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OPERATING RESULTS FROM FERMILAB

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Introduction

Since the 1973 Particle Accelerator Conference, the National Accelerator Laboratory has come of age and at the formal dedication ceremony held in May of 1974 the name was formally changed to the Fermi National Accelerator Laboratory in honor of Enrico Fermi whose many contributions to particle physics are well known. In this period of coming of age, the Laboratory has changed in many ways from a situation where experiments were installed in areas still crowded with the continuing efforts of construction, with all the consequent mud and dust, to more mature facilities where experiments can be efficiently installed and removed as the course of a dynamic physics program is carried out. The personnel of the Laboratory have moved from temporary quarters in the temporary housing of the Village to permanent quarters which are comfortable, efficient and esthetically pleasing. The accelerator has kept pace with these changes as its operation has become increasingly sophisticated and free of the operational difficulties inherent in the birth of a new accelerator.

The physics program which is accomodated by the accelerator has become a widely diversified program which continually taxes the expertise of the accelerator builders and operators.[1] Figure 1 illustrates the growth of the physics program. At present, over 370 proposals for experiments have been received of which 183 have been approved for running. The approved experiments represent the participation of sixty-eight United States research institutions and forty-seven foreign institutions in the physics program. Of these approved experiments, 70 have completed data taking and the results either have been or are being analyzed and published by the experimenters. Other approved experiments are either underway or to be done in the near future. The utilization of the accelerator by these experiments is illustrated in the data of Table I which shows the scope of the research program for approved experiments as of January 1, 1975. Here, the major experiments in the beams using electronic and bubble-chamber detectors are explicitly indicated. The most time-consuming users of the research facilities have their quantitative extent expressed in this table. The other experiments on the table are ones that are not major users of beam time and fit in among the major users of the beam lines.

The utilization of the beam by so many experiments for such a large accumulation of beam hours is due to the splitting stations which make it possible to provide steady and controlled beams to the three external beam experimental areas during each pulse of the main accelerator. The beam during each pulse is shared among the three areas in ratios which are predetermined according to the needs of the experimental program. The long spills are available for counter-experiments for 900 msec of each main accelerator cycle and this may be interspersed with short spills for bubble chambers during the pulse or at the end of the long spill. As many as four bubble-chamber spills have been used at equal intervals during the slow spill from the accelerator. These short bursts are used to produce secondary beams for bubble chamber pictures of hadron interactions in the 30" chamber. One of the external beam

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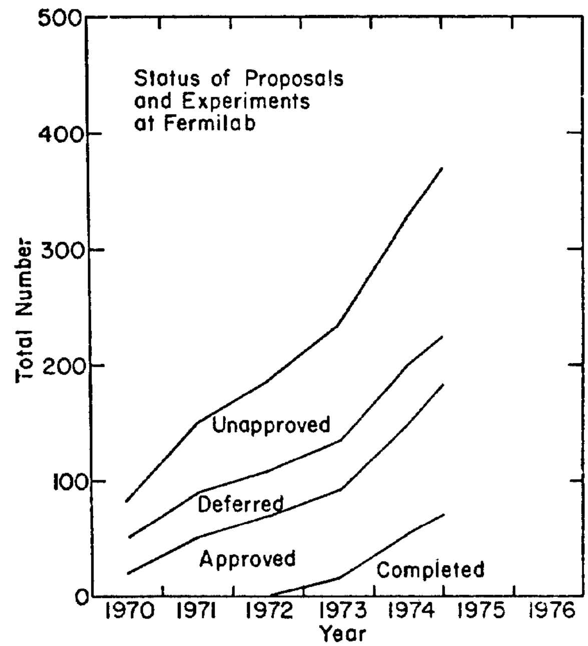

Fig. 1. These curves show the growth of the experimental program at Fermilab.

areas called the Meson Laboratory has five secondary particle beam lines originating at a single target. This allows for simultaneous use of the beam by five or more experiments at one time. Presently, the Meson Area is limited to 300-GeV protons on target due to the upper limit of the bending field available for proton beam transport to the target. Figure 2 is a schematic diagram of the layout of the experimental areas relative to the accelerators. The variety of experiments being pursued in the various beam lines is also seen in their relative locations.

