STATUS OF THE MAINTENANCE FOR THE KEK 12GEV-PS MAIN RING AND POWER SUPPLY

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Abstract

More than 30years passed since the KEK 12GeV-PS construction, some of accelerator equipments are highly radiated, especially the injection and the extraction equipments. In recent years, the higher intensity beam has been required for such as the long baseline neutrino oscillation experiment and rare decay experiments. Then, the circumference of the maintenance work has become severe. Further, almost equipments of main ring and power supply have deteriorated. Status of the Maintenance for the KEK 12GeV-PS main ring and power supply are presented.

1 OVERVIEW OF THE 12 GEV PROTON SYNCHROTRON ACCELERATOR COMPLEX

The 12 GeV Proton Synchrotron (PS) accelerator complex comprises two 750 keV H-ion sources, the 40 MeV Linac, the 500 MeV Booster Sychrotron, and the 12 GeV Proton Synchrotron. The 12 GeV Proton Synchrotron, which is called the Main Ring, supplies proton beams to the long base-line neutrino oscillation experiment (K2K), on which most of our effect is focused, and to two slow-extraction lines (EP1 and EP2) for various physics experiments. The Booster not only operates as the injector to the Main Ring, but also supplies proton beams to the Neutron Science Laboratory and the Meson Science Laboratory (NML). The beam pulse rate of the Booster is 20 Hz, while the cycle time of the Main Ring is variable from 2.2 to 4 sec, depending on the physics experiments. Only nine of the beam pulses the Booster can afford to supply are injected to the Main Ring in a cycle time, and the remaining pulses are supplied to the NML.

Machine layout of the PS complex is shown in Fig.1 and the basic parameters of the booster and main ring are shown in Table1 and 2, respectively.

Table 1: Parameter of the 500 MeV Booster

Circumference :37.699m
Injection Energy :40MeV
Extraction Energy :500MeV
Number of Period=8 (Combined Function)
RF :2Mhz to 6MHz
Harmonic Number :1
Repetition :20Hz
ν_H=2.2
ν_V=2.3

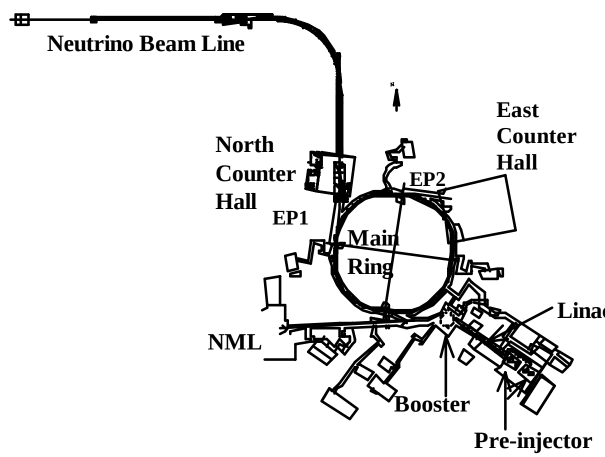

Fig.1 : Machine layout of the PS complex.

Table 2: Parameter of the 12 GeV Main Ring

Circumference :339.29m
Injection Energy :500MeV
Extraction Energy :12GeV
Number of Superperiods=4
Number of Period=28 (Separated Function)
ν_H=7.1
ν_V=5.2, 6.2, 7.2
γ_t=6.76
RF :6MHz to 8MHz
Harmonic Number :9
Repetition :2.2s – 4s
Nominal Intensity : 2-4$\times 10^{12}$PPP (slow extraction)
6-7$\times 10^{12}$PPP (fast extraction for K2K)

2 OPERATING STATUS

For recent few years, the Main Ring supplied proton beams almost according to schedule without any serious failure. PS is operated continuously except a long shut down in summer (about two months) and twice short shut down in a golden week (from end of April to early May) and the end of year to new year holiday. The Main Ring supplied protons to the slow-extraction line EP1 and EP2 for a proton of operation time. Almost three quarters of operation time is dedicated to the fast-extraction line EP1 for the K2K experiment. Run was conducted to supply sometimes the two slow-extraction lines EP1 and EP2 simultaneously. The number of protons in the neutrino production target of K2K accumulated during FY2000 is

2×10^{19} and the total number accumulated so far has exceeded 4×10^{19}, which is 40% of the target value of the K2K experiment.

