	08-23-84	16	2
			^{14}N	30	10-23-84	12	3
Cramer	72	S-320	^{12}C	15-35	02-22-84	76	1
			^{22}Ne	25	05-11-84	72	1
Nolen	149	RPMS	^{16}O	30	08-30-84	72	2
Curtin	140	S-320	^{14}N	20-35	04-16-84	144	1
Garg	72	S-320	^{14}N	35	05-29-84	72	1
Caskey	88	NC	^{14}N	35	08-25-84	87	1
Lynch	130	SC	^{14}N	35	09-10-84	130	1
Beard	90	ENGE	^{14}N	40	10-10-84	138	1
Gelbke	72	SC	^{14}N	35	02-27-84	72	1
Anantaraman	72	S-320	^{6}Li	35	08-06-84	72	1
Natowitz	120	SC	^{14}N	35	06-03-84	127	1
Anantaraman	18	S-320	^{12}C	35	06-30-84	18	1
Saha	48	S-320	^{6}Li	35	12-13-84	48	1
Morrissey	184	Users	^{7}Li	8	11-25-84	91	1
			^{14}N	8-15			
			^{14}N	8-25	12-19-84	93	2
Tiedje	48	M-1	^{14}N	30	10-29-84	12	1
			^{14}N	30	11-13-84	12	2
McHarris	48	Users	^{14}N	15	10-30-84	24	1
					11-10-84	24	2
Beard	115	ENGE	^{14}N	40	11-16-84	115	1
Crawley	48	S-320	^{4}He	25	11-29-84	72	1
Lynch	168	SC	^{14}N	35	09-19-84	168	1
Viola	72	SC	^{14}N	35-45	12-05-84	72	1
			^{6}Li	30-35			
			^{12}C	20-35			

K500 RF SYSTEM DEVELOPMENT

J. Vincent, J. Brandon, P. Miller, D. Scott

1. INTRODUCTION

In the period since the last annual report, the K500 RF system has progressed from operational infancy to basically a reliable working system. As the entire research program has progressed at M.S.U., higher energy beams have become more and more the norm which has required greater steady state power capabilities from the RF system. As the normal steady state power levels increased, previously unforeseen technical difficulties began to emerge. Also, with an expanding research program, we needed to enhance our capability to change beam energies more rapidly and efficiently. Many people are responsible for improvements to many systems to accomplish these basic goals; we will describe some of the RF improvements. The improvements described here involve; sliding contact fingers, remote controls, input couplers, phase shifters, frequency distribution systems, thermal protection, proposed corona ring modifications, hydraulic actuators and valves, computer algorithms, and proposed x-ray calibration technique improvements.

2. SLIDING CONTACT FINGERS

These fingers made contact from the dee stem sliding short to the dee stem outer conductor panels. The original fingers were small with gold plated contact surfaces. Each strip of fingers was soldered to a copper bar which was connected to the sliding short. An air cylinder applied pressure to the fingers via a pliable rubber strip backed by a rigid copper band. Although the air pressure was removed during short movement, the fingers remained in contact with the conductor surface. In time the gold plating wore off the contact surfaces due to friction. The resulting indifferent contact caused non-symmetric field gradients to occur along with unequal I**2*R losses. We infer that any sparking on the fingers led to a chain reaction of finger destruction. We had several spark detectors monitoring the fingers, but rather than supplying protection, as was intially desired, they became indicators of when to replace fingers.

The solution concept came from a couple of cyclotrons in Europe. The cyclotron currently under construction in Milan uses silver graphite balls to make contact, while those in Ganil use fingers with silver graphite buttons for the contact surfaces. Since the concept used at Ganil is much simpler and cheaper, we decided to use it here. We then found a U.S. manufacturer willing to specially produce similar finger stock for us. The advantages of this material over the original type are: 1) the heavy gauge spring stock maintains contact pressure without need of air pressure, 2) the fingers are silver plated to reduce losses, and 3) they are tipped with long lasting silver graphite buttons for low resistance and lubrication during movement.

The initial stock we received did not meet our specifications for required silver plating thickness and this test batch gave out in time. The destruction of this stock, however, was much less severe than would have occurred with the old style. Shortly after this initial test we installed this type of finger, which met our specifications, on all of our dee stems and transmitter stems. These fingers have been in operation for ten months now without a single failure. We have also recently tested one such finger at greater than 100 amperes @ 60 hertz and 45 amperes @ 30 Mhz. Our tests have yet to damage one of these fingers.