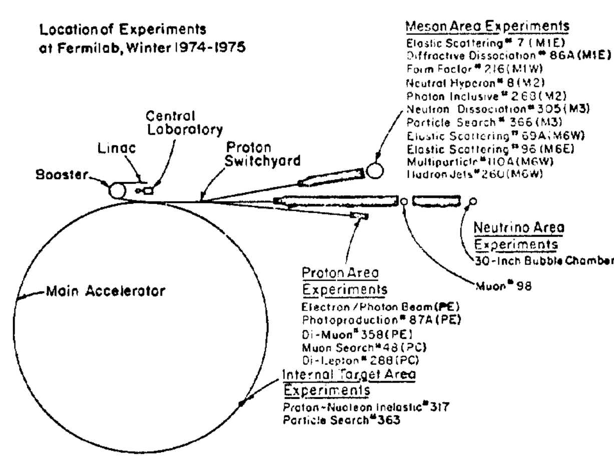

Fig. 2. Experiments installed at Fermilab, Winter 1974-1975.

In this diagram is indicated the work associated with tests of a new secondary beam line of electrons or tagged photons to an experimental hall still under construction in the Proton Area. This is a multistage beam designed around the production sequence,

$$p \rightarrow \pi^0 \rightarrow \gamma \rightarrow e \rightarrow \gamma.$$

TABLE I

SCOPE OF THE RESEARCH PROGRAM FOR APPROVED EXPERIMENTS
AT FERMI NATIONAL ACCELERATOR LABORATORY AS OF JANUARY 1, 1975

	Major Electronic Detector Experiments			
Data-taking complete		26	@	23,700 hours
Experiments underway - hours used		21	@	15,600 hours
hours remaining		(21)	@	~8,000 hours
To be done		39	@	20,000 hours
	Subtotal	86	@	67,300 hours
	Bubble-Chamber Experiments			
Data-taking complete		15	@	1,350,000 pictures
Experiments underway - pictures taken		8	@	330,000 pictures
pictures remaining		(8)	@	700,000 pictures
To be done		18	@	2,020,000 pictures
	Subtotal	41	@	4,400,000 pictures
	Other Experiments			
Data-taking complete		29		
Experiments underway		7		
To be done		20		
	Subtotal	56		
	Totals	183		

The maximum momentum is to be 300 GeV/c and the electron beam should be capable of intensities of about 2×10^7 electrons at 100 GeV/c from an incident proton flux of 5×10^{12} per pulse at 300 GeV. The first stages of this beam were tested last fall and electrons of 225 GeV/c were transported into the new hall. Further tests are scheduled for later this spring with the startup of an experiment to measure the photon total cross sections into hadrons planned for later in 1975.

This vigorous and diversified physics program is made possible by the ever-improving operation of the accelerator and its subsystems.

Accelerator Performance[2,3,4,5]

The accelerator peak intensity has improved by nearly 4 orders of magnitude since the first operation at 200 GeV in March of 1972. The most recent intensity record was set in early February when a peak intensity of 1.55×10^{13} was achieved. The increase in intensity together with steadily improving reliability has resulted in an increasing number of useful protons being accelerated per operating period as is shown in Figure 3. The increasing beam current has not been accompanied by large increases in residual radioactivity since extraction losses have decreased as the intensity has risen and much of the intensity increase has been due to improved containment of the beam injected into the accelerators which results in improved accelerating efficiency. Extraction efficiency now exceeds 98½% over the long term and has reached over 99% in shorter runs. In particular, highest extraction efficiencies are achieved when large percentages of the beam are being extracted in a fast spill at the end of the 900-msec long spill.

The scheduled operating time of the accelerator is divided as shown in Figure 4. An increasing amount of time has been devoted to high-energy physics and accelerator studies as system reliability has improved. This improvement has come from careful attention to the detailed causes of downtime. Table II shows how the reliability of the various subsystems has changed during the life of the accelerator.