An operating time in FY2000 and FY2001 are shown in Table 3. The experimental time for high-energy physics amounts to 4,141 hours. It accounts for 79% of the total operating time of 5,715 hours. The beam untilization time for the NML, most of which is shared with the 12 GeV Proton Synchrotron users, is more than 5,000 hours, accounting for 88% of the total Booster operation time.

In FY2001, the beam intensity of the Main Ring was held at the level required by the K2K experiment; i.e., about 7×10^{12} protons per pulse measured at the end of acceleration. This value of beam intensity was already achieved at the beginning of FY1999 after a series of machine development steps. The history of the average beam intensity of the Main Ring is shown in Fig. 2. For slow-extraction operation, however, the beam intensity is limited by the radiation hazard near the extraction section, which appears in Fig. 2 as lower intensities in the latter half of FY2001. The beam loss has increased with the intensity upgrade, then the residual activation was getting high level as shown in Fig.3.

Total operation time was more than 4500 hours per year for a recent few years, and 70-77% time was dedicated to physics experiment and about 15% was used for the accelerator study and tuning. The accelerator was operated in fairly good condition with less than 5% machine failure. However, the maintenance should be reduced due to the cut down of expenditures and every body anxious for the troubles of decrepit since PS is so old machine.

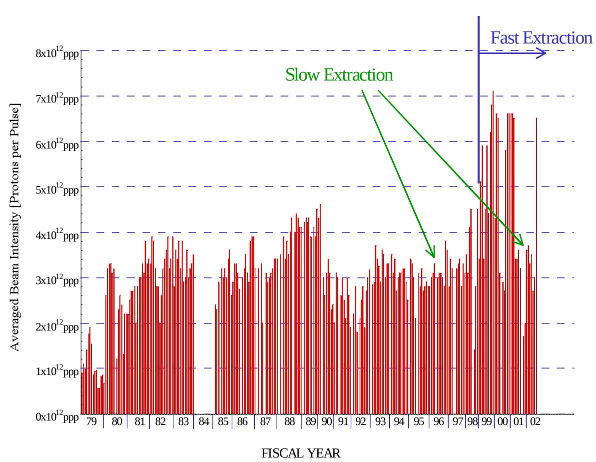

Fig.2 : History of the average beam intensity of the Main Ring.

Accelerator failure in FY 2000 and 2001 are summarized in Table 4. Rate of failure time is less than 5%, but in FY1999 the failure time was 450 hours(7%). We had no extra budget to construct the fast extraction system at EP1 for K2K experiment, but the maintenance budget had been cut almost 1/3 for three years, 1996-1998. Then, the several sever break down of equipment , had occurred at the commissioning for K2K experiment in 1999.

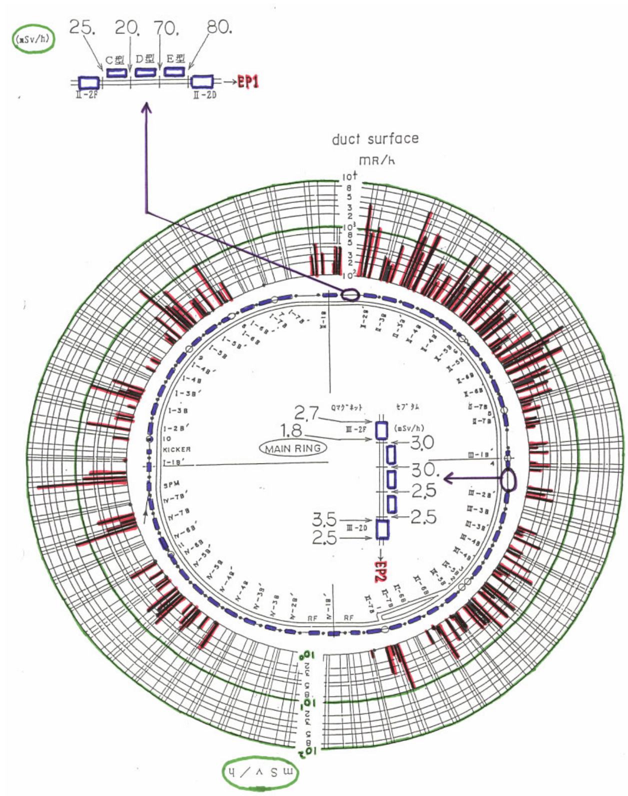

Fig.3 : Residual Radiation Level in the Main Ring

Table 3: Operating time in FY2000(upper) and 2001(lower)