3. REMOTE CONTROLS

Until recently, we could not control the dee stem sliding short positions except with controls on the cyclotron. The computer and electronics groups have recently provided remote controls for us which are adjustable from the RF console. This, in itself, has greatly reduced the time required for frequency changes and has enticed greater accuracy and reproducibility in tuning this system.

4. INPUT COUPLERS

Our input coupling capacitors were initially rather delicate devices. These couplers would fail anywhere from initial operation to probably a month of normal operation. Various models of situations leading to coupler failure were considered. One thought, for sure, came out of all this; whether an arc would develop and live or whether destruction due to a single energetic spark was the cause. We did not have any circuitry operating that was adequate to protect us from any conceived scenario.

With a high gain closed loop RF system, such as this one, feeding a match terminated transmission line, should anything occur to increase the VSWR and therefore decrease the delivered power; the drive level will automatically track this to hold the dee voltage constant. If the change in VSWR is due to an arc, and if the gain is high enough to dis-allow triggering of a dv/dt circuit; then the odds are the increased drive will keep this arc alive as if the system were designed to do this! This RF welder would then punch a hole through the most delicate place available which, in our case, is the alumina insulator vacuum window. Since the insulator is at the top of the coupler, which is the preferred direction for heat to travel I hear; irregardless of where this arc began, it would probably travel to the insulator in a Jacob's ladder type fashion. Well, this scenario or something much like it caused us a great deal of coupler failures.

Since this time we have designed and installed VSWR circuits that both aid in tuning the coupler for minimum reflected power and generate a fault signal should this ratio become worse than an operator set level. The fault circuit is designed to cut RF drive off in less than 10 microseconds after a fault condition. At approximately the same time we began bleeding a small amount of nitrogen around the couplers air side to prevent stagnant gases from building up. All this seems to have solved the problem for now.

Another development in this area, yet to be implemented, involves a new mechanical design for the vacuum window insulator on the coupler. Versus the hollow bottle like shape now used, we will implement a solid planar alumina disk. The first such coupler tried had a few mechanical deficiencies which caused it to bind up by the dee. Although the binding caused the coupler probe to deform and numerous sparking resulted, we never noted a vacuum leak! Other problems with the initial new style coupler involved the copper sleeves which are affixed to the alumina. These sleeves were thin and weak which caused sealing problems during assembly. This design has been upgraded and we are currently waiting for parts to try again. With the implementation of this new coupler design along with the electronic protection curcuits, we hope to solve this problem for good.

5. IMPROVED PHASE SHIFTERS

The fast phase shifters (regulators) we now use break down more than an acceptable amount and are tricky to repair. The majority of the failures involve a mechanical phase pot which allows one to set the phase reference through a complete 360 degrees. To eliminate these problems and others, we have tested a new design which is totally electronic. This new design also yields an output which is only dependent on the input for phase and not amplitude for a much broader range. In fact the output is regulated and adjustable from 300 mVrms to 3 Vrms for an input of 100 mVrms. We are currently waiting for the PC boards needed to assemble the phase shifters. The old ones will be saved intact for K800 RF system development if necessary.

6. FREQUENCY DISTRIBUTION SYSTEMS

The current system used to generate and distribute the 3 phase RF signals, local oscillator signals, etc. has a few shortcomings. These are: 1) signal levels which are not independently adjustable, 2) a low pass filter design which is hard to fabricate, maintain and adjust, 3) local oscillator signals which are not well regulated, and 4) drive levels which are too low. The overall design philosophy is excellent, therefore individual modules comprising the total system have been re-designed and built leaving the design philosophy intact. The re-designed modules are the AGC/Pre-amp group, the mixer oscillator group, and the low pass filter. Also, a more powerful RF amp group has been added. Two new systems are currently under construction. One for the K500 and one for the K800. The unit currently operating the K500 will be upgraded and saved for circuit development and spares. We expect the units under construction now to be available in March 1985.

7. THERMAL PROTECTION

Recently, thermal switches were added to the Rf waterlines for additional protection against insufficient water flow. These switches are interlocked through the modicon to shut the system down should the temperature become excessive.

8. PROPOSED CORONA RING MODIFICATIONS

We have recently limited ourselves to running beam energies of 40 Mev per nucleon and below to avoid unnecessary heating of the corona rings in our dee stems. One of the corona rings reached a temperature of 250 degrees celsius at 75 KV peak dee voltage. We have determined this to be due to poor thermal contact between the corona ring and the water cooled portions of the dee stem. The corona ring makes contact with these areas via Rf contact fingers only and calculations along with experience has shown this to be inadequate for good heat transfer.