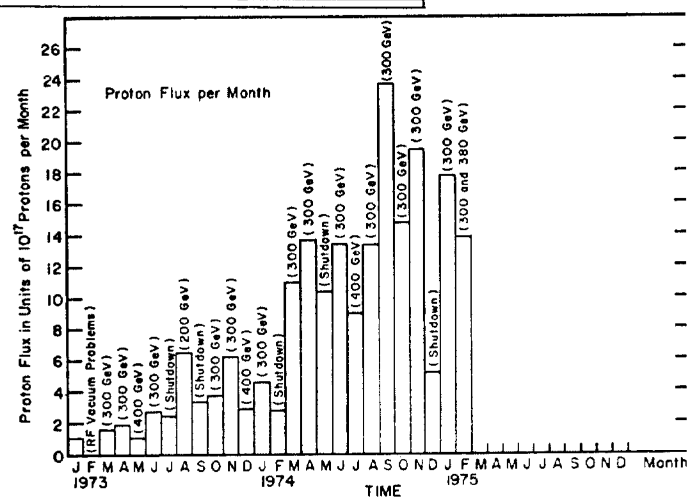

Fig. 3. Accelerated protons per month.

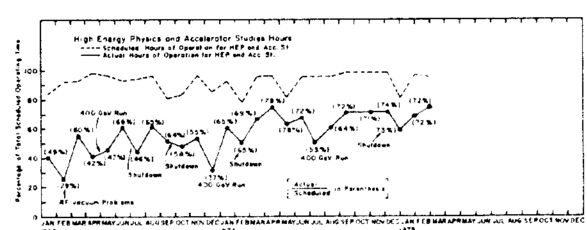

Fig. 4. Scheduled and actual use of accelerator times.

It can be seen that most systems have improved substantially in reliability and now are operating at 98% reliability or better. The main-ring downtime which was caused mostly by magnet failures in early times has been improved greatly due to installation of many improved magnets and the installation of improved water insulators on the magnet manifolds. The improvement in the main-ring reliability has been one of the most important factors in achieving improved intensity and is an important overall factor in producing the

TABLE II

ACCELERATOR-SYSTEM OPERATING EFFICIENCY
(Percent of Scheduled Operating Hours)

		300 GeV				400 GeV				
		First Half 1973	Second Half 1973	First Half 1974	Second Half 1974	First Half 1973	Second Half 1973	First Half 1974	Second Half 1974	*** First Half 1975
1.	Preaccelerator	97.57	98.27	99.13	98.32	98.55	99.55	**	99.21	99.77
2.	Linac	95.14	95.78	97.35	96.70	96.73	94.75		96.51	96.91
3.	200-MeV Line	98.26	99.14	99.15	99.59	99.30	99.55		97.90	99.85
4.	Booster	96.65	95.35	98.82	98.87	98.18	97.97		99.74	98.72
5.	Booster RF	96.72	97.12	98.99	98.82	98.84	98.40		99.54	99.06
6.	8-GeV Line	97.72	98.33	99.15	98.95	98.47	95.58		99.18	97.94
7.	Main-Ring Power Supply	89.69	96.57	96.25	96.93	79.72	91.30		83.54	96.34
8.	Main Ring	90.62	91.61	94.89	96.48	87.50	86.20		85.82	97.48
9.	Main-Ring RF	81.84	95.60	99.05	97.14	91.76	99.35		99.12	99.84
10.	Extraction	97.75	99.73	98.88	97.58	97.97	97.65		98.49	96.03
11.	Switchyard	97.56	97.64	98.16	98.53	99.50	97.76		96.28	97.98
12.	Controls	92.68	97.33	97.14	98.13	91.63	97.64		96.21	99.84
13.	Safety	98.76	98.11	99.64	99.46	99.88	99.87		98.77	98.34
14.	Utilities	98.92	98.45	98.03	98.23	99.17	85.33		90.30	99.77
15.	Human Error	*	99.14	97.88	98.55	*	99.45		88.89	98.45
	Total Accel. Oper. Eff.	.474	.653	.742	.756	.509	.535		.421	.776

* Not logged.

** No 400-GeV run in this period.

*** This run is incomplete. Data represent slightly less than two weeks of operation at 380 GeV.

level of physics program that is available today.