	12GeV PS hours	12GeV PS %	NML hours	NML %
Total	5235.3	100	5714.8	100
		100	5877.3	100
Accelerator tuning	267.7	5.1	148.5	2.6
	212.3	4.1	154.5	2.6
Accelerator studies	374.2	7.1	226.3	4.0
	221.2	3.8	221.2	3.8
Beam utilization	4141.6	79.2	226.3	4.0
	4214.5	80.6	5062.8	86.1
System down	451.8	8.6	306.6	5.4
	583.3	11.5	438.8	7.5
Accelerator failure	289.8	5.5	174.2	4.1
	278.1	5.3	239.4	4.1

Table 4: Accelerator failures in FY2000 and 2001

	FY2000		FY2001	
	minutes	number of failure	minutes	number of failure
1.Pre-Injector	118	9	624	22
2.Linac	2697	226	2544	130
3.40 BT	662	109	8358	81
4.Booster MAG	887	10	354	12
5.Booster RF	737	6	30	6
6.500 BT	1434	23	162	20
7.Main Ring MAG	0	0	918	8
8.Main Ring PS	3457	4	126	4
9.Main Ring RF	3657	23	666	22
10.Extraction	1554	31	2292	18
11.Control	38	6	612	25
12.Monitors	139	1	0	0
13.Vacuum (B+M)	2005	1	0	0
14.Human error	51	10	48	14
15.Others	60	3	6	2
Total	17496	462	16740	364

3 PERSONNEL ORGANIZATION SYSTEM

The total number of the KEK staff is 733, consisting of 380 Research Scientist, 196 Technical Engineering Staff and 129 Administrative Staff. Usual Personnel Organization depends on the needs of equipment maintenance number of staff in accelerator department is 127 Research Scientist, 60 Technical Engineer and 5 administrator. PS group (36 staffs) is belonging to the Accelerator Division IV and comprises nine teams, Pre-Injector, Linac, Booster Ring and Beam Transport, Main Ring and Extraction, Accelerating RF for Booster and Main Ring, Control and Beam Monitoring, Vacuum System and Beam Handling. Table 5 shows a personal organization of PS division in 2003 and 1998. Situation of the research scientist is organized like University system. Number of persons reduced for five years, although the maintenance work and operation have become severe condition.

4 HOW IS MAINTENANCE AND OPERATION ORGANIZATION AND PERFORMANCE

Maintenance staff and Operating staff are not divided clearly. All of staff have the maintenance and machine operation duty. Five staffs in accelerator division 1 , who dedicate to work for the High Intensity Hadron Project, cooperate us for machine operation as shown in Table 4. Usual operation cycle was 16 days operation and five days scheduled maintenance at the WAO 1998[1]. First two days were used for machine tuning and several shifts were utilized for the beam study. We have to work for the starting up of beam tuning and also repeat a machine operation shift as two to three times in one operation cycle. After starting the K2K experiment, an operation cycle extended to two or three months continuously including two days of the conditioning for the pre-injector should be scheduled for every three weeks.

Staff can not become to expert for the every part of machine operation and maintenance except for one's duty, so the operating shift staff and beam handling group ask for the maintenance group to tune the corresponding part of machine. If tuning work continue to after five or till midnight, it should be a volunteer work.

We did the simple and easy maintenance during the short shut down (five days including the week end) as a former case. For the case of the severe break down, the chief of beam handling group should decide to change the machine operation schedule and order to the maintenance group to fix it. Shift leader can also decide in stead of the chief of beam handling group. If the trouble is so hard to continue the machine operation for a long time, the director of PS division have to decide the managing of fixing and re-start schedule.

At this present, unscheduled maintenance is main rule for minor troubles but heavy maintenance is scheduled in the summer shut down.

Several months shut down period is scheduled for every summer, but it is reduced to two months recently according to the user request. All of us would like to escape the work during a golden week and the new year holiday week, but the staffs of the group, which has the equipment to fix until machine start up, have to work hard with giving up their vacation and it is also a volunteer work.