P. Miller has computed and experimentally measured various methods of acheiving good contact for both Rf and thermal considerations which can be implemented here in a straight forward fashion. He has both calculated and shown experimentally that the springs we use for RF contact in other places are very good conductors of both heat and RF. The new design we will be testing for the corona ring is a three section split ring. The contacts between the corona ring and dee stem are made with Rf contact springs. Pressure is applied to these springs via 3 bolts which draw the three sections of the ring together during installation. The bolts are recessed into the side of the ring, and this recess is electrically concealed with an inserted copper plug after the rings are adjusted. The fabrication of these parts is currently in progress.

9. HYDRAULIC ACTUATORS AND VALVES

The original hydraulic valves, which were used to servo the dee fine tuning capacitors and input coupling capacitors, were Moog valves. These valves are no longer available commercially and, in fact, were only available through federal surplus originally. To eliminate the concern about spare parts we have implemented Atchley valves on all of our hydraulic axes. The Atchley valves are used on many types of commercial aircraft and industrial robots and should be readily available for years. These valves have a frequency response much greater than the Moog valves and are less susceptible to clogging from oil impurities.

During the initial testing of a Atchley servo valve, we found them to be unstable when driven by our hyraulic motor servo controllers. The original servo controllers, which controlled the Moog valves, supplied a voltage as the actuating signal. Current control, on the other hand, is more appropriate here. Re-design of the controller to a transconductance output with regulated current drive, along with re-adjusting the compensation and gains, stabilized everything well. The new controller also places the phase feedback loop, used in closed loop operation of the cyclotron RF system, in a rate feedback configuration. This is, in general, a configuration which is inherently more stable because the gains and compensation of the two loops are more independent of one another. One other problem with the Atchley controllers involves their tendency to oscillate in the presence of large external magnetic fields. These valves must be well shielded from external magnetic fields. We now have implemented Atchley valves and new controllers on all the Rf hydraulic axes with good performance. Incidentally, the new controllers also yield greater control response from the Moog valves; therefore, all the working Moog valves are available to us as spares.

10. COMPUTER ALGORITHMS

We have made available to the operations group a user-friendly program known as RFTUNE. The RF group tuned the RF system through the entire band (9 - 27Mhz) in 2Mhz increments and logged all settings for all tuned axes in the process. The program (RFTUNE) was then written which uses the data to yield a cubic spline fit for axes positions for any operator-requested RF frequency. The data generated from this program has been found to be highly accurate and has allowed the operations group to tune to new operating frequencies without assistance from the RF group. It has now become standard procedure for energy changes to occur any time day or night. This program will also supply tuning instructions on request. In the future, a program to be known as RFMAINT will generate, in the same fashion as RFTUNE, all pertinent calibrations for all RF pickup loops and monitors which are frequency dependent.

11.PROPOSED X-RAY CALIBRATION TECHNIQUE IMPROVEMENTS

The K50 cyclotron successfully implemented a hot filament to generate controlled electron flux levels, while making x-ray measurements, to determine dee voltages. Due to the complicated and tight central region of the K500 median plane, and the lack of a good x-ray path from source to window which works for all dees, we are currently constructing a hot filament for insertion in the center hole instead of the ion source. We believe by controlling the electron flux we can make more accurate dee voltage measurements, with currently available windows, using the x-ray calibration technique.

OPERATION OF THE PIG ION SOURCES IN THE K-500

D. Poe, T. Antaya, P. Miller, G. Horner, N. Friedman, G. Humenik, M. Garbek, H.A. Thulin, L. Wilkinson, and J. Kuchar

PIG source operation is by now probably as routine as such an operation can be, and the sources deliver beams for reasonable times. I do not wish here to reiterate the article on K-500 operation, but rather to give an overview of source operating features.

Three basic modes of source operation have been in use; the use of tantalum cathodes, hafnium cathodes, and "solid feed" sources, of which only lithium and boron have been run.

Tantalum sources allow running at high duty factors while still maintaining adequate beam. Their main disadvantage is a short lifetime, and they incur more failures of the sort requiring shop attention.

Hafnium sources can maintain good beam only at low duty factors, but they last longer and lead to faster rebuilding and fewer serious difficulties.

Lithium beams are run by the use of a pellet of lithium fluoride mounted at the rear of the chimney. They run only with a special high voltage rod in the source, which we believe is damaged by the use of tantalum cathodes. Lithium sources always therefore run with hafnium cathodes, and will run with long lifetimes, for one and two plus ions, when run properly.