Figure 5 shows the magnet failure rate in number of failures per 100 accelerator operating hours. Not included in this graph are magnets which have been changed during the scheduled downtime because of a known history of water leaks or unusually low resistance to ground. Also, not included in this graph are magnets which have been changed during normal scheduled maintenance periods which have had turn-to-turn shorts that have not caused interruption of accelerator operation. It is clear that some magnet failures will continue in the future. However, we are now optimistic that the rate of failure of the order of one magnet per month or so will not be serious.

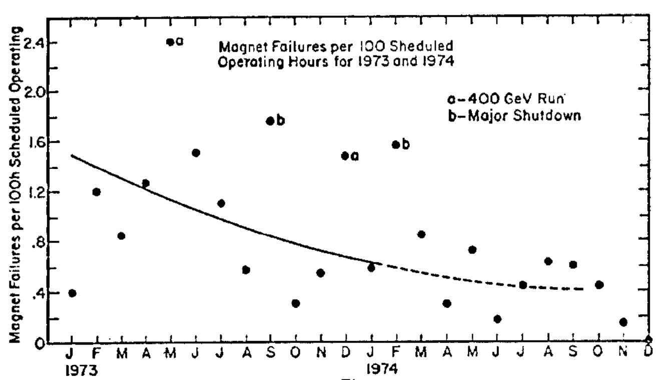

Fig. 5. Main-ring magnet failure rate per 100 of scheduled operating hours for 1973 and 1974.

In mid-February, a physics run was started at 380 GeV to complete a search for photoproduction of massive particles. The change to this higher energy was made in a 12-hour startup period and has proceeded with a level of operating efficiency not too different from that seen in the 300-GeV operation in recent months. The 380-GeV operation is being carried out with a new main-ring power supply control program which is more versatile and allows easier changes in the operating program than that originally written. This system allows operation with front porches at any energy with only minor modifications of the accelerator operating parameters in the program. The principal difficulties now encountered are the timing changes required for extraction and switchyard pulsed equipment.

Figure 6 is an oscilloscope trace which shows some interesting features of this operation. The trace with the staircase on the left is the main accelerator intensity. The staircase effect is the injection of the 13 booster pulses into the main ring during the 400 gauss front porch of the main ring bending field. At the right end of this trace is the slow spill at 380 GeV followed by a fast (1 msec) spill just before flattop. The ramp trace is the magnetic field (B) in the bending magnets and the lower trace is the rate of change of field ($\dot{B}$). The low-ramp slope following injection was inserted to allow a longer period for data taking in the Internal Target Laboratory for an experiment which took data at energies only below 100 GeV.

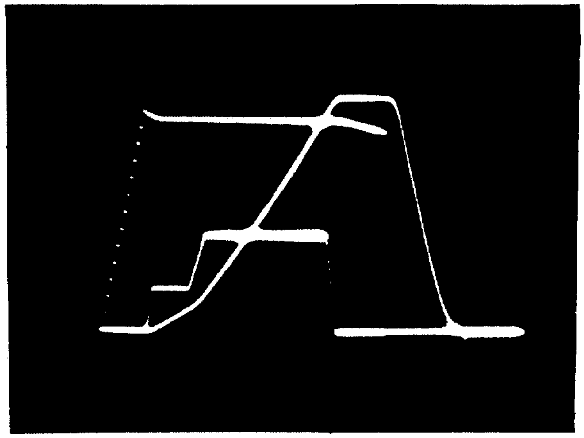

Fig. 6. 380 GeV main-ring ramp and beam intensity waveforms with reduced $\dot{B}$ for Internal Target experimental use.

The success at 380 GeV increases our confidence concerning operation at energies of 400 GeV or higher later this spring or next fall. Test of such operation will be attempted as soon as the rebuilt pulsed power transformer is installed.

In May of 1974 preliminary tests were carried out with a series capacitor in the secondary of the 345 kV to 13.8 kV transformer for the pulsed power to the main accelerator. This installation was shown to satisfactorily compensate for the voltage drop on the power lines due to the high power pulses required for excitation of the main accelerator to energies of 400 to 500 GeV. During these tests, the magnet was successfully pulsed to over 480 GeV. Unfortunately, the transformer failed before we had an opportunity to carry out tests of beam in the accelerator and the repair of the transformer will not be completed until the end of this month. Installation of the transformer is scheduled to be complete by the second week of May and tests again will be made at higher energy in the main accelerator.