We try to find the cause of break down and to change the break part to the spare if we have. In the case of no stock and/or the trouble of unknown reason, we order to a maker. We contract the emergency call with the important maker. We have no trouble shooting guides and procedures, it depends on the artificial technique of the expert, but the beam handling group is under processing to do it.

If the radio-activation of the break down equipment is too high to fix it by it's maintenance group only for the activation protection. Beam handling group arrange to ask the help to another staff in according to the order list which is made by some formula consists of individual age and radiation exposure amount[2]. This list is maintained by the beam handling group to averaging the activation level for all of the staff under some correction equation.

Table 5: Personal Organization at the PS division

19(27) Research Scientist
17(19) Technical Engineer
36(46) Total
( ) number at WAO1998

	Pre-Injector	Linac	Booster &Beam Transport	Main Ring & Extraction	RF	Control & Monitor	Vacuum	Beam Handling	Helper For Operation shift from ACC.Div.1
Professor	0	1	1	1	0	0	0	3 (1)	0
Assistant Professor	0	0 (1)	1	1	1	0 (1)	0 (1)	0 (1)	1
Research Assistant	1	0 (3)	1 (3)	2	1 (2)	3 (2)	1	1 (2)	1
Technical Engineer	2 (3)	3 (4)	3	3	1	3	2	0	3

5 EXAMPLE OF THE MAINTENANCE FOR THE MAIN RING GROUP

Main ring group comprises two sub groups. Two expert engineers and one research associate take care of the main ring magnet power supply system. The others (one associate professor, one research associate and one engineer) take care of the main ring magnet, the correction magnets and the equipment for the slow beam extraction. We have been performed the periodical maintenance once a year (every other years on every three years depend on the items to save the budget) during summer long shut down. A few days later from beam off, the officer at the radiation science center measure the residual radiation level in the ring as shown in Fig.3[3]. We start the maintenance work at the lower radiation area and do it a later half to reduce the expose rate.

5.1 Scheduled maintenance

Example 1: Power Supply System

Periodical maintenance of the power supply once a year during summer long shut down. It is not preventive, but only check. If weak or break point are noticed in the heavy equipment, repair work will be scheduled to next year maintenance.

Comporment of the Main Ring Power Supply:

AC harmonic filter
DC passive filter
DC active filter
Main Power Supply System
(Converter/Inverter, Transformer, Interlock etc.,)
Analog Control System
Computer Control System
Others:
Septum Magnet Power Supply
Steering Magnet Power Supply
6, 8 pole Magnet Power Supply
Bump Magnets Power Supply

- Insulation check of the magnets and power supplies.
- Cleaning of all of the equipment.
- Check the screwing bolts.
- Check the decrepit parts and repair or replace them if it is necessary.
- Check the leakage of the cooling water.
- Check the interlock system.

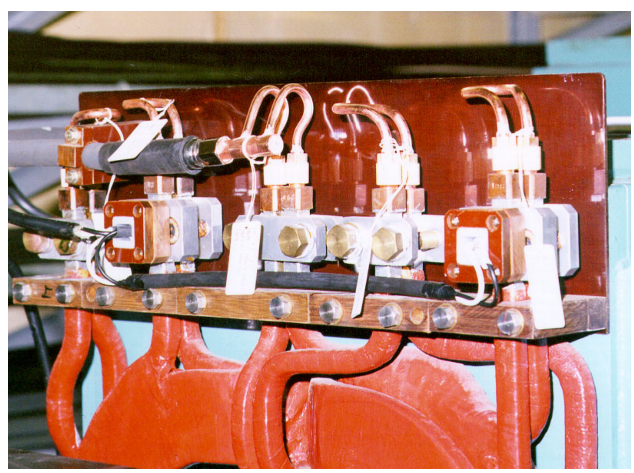

Fig.4: Top of the quadrupole magnet. Too many small parts of cooling pipe.

Example 2: Cooling Water System of the Main Ring

Until several years ago, maintenance of the cooling water system was unscheduled, but many troubles have occurred recently[4]. Then we changed this scheduled job. The work at the highly radiation area should be to latter half or quit by case. This is very difficult work to replace the small parts of cooling system due to too many parts and narrow working space as shown in Fig.4.