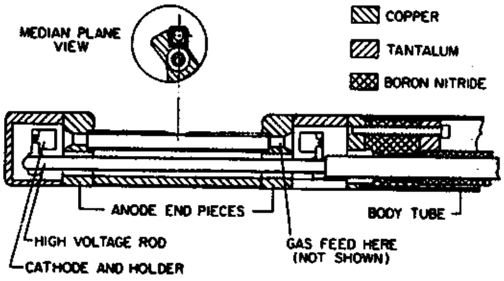

Fig. 1 K-500 ion source.

Figure 1 shows the K500 ion source. The cathodes run at a potential of a few hundred volts negative and the anode is at ground potential. The axis of the ion source is parallel to the magnetic field. The plasma, made of positive ions and electrons, is inside the anode, at ground potential, and the plasma may itself be electrically neutral. Positive ions in the anode spiral around the magnetic field lines until they reach the anode to cathode gap, where they are accelerated though the few hundred volts potential, then striking the cathodes. This keeps the cathodes hot enough to cause significant thermionic emission of electrons, which are accelerated across the same cathode to anode gap. It is these electrons, of a few hundred electron volts energy, which supply the energy to ionize the gas being bled into the anode. In addition to heating the cathodes, the positive ions dig deep craters in them, leading to loss of electron emission and loss of the arc.

Positive ions leave the ion source for acceleration in the cyclotron through a slit in the anode which faces the "A" dee tip. When the "A" dee is negative, positive ions are attracted to it from the grounded anode, starting their acceleration in the cyclotron.

A solid feed ion source differs mainly in the presence of a solid pellet at the back of the anode, lithium fluoride in the case of lithium beams. See figure 2. A support gas, usually nitrogen, is used to create a plasma. Atoms of nitrogen are pulled from the anode by the electric field of the "A" dee, but most get only part way to the dee tip before being pushed back into the anode by the reversing electric field, where they strike the solid pellet. Lithium ions are thereby released into the plasma, but the plasma itself does not contact the pellet.

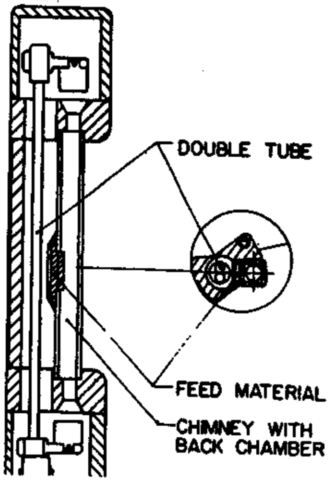

Fig. 2 K-500 ion source with solid feed.

If the arc were run by a voltage controlled power supply the arc current would increase rapidly as the cathodes heated up, leading to a current runaway. The power supply is therefore current regulated, and the voltage settles at whatever the arc conditions allow. The operator may adjust the gas flow to change the arc condtions, select tantalum or hafnium cathodes, or change the duty cycle in an effort to get the source to do what he wishes.

Typical parameters from typical beams might be like this:

E/A (Mev)	ION Cath.	TYPE	AVG.V	AVG.I	POWER (Watts)	GAS (cc/min)	DUTY	BSO(ena)
35	14N5+	Ta	850	1.6	1700	1.8	100%	20
35	14N5+	Ta	700	2.5	1700	2	100%	75
30	14N4+	Hf	500	1.2	750	3	65%	250
35	6Li2+	Hf	380	1.8	700	2.5	95%	75

Table one shows some further K500 cyclotron extracted beam data. It is thought (1) that the effect of pulsing is to allow for higher instantaneous voltages at any given average arc current. Thus, if the arc current is held constant while the duty factor is lowered, the cathodes will cool off and the instantaneous voltage will rise. This is especially important in cases, such as when running N5+ beams, where

Table 1. K500 CYCLOTRON EXTRACTED BEAMS.