Our record of being able to continuously push accelerator operation at increasing intensities, will show a decrease over the last five months of this fiscal year since it will be necessary to curtail the operation of the accelerator during these months due to insufficient funding for the program. It is hoped that this situation will not prevail in the coming fiscal year so that the increased program can again carry on after July 1.

Accelerator Status

Many improvement programs have been carried out in the various components of the accelerator in the two years since the last Particle Accelerator Conference. These projects and their results will be discussed in detail in many papers at this conference. For this reason, I will only summarize the results of the activities in the various parts of the accelerator system.

Preaccelerator and Linac System Status

Table III contains a listing of the preaccelerator and linac parameters. Included in this table are the design parameters, conditions of normal operation, the best performance observed to-date and what can be expected with future improvements. The principal improvement in the linac system has been the installation of the debuncher cavity.[6] This installation has resulted in improved booster performance by decreasing the momentum spread of the beam injected into the booster and by stabilizing the mean momentum.

Reliability of the linac has been considerably improved by installation of solid-state amplifiers in the low-level stages of the driver and improvement in the mechanical arrangements of the drivers which had previously resulted in excessive downtime when component changes were required.

Installation of a permanent driver for the debuncher will allow the linac to be retuned for optimum operation of the linac with the debuncher probably before early summer. Since the debuncher is now driven by the driver of the linac RF test set, such optimization has not been attempted since, when the test set is required for linac testing, the debuncher is turned off and it is not desired to have to retune the booster injection system to achieve optimum operation.

Booster System Status

Table IV is a table of booster synchrotron parameters. Booster accelerating efficiency has been limited by a drop-off in the RF bucket area from 3.2 eVsec at capture to a minimum of about 1.8 eVsec at 3 msec into the accelerating cycle. This drop-off is partially due to a high-loss effect in the ferrite of the booster cavity tuners which occurs at the RF accelerating frequency just above injection. In addition, the RF voltage requirement for the booster is greater than originally contemplated because of phase space dilution due to space charge and non-adiabatic capture processes. Recently two new RF stations were installed to increase the booster capability. The first cavities installed were special cavities which had a limited tuning range through the high-loss region. By virtue of alignment corrections in the booster and by operating these cavities and driving the rest of the RF system at higher power later, it has been possible to accelerate 1.96 x 10^{13} protons in the 13 booster batches in the main-ring cycle. A permanent solution requires tuners which do not exhibit the high-loss process. Such a set of tuners has recently received a successful preliminary test at high power, and it is hoped that the solution will be well underway by this summer.

The extraction septum used in the booster is a known obstacle in the vertical aperture of the machine. A new extraction septum has been built which will allow higher beam currents to be available in the booster as well as improving the beam emittance into the main accelerator by minimizing the distortions due to bad fields in this magnet. This will be installed during the shutdown in late April.

Other substantial improvements in the booster have included changes in the 200-MeV transport line which allow the line to be operated achromatically and with careful alignment adjustments so that no steering of the beam is done by the quadrupoles. Proper emittance matching of the beam to the booster can now be done. These improvements, together with diagnostic improvements, have made accelerator studies possible which make us enthusiastic about the future and the possibility of the booster achieving the ultimate intensity of 4 x 10^{12} protons per booster pulse with multiple-turn injection.

Main-Accelerator Status

Table V lists the main accelerator parameters. In the main accelerator the most substantive improvement has been the implementation of a new power supply control system. This system permits operators to make rapid changes in the number and variety of front porches and other parameters. It also regulates the magnet current throughout the entire cycle which results in a

TABLE III

PREACCELERATOR AND LINAC PARAMETERS

	DESIGN	NOMINAL OPERATING	BEST TO DATE	IMPROVEMENT EXPECTED
Preaccelerator				
Energy (keV)	750	750	--	
Beam Current (mA)	250	120 - 200	320(1)	
Emittance(2) (mm-mrad)	50π	50π - 60π	40π	
Linac				
Energy (MeV)	200.3	205	--	
Beam Current (mA)	75	60 - 100	120	
Beam Pulse Length (μsec)	Up to 100	12	--	
Momentum Spread $\frac{\Delta p}{p}$(3) at the Booster				
(a) without debuncher	3.2×10^{-3}	2.2×10^{-3}		
(b) with debuncher	1.6×10^{-3}	1.6×10^{-3}		$\leq 1.5 \times 10^{-3}$
Mean Momentum Variation	--	3×10^{-4}	1×10^{-4}	1×10^{-4}
Emittance(2) (mm-mrad)	5π - 10π(2)	10π(2)	8π	

(1) Departure from Pierce geometry. Maximum of 240 mA with Pierce geometry.
(2) For 90% of beam.
(3) Measurement in the booster for 95% of beam with 80 mA from linac.

TABLE IV

BOOSTER SYNCHROTRON PARAMETERS

	DESIGN	NOMINAL OPERATING	BEST TO DATE	IMPROVEMENT EXPECTED
Energy (GeV)	8	8	8	
Cycling Rate (Hz)	15	15	15	
Peak Intensity (Protons per Pulse)	3.5×10^{12}			
(a) Single-Turn Injection		0.74×10^{12}	0.84×10^{12}	1.5×10^{12}
(b) Multiple-Turn Injection		1.0×10^{12}	1.5×10^{12}	4.0×10^{12}
Acceptance (mm-mrad)				
(a) Horizontal	90π	$22\pi - 55\pi^{(1)}$		85π
(b) Vertical	40π	10π		$22\pi^{(3)}$
Emittance (Vertical at Extraction)	π	π		
RF Bucket Area (eV-sec)	2.4	1.8	1.8	3.0
(16 RF Stations)				
Injection Momentum Spread$^{(4)}$	1.6×10^{-3}	1.5×10^{-3}	1.5×10^{-3}	
Transmission (percent)$^{(4)}$				
(a) Single Turn		55	65	90
(b) Two Turn		40	60	80

(1) The transmission decreases to zerio between these two values.
(2) 3.2 eV-sec bucket area decreases to 1.8 eV-sec at 3 msec.
(3) With extraction septum in aperture.
(4) With debuncher and 60-70 mA from linac.

TABLE V

MAIN-ACCELERATOR PARAMETERS

	DESIGN	NOMINAL OPERATING	BEST TO DATE	IMPROVEMENT EXPECTED
Energy (GeV)	200	300	400	450 - 500
Peak Intensity (Protons per Pulse)	4.5×10^{13}	1×10^{13}	1.55×10^{13}	$2.5 - 5 \times 10^{13}$
Cycling Rate (sec)				
200 GeV (no flattop)	3.3	--	--	--
200 GeV (1-sec flattop)	4.3	4.8	4.5	4.2
300 GeV (1-sec flattop)		5.9	5.3	--
400 GeV (1-sec flattop)		12	12	7 (2-sec flattop)
500 GeV (1/2-sec flattop)		--	--	12
Rate-of-Rise (GeV/sec)	125	100	150	150
Slow Spill Flattop Length (sec)	1	1	1	
Peak RF Voltage per Turn (MV)	3.47	3		4
Momentum Spread $\frac{\Delta p}{p}^{(1)}$	1×10^{-4}	$\sim 1 \times 10^{-4}$		
Beam Emittance (mm-mrad)				
200 GeV, vertical	$.09\pi$	$.06\pi^{(2)}$		
200 GeV, horizontal	$.23\pi^{(3)}$			
Betatron-Oscillation Wave Number	~20.25	~19.4		
Transmission (percent)				
(a) Booster Single-Turn Injection	100	95	100	100
(b) Booster Multiple-Turn Injection	100	90	95	100

(1) Total spread measured at 100 GeV.
(2) Either horizontal or vertical with booster single-turn injection.
(3) In the accelerator for booster multiple-turn injection.

more stable pattern of remnant fields at injection time.