ION	ENERGIES (MeV/n)	EXT. CURRENT (enA)	CATH	DUTY	FEED MATERIAL	AVER. TIME (h)	MAX. TIME (h)
2 D 1+	53	800	Ta	100%	D2 + CO2		
4 HE 1+	15,20,25	400	Hf	100%	1% He in N2 + N2	12.9	20.5
4 HE 2+	53	250	Ta	100%	He + CO2		
6 Li 2+	35	200	Hf	80%	6 LiF Pellet + N2	37.3	67.6
7 Li 2+	20,25	200	Hf	80%	LiF pellet + N2	16.0	42.5
12 C 3+	15,20,25	180	Hf	100%	CO + N2	10.6	19.0
12 C 4+	30,35	200	Hf	100%	CO + N2	14.1	31.6
14 N 3+	15,20	300	Hf	100%	N2	15.4	27.8
14 N 4+	20,22,25,30	150	Hf	100%	N2	23.4	55.0
14 N 5+	35	120	Hf	30%	N2	24.9	55.1
	35	100	Ta	100%	N2	6.4	10.6
	35	150	Ta	80%	N2	5.5	7.6
16 O 4+	20	120	HF	15%	O2 + N2	10.8	13.9
20,22 Ne 5+	25	80	Ta	10%	Ne	2.2	4.1
40 Ar 6+	10	80	Ta	10%	Ar	1.8	2.6

the energy needed to remove the last electron is comparable to the kinetic energy gained by an electron in crossing the cathode to anode gap. In these cases, the inability to run in a pulsed mode will set the kinetic energy of these electrons to such a low value that little beam will be obtained. For instance, one cannot run an $N5+$ beam DC with a hafnium ion source (although tantalum will work for this), but with some pulsing, the instantaneous arc voltage in a hafnium source becomes large enough to supply enough kinetic energy to the electrons to ionize nitrogen to a five plus state.

The performance of a tantalum ion source is limited by the power one may allow the arc to draw. For a nitrogen five plus ion, one finds the maximum beam output comming at about two kilowatts. At power levels higher than this, the beam becomes unstable and parts of the ion source will probably melt. The water flow to the cathode and anode circuits is each about 1.2 liters/minute.

The performance difference between hafnium and tantalum cathodes is thought(2) to be due to a difference in the vapor pressure of the materials at running temperatures. The vapor pressure in the 2000-2500^0 C region is five orders of magnitude higher for hafnium than for tantalum, leading to lower arc voltages at given arc currents, and generally poorer performance. It is only due to the extended lifetimes of the hafnium sources that we use them at all.

Because of the aforementioned necessity of maintaining a reasonable average arc current at low duty cycles, it was decided to purchase an ion source power supply capable of supplying high instantaneous currents. This was in order to take advantage of the pulsing effect at the lowest duty factors, where a very high instantaneous current is needed in order to keep the average current high enough to keep the cathodes hot enough for thermionic emission to be maintained. A power supply was therefore purchased with an average current maximum of six amps, more than is normally useable, but with a peak current rating of eighteen amps, allowing improved operations at low duty factors. This has allowed the running of oxygen beams with much improved source lifetimes, for instance. One may run an oxygen beam with almost all nitrogen support gas and only a small amount of oxygen, and use low duty factor pulsing to retain the beam intensity. This lengthens the lifetime from very few to maybe twenty four hours.

Why hafnium ion sources provide longer lifetimes has been discussed by Antaya et. al.(2). He points out that the preponderance of evidence favors the hypothesis of a surface layer buildup of a reaction product of hafnium with the arc support gas. This surface layer is thought to have a lower sputtering rate than the hafnium alone.

Operationally, it is necessary for the operator and the experimentor to try to arrive at the best running condition, given the nature of his experiment.

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1. T.A. Antaya, et. al., Tenth International Conference on Cyclotrons and their Applications, April 30-May 4, (1984), F. Marti, ed., IEEE,126
2. T.A. Anataya and P.S. Miller, Tenth International Conference on Cyclotrons and their Applications, April 30-May 4, (1984), F. Marti, ed., IEEE,341

K500 CYCLOTRON VACUUM SYSTEM DEVELOPMENT

R. Blue, P. Miller, M. Mallory, D. Poe and H. Laumer

1. Cryopumps

The main pumping for the beam chamber is provided by cryopanels installed below the median plane inside the dees. The liquid nitrogen and helium are supplied by vacuum-insulated coaxial transfer lines inside the lower dee stems. The helium-cooled cryopanel is surrounded by a nitrogen-cooled copper box covered by a chevron baffle to admit gas to the cryopanel inside and block thermal radiation.[1] The cryogens are fed through the three pumps in series to minimize the number of valves and controls.[2]

As installed originally, two of the pumps (B and C), which had been slightly redesigned since the testing of the prototype, were found to require high flow rates of liquid nitrogen and even then the shield temperatures were marginal, thus degrading pumping performance. A new pump employing copper clad stainless steel material where advantageous was designed.[3] After pumps B and C were modified to this form they operated as intended and used much less liquid nitrogen. In fact, we found that the lowest usable flow rate of liquid nitrogen was determined by the temperature of pump A. We bypassed this pump by disconnecting the nitrogen and helium feed bayonets outside the cyclotron, which further reduced the nitrogen consumption and the heat load on the helium refrigerator. The cyclotron operation was not impaired perceptibly. Since these modifications were done the pumps have worked well. Leaks, rather than pump failures, have been the main vacuum-related problem that interrupted cyclotron operation. The one exception was a failure of the clamping mechanism which attaches the radiation shield for cryopump B to the hub of the cold head. The problem was traced to a tapped short thread which was easily corrected by tapping deeper.