An additional power supply was added to the injection kicker magnet to permit the injection of 13 booster batches. Transverse beam instabilities have been controlled through modification of the sextupole correction magnets and through the development of a bunch-by-bunch vertical beam damper.[8] The cause of a high energy longitudinal instability has been traced to parasitic resonances in the RF cavities. Work is underway to modify the cavities by installation of a ferrite damper. In the booster to main-ring transfer line a new extraction septum is nearing completion. It should allow for a larger aperture in the booster as well as improve the efficiency of the beam transfer to the main ring.

A system of air coolers has been installed which together with the cooling ponds originally provided increase the cooling capacity for the main accelerator magnet system. These air coolers will remove limitations on accelerator performance during warm summer months.

The most extensive improvement in the main ring has been the rebuilding of the accelerating cavities to install improved electrode geometries and higher purity alumina vacuum windows in the cavity to allow higher accelerating voltages to be obtained from each cavity.

As a part of this rebuilding program, additional cavities are being built to allow the installation of two additional accelerator cavities to increase the redundancy and add to the available voltage. These activities will allow operation of the main ring with a higher $\dot{B}$ and therefore a faster repetition rate.

Extraction and Switchyard Status

A summary of the types of spill available from the main accelerator are given in Table VI. Normally there is slow spill for counter experiments, punctuated by short bursts for the bubble chamber and ended with a high intensity fast spill for neutrino experiments. Routine operation can now include delivery of slow spill to the three external experimental areas with up to ten enhanced spikes of 0.3 to 1 ms duration exclusively for the bubble chmaber. Fast ferrite pulsed magnets have been installed in the extraction lines to prohibit the fast spikes from reaching the Proton and Meson Experimental Areas.

A new fast spill of length 1.5 to 3 ms has been developed for neutral current neutrino counter experiments. It is achieved by pulsing an iron core quadrupole, thus driving the beam through the half integer resonance in the desired length of time. This spill rate of 0.8×10^{13} protons/ms is high enough to give a negligible number of triggers from cosmic rays and it is low enough to avoid flooding of conventional spark chambers with unwanted background tracks.

The extraction efficiency and losses on the external beam splitting stations has improved with the implementation of a new generation of electrostatic wire septa. The new design has improved alignment of the wires by winding them on a one-piece aluminum frame ten-feet long. The wires are wound using a lathe, and springs automatically retract accidentally broken wires when the septum is in use. Details regarding this new system design are described in a separate paper in this conference.[9] These new septa have helped achieve a slow spill extraction efficiency of 98⅓%. In both the extraction and splitting stations, losses have been reduced by about a factor of three. In general, reliability of the septa has improved due to the new mechanical design and the choice of materials. They have been operated at voltages of 90 kV per cm and, with the resulting decrease in losses, the residual radioactivity has lessened as the machine intensity has come up during the last year. Radiation levels are typically 0.5 R/hr one foot from the septa after shutdown when running 10^{13} ppp.

Spill structure in the frequency range 0 to 2000 Hz is smoothed with two servo systems which have been described elsewhere.[10] An additional servo system is now employed to stabilize horizontal beam position at the exit of the extraction channel by feeding back current to main-ring extraction position and angle bumps. This improvement has been of particular advantage for the Proton Experimental Area where part of the extracted proton beam is used on the experimenters targets. A vertical position servo will probably be installed. The typical duty factor disregarding booster bunch and RF structure is 75%.

Improvements to be completed in the next few months are: (1) upgrading the Meson Laboratory transport line to 400-GeV capability (present limit 300 GeV), and, (2) installation of a triple splitting station in the Proton Laboratory beam line.

Advanced Accelerator Projects

Energy Saver/Doubler

For the past two years the Energy Doubler Group of the Accelerator Division has been working on the design of the proposed Energy Saver/Energy Doubler.[11, 12] The present reference design for the 20-foot long dipoles is one which has a 2.5 inch clear cold-bore aperture, is expected to reach a 4 Tesla central field (which is equivalent to 1 TeV with small lattice charges that are being considered) and will be made from Rutherford-type cable in a four-shell coil geometry, which approximates a cosine distribution of the superconductor. Detailed reports on the status of the Energy Saver/Energy Doubler will be given at this conference in Session D.