The pumping speed was measured to be 3600 l/sec with cryopanels B and C at 7K and A at room temperature by flowing nitrogen gas into the ion source (no arc present) and observing the response of the "median plane" ion gauge on the upper pole cap. Recently the cryopump A was reconnected. The pumping speed with 3 pumps was 5600 l/sec, which is 1.5 times the speed with just B and C in operation, as expected. The last time pumping speed was measured with 3 cryopumps (in Dec 1982) the total was 3500 l/sec. The cryopanel temperatures were slightly higher (A,B,C=8,11,11K) and the gas inlet may have been connected to a different port than the ion source.

2. Vacuum seals

We now use indium wire to seal vacuum joints that were designed originally for C-seals. This retrofit is accomplished by placing a metal ring with grooves to hold the indium wire in the C-seal groove. We have replaced the C-seals in this way on 4 of the 6 dee stem insulators in the K500, with only A and B upper still containing the original C-seals.

An indium vacuum seal backed up by an O-ring is used in the joint between the upper dee and the dee stem inner conductor. The indium carries the rf current from the stem to the dee. In this circumstance the clamping force is limited by deformation of the dee stem. This force also varies somewhat because of thermal expansion of the dee stem. We find that the clamping force decreases gradually over the first two days after new indium is installed, and we must retighten the bolts periodically until this effect, presumably due to cold flow of the indium metal, stabilizes.

3. Controls

The automatic controls for the pumpdown and venting of the beam chamber with various protective interlocks were implemented as planned. There are two oil diffusion pumps in use: 1) main coil cryostat vacuum jacket, and 2) lower ion source air lock. The original plan called for these to share a common forepump which, with suitable branch valves and controls would also serve as a "guard" pump to maintain a rough vacuum between double gaskets. This concept was abandoned and separate forepumps were purchased for each diffusion pump because that system was simpler and less likely to experience an accidental inrush of air. The "Guard Vacuum System" is a separate pump with multiple branch valves that are interlocked together. In addition to the gasket guarding function mentioned earlier it is used to rough pump the ion source air lock. There is a similar system dedicated to maintaining the vacuum between the rf liner and the magnet poles. The controls are designed to protect the system from oil backstreaming and unwanted venting. The control logic is implemented in the Modicon 584 programmable controller.

The need for a certain interlock for the cryopumps was demonstrated by an accident in Nov 1983 which resulted in damage to water pipes in the lower dee stems. This occurred during an extended maintenance period when the water to the dees was turned off but the cryopumps were being cooled. The water in the pipes near the cryopump eventually froze because it was not flowing and burst the pipes. The cryopumps are now interlocked to the appropriate water flow switches as well as to the vacuum gauges in the insulating jacket on the cryolines.

4. Turbomolecular pumps

The beam chamber is pumped by three Balzers TPU 510 turbomolecular pumps which can be isolated individually for maintenance. The pumps are operated at a rotation rate of 715 Hz, instead of the standard 1000 Hz, for reduced eddy currents and longer life. The pumping speed is reduced at the pump itself, but this has little effect on the overall pumping speed, which is limited by conductance. The oil is changed every 3 months and bearings are replaced every 6 months. The maintenance schedule is staggered so only one pump is serviced at a time. This has eliminated the bearing failures that were causing unscheduled stoppages for a period of time.

On one occasion when all cryopumps were at room temperature the nitrogen pumping speed of the 3 turbo pumps together was measured to be 100 l/sec using the same proceedure as described in section 1. This value should be compared with the calculated conductance limit of 160 l/sec for the pumping ports through the magnet pole.