During the past two years about 25 model magnets have been built to test various aspects of the design. In the most recent series of model magnets, two 2.5-foot magnets of the present reference design have reached the 4 Tesla field required for 1 TeV. The best 10-foot model of that design has just been successfully tested for over 12,000 pulses at 2.2 Tesla in the energy saver mode, i.e., a 400/500 BeV acceleration with a pulse rate of 8 to 12 seconds that would have approximately the same average intensity and duty cycle as the best we could do with the present conventional accelerator but which would use about 1/3 of the power, thereby

TABLE VI

EXTRACTION MODES AT FERMILAB

SPILL	METHOD	SPECIAL DEVICES	SPILL DURATION	INTENSITY	DUTY FACTOR
Slow for Standard Counter Experiments	ν_x = 19.5 resonant	2 ramped iron-core quads 1 spill feedback regulating iron-core quad 2 spill ripple-structure-reduction air-core quads 1 ramped iron-core octupole 3 ramped orbit-bump dipole pairs	1 sec	10% - 100%	70%
Enhanced Beam for Bubble Chamber	Resonant	Slow devices 1 air-core pulsed quad	1 msec	1×10^{10}- 5×10^{11} P/b.c.p.	
Coherent Fast for Neutrino Experiment B.C. & Counter Horn	Resonant	Slow devices 1 air-core pulsed quad 2 pulsed orbit bumps 1 ferrite single-turn kicker	100 - 300 μsec	< 80%	< 50%
Fast Horn Neutrino B.C.	Single-Turn	2 pulsed orbit bumps 1 ferrite kicker	21 μsec	0 - 100%	
Fast Neutrino (Quad Beam & Dichromatic) Counter Experiments (Neutral Current)	Resonant	1 iron core pulsed quad 2 pulsed orbit bump dipole pairs	1.5 msec	0 - 100%	RF structure only

making it possible to undertake a comprehensive physics program at 400 to 500 BeV without major changes in the experimental areas but at an operating cost of 4 to 6 million dollars per year less than what we could do with the present accelerator.

These results plus the encouraging results from our refrigeration test loop and the fact that we are able to obtain from industry, wire of sufficient quality and refrigeration of sufficient capacity have encouraged us to submit a request for FY '77 funding of the Energy Saver Phase of the Energy Saver/Energy Doubler.

Superconducting Transmission Line

Development work for construction of a superconducting ac transmission line has been started. The line to be built will be 1500-feet long and will be in parallel to the existing underground feeder cables from the master substation to the main accelerator. The power rating for the existing lines must be increased since they were originally sized for lower energy operation than is presently anticipated and their heating is exaggerated by the large reactive currents which the cables carry due to the inductive nature of the main-ring power supply loads.

The line being planned will operate at 13.8 kV at a peak current of 6,000 amps and uses conductors which have the geometry of heliax coaxial cables. The conductors are made of pure niobium bonded metallurgically to copper as normally used in the coax. Six of these conductors will be bundled into a common dewar. The center conductors will be used as a channel for liquid helium flow and the return to the refrigeration system will be by 2-phase flow through the space between conductors.

A six-foot section of this line has been tested. The test section was superconducting but poor surface finish and poor seam welds in the conductors made the losses increase with increasing current at a much faster rate than can be tolerated. The first test section was only tested for current carrying capability and no voltage breakdown tests were made.

New test sections made with the collaboration of the manufacturers of the heliax cable are nearly ready to be tested. These sections appear to be large improvements over the first section and we are very enthusiastic about the imminent tests. Factors which must be evaluated in early tests are: niobium bonding techniques; surface finishes; welding techniques; joint techniques; insulation and terminating design and cryogenic designs.

POPAE

A study was initiated in 1974 on the system of storage rings for Fermilab called by the acronym POPAE (Protons on Protons and Electrons). It is intended to include two proton rings and an electron ring so that both pp and ep collisions can be achieved. The general scale of the facilitiy is consistent with 1000 GeV proton energy and 20 GeV electron energy. A report describing progress thus far will appear in the proceedings of this conference. In addition, a discussion of some of the consequences of the single period lattice under examination in the proton rings will be presented in Poster Session K.

Acknowledgements

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