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1. M. Mallory et. al., Annual Report, Cyclotron Lab., MSU 1979-80, 102 (1980)
2. P. Miller et. al., ibid., 1982-83, 128 (1984)
3. P. Miller, Proc. 10th Int'l. Conf. on Cyclotrons and their Applications, April 30-May 4. F. Marti, ed., IEEE, 11 (1984)

THE K500 RADIATION PROTECTION SYSTEM

L. Wilkinson, P. Miller

As the date approached for bringing the K500 Cyclotron operationally on line, a simple interlock system was installed to protect personel from potentially dangerous levels of radiaton when the accelerator was functioning. Verification of "cleared" vaults was more cumbersome than for the K50 Cyclotron. Unlike the K50 Cyclotron, which had only one main vault, the K500 machine setup encompassed two vaults (fig. 1), and the K500 vault itself contained four primary levels. Multiple entrances to the vaults compounded the problem.

The initial simple shield door interlock required that the vaults be cleared or "secured" by closing all doors except one, stationing one person at that door, and sending another through the vaults. This system had some inherent disadvantages.

1) Two people must be present to properly execute the procedure.

2) Whenever a vault was entered to make an adjustment on the cyclotron or beamline, the entire system of vaults had to be rechecked to verify that no one had entered unnoticed, causing extensive delays.

3) No provision was made in the old system for ensuring that all areas of the vaults were carefully checked for workers, other than relying on the person doing the check.

With these concerns in mind, planning for a new system using the MODICON programmable controller was begun in the summer of 1982. The desired characteristics of the system were set down to ensure it performed as required.

1) The act of opening the door or barrier for access to a protected area will interlock the beam off, via the cyclotron Rf system.

2) The operation of clearing and securing the vaults can be done safely and quickly by one person.

3) The system requires that all areas of the vaults be inspected.

4) Re-entering one vault or section of a vault does not neccessitate searching through the rest of the vaults.

5) Audible alarms sound when closing the

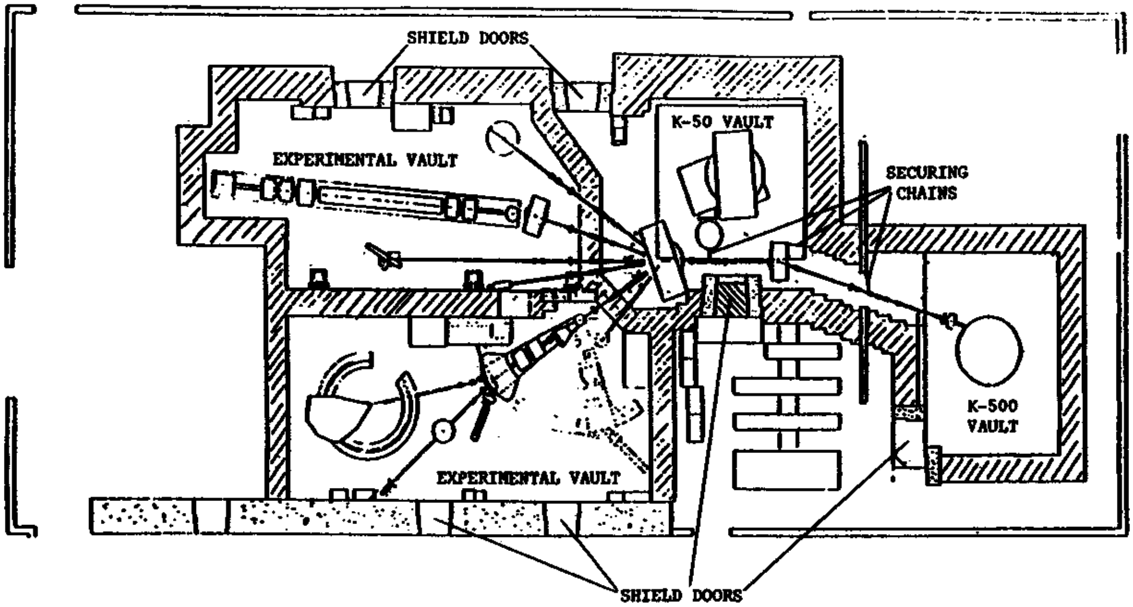

Fig. 1 Diagram of the main levels of the two cyclotron vaults, showing location of shield doors and securing chains.

vaults.

6) Door controls inside the vaults allow escape, and interlock the Rf.

The series of vaults was divided up generally by level, and each level was designated a "SECURE" area. The entrance(s) to each area were closed off through the use of yellow chains or shield doors and associated switches tied to the MODICON. In each area, one or more buttons were placed in strategic locations to ensure that the area was thoroughly checked. To secure an area, all but one entrance is closed with the chains or doors, the button or buttons is then pushed, (signifying visual inspection), and the last chain or door is put in place within a certain period of time. If the time runs out, the procedure has to be repeated. In addition, if any chain or door is lowered at some future time, the area has to be re-secured. This ensures that no entrance is made to a secured vault without stopping the cyclotron and alerting the operator. A display panel outside the K500 vault and in the control room shows when each area has been secured . Once the complete vault system has been cleared and secured, the MODICON allows the Rf Drive to be turned on to begin accelerating the beam. A bypass key allows the Rf Drive to be turned on with the vaults open for adjustments to the Rf system, but only if the ion source is not running, thus preventing acceleration of ions. The procedure of securing the cyclotron vaults is performed only by the operation staff, but opening doors and chains is not restriced to this group.

In addition to the cyclotron vaults, there are currently two experimental vaults where the beam is sent for the user experiments. These two vaults are not included in the main MODICON Radiation Protection System, but have interlock systems of their own. Each vault has only one entrance, closed by a shield door, and the beam is prevented from entering the vault when the door is open by a series of wall plugs. Should any of the wall plugs for a particular vault be open when the door to that vault is also open, the Rf is interlocked off through the MODICON. Securing these vaults is not limited to the operation staff, but may also be accomplished by the experimental research staff.

Both cyclotron and experimental vaults also contain an independent system of neutron monitors, which interlocks the Rf if radiation is detected in any vault that has not been secured. Each interlock system is routinely checked to verify proper operation.

RADIATION MONITORING AND SAFETY AT THE NATIONAL SUPERCONDUCTING CYCLOTRON LABORATORY

R. Lassin and R.M. Ronningen

The radiation safety program at the cyclotron laboratory adressed several issues during the past 15 months. The major ones included changes in the personnel monitoring program, the rewriting and distribution of the radiation safety manual, contamination and exposure investigations, and initiating and implementing programs that assure that the lab is in compliance with all appropriate federal, state, and university regulations in regards to ionizing radiation.

Personnel monitors are worn by all employees at the cyclotron lab. In April, 1984, a more neutron-sensitive, film badge was issued after several tests using a Pu-Be source demonstrated that the former dosimeters were not very effective in detecting moderate to high energy neutrons. Currently we are using the R.S. Landauer B-1 series badge that is sensitive to X,γ,β^-, and neutron (up to about 10 MeV) radiation. Neutrak-ER badges are sensitive to neutron energies of up to 15 MeV and are being used as area monitors.The badges are now exchanged on a monthly basis whereas in the past the film badges were exchanged every two weeks.

A significant upgrade in monitoring equipment was also made,with the purchase of several portable ion chambers, GM counters, and pocket dosimeters. A HEPA-filter shop vacuum cleaner was also purchased.

The cyclotron's radiation safety program includes the training of its personnel. This was accomplished by giving lectures and demonstrations throughout the year. A new radiation safety manual was also distributed to the laboratory staff and students in June, 1984. The manual is required reading for all those working at the facility and each person signs a statement upon reading it. All new employees meet with the radiation safety officer or health physicist which allows time for discussion so that particular safety concerns and problems can be addressed.

Tours and instruction, including but going beyond the scope of radiation safety, were given to nearly the entire staffs of the university's Department of Public Safety and fire department, and to East Lansing's fire department.

Part of the function for the radiation safety unit is making investigations and reports on contamination and overexposure. During the past 15 months, only two investigations needed to be conducted. In early 1984, it was found that the RF couplers were activated by neutron radiation. When these parts needed repair, they were sent to the welding shop where new insulators were installed. This job required a grinding and welding procedure and there was concern that the welders were being exposed by means of inhalation of radioactive dust and fumes. Since this was a routine maintanance procedure, there was concern that a chronic radiation problem existed. In order to determine the welder's exposure, a RF coupler was removed from the K-500 cyclotron. The entire repair process was reproduced and air samples were collected and counted on a germanium detector so that the radioactivity could be identified and the internal dose commitment could be estimated. The radiation emitted was found to be primarily from the silver solder (Ag-107 positron emitter). The internal dose commitment was estimated to be significantly less than 1% of the applicable maximum permissible concentration established by Federal regulation 10CFR.20. The other investigation involved the reported exposure of 47.4 Rem to a finger ring (TLD) used by one of the cyclotron operators. The investigation revealed that this badge was lost for a period of about two to three months. Since no other operations staff member received any significant dose during this time period and the fact that this operator's whole body badge had minimal radiation exposure for the same period, it was assumed that the reported dose was not indicative of a personnel exposure. A study by P. Miller showed that such a large exposure could be obtained if the finger ring were lost in the cyclotron's main vault for the same period of time, assuming normal operations.