- Cleaning of the equipment such as flow switch, flow meter, valves, tubes, etc.
- Check the screwing bolts.
- Check the decrepit parts and repair or replace them if it is necessary.
- Check the leakage of the cooling water.
- Check the interlock system.

5.2 Unscheduled maintenance

When a machine stop due to some equipment break-down, experimental user request to repair it as fast as possible. The officer of radiation science center is not police then they suggest only to take care at the maintenance work. We negociate with user directy for the repair work schedule.

Example 1: Water Leak at the Main Ring Quadrupole Magnet.

Date & Time : 1999 Oct.4. 10:00 am.
Repair Work : 16:50 – 19:00 (2 hours) after 9 hours cooling.

Worker (Total)	16
Main Ring Group	3
Volunteer	7
Out-sourcing	6

Total Expose 3.439mSv
Maximum Individual Expose 0.3mSv
Number of people exposed over than 0.27mSv 6
Place : Quadrupole magnet neighbour the extraction septum at EP1, that is very high radiation area.
Experience Report

: Curie Mats set on the Quadrupole Magnet and Septum.
: Off the Interlock power supply
: Remove the cover for insulation
: Notice the impossible work to replace the O ring and short pipe.
: Try to tighter the bolt -> Reduce the water leak.
: Set the funnel under the pipe and hosing to the drain.
: Pull away the curie mats.
: On the interlock power supply.

This is only first aid!!
-> Proper repair was scheduled to next summer long shut down.

Example 2 : Insulation break of the extraction septum .

Date & Time : 1999 Nov.9 14:15
Repair Work : Nov.9 14:15 – Nov.11 18:10 (52 hours)

Worker (Total) :	42
Main Ring Group	5
Volunteer	29
Out-sourcing	8

Total Expose 9.619mSv
Maximum Individual Expose 0.37mSv
Number of people exposed over than 0.3mSv 14
Place : Extraction septum at EP1.
Experience Report

: Nov.9 12:40, 1999 Beam loss increased at EP1 area.
: Septum power supplies were down.
: Notice the interlock of the insulation break.
: Radiation survey by the radiation safety control group.
: Radiation level : 20 – 40 mSv/h.
: Notice the water leak from the septum.
: Identify the impossibility of repairing.
: No spare septum -> Transfer from the using septum at EP2.
: Set the Curie mats near EP2
: Remove the power cable.
: Remove the septum at EP1.
: Remove the septum at EP2 and transfer to EP1.
: Set the Curie mats at EP1.
: Alignment of the septum at EP1.
: Tighten the bolts.
: Re- Alignment of the septum at EP1.
: Set the power cable.
:Test Operation

Example 3 : Water leak at the extraction septum.

Date & Time : 2001 Oct.9 12:00
Repair Work : Oct.9 12:00 – Oct.10 17:30 (29.5 hours)

Worker (Total) :	22
Main Ring Group	5
Volunteer	14
Out-sourcing	3

Total Expose 5.4mSv
Maximum Individual Expose 0.3mSv
Number of people exposed over than 0.3mSv 11
Place : Extraction septum at EP1, that is very high radiation area.
Experience Report
Oct.9 :10:30 Mechanical Center informed to CCR that a lot of amount water leakd in the tunnel.
:12:00 Notice the water leak in the septum at EP1.
:13:00 Survey the radiation level.
:15:00 – 16:30 Remove this septum.
:17:30 – 19:30 Move the spare septum in the tunnel from the storage
Set the power supply cable and cooling water pipe.
Oct.10 :9:30 – 12:00 Measure the insulation between coil and core and Alignment
Fixed in to beam line.
:13:30 Excitation test
:17:30 Check the stopper bolts of coil.

Break down of the septum magnet was occuerd concentrated in 1997-1999. This is depend on the life time of original constructed septum, but also there have some weak point in the design against the electro-magnet force. Main ring operation cycle become 2.2s for the K2K experiment, that is twice faster than former cycle, then life time became short. It was difficult to remove the septum from the beam line, since original design was not considered hands on maintenance. This caused highly exposure in maintenance works[2].

We re-considered the design to proof the electro magnetic force at the new spare septum construction, and also in order to remove the septum easily from the beam line, slide base was improved as shown in Fig.4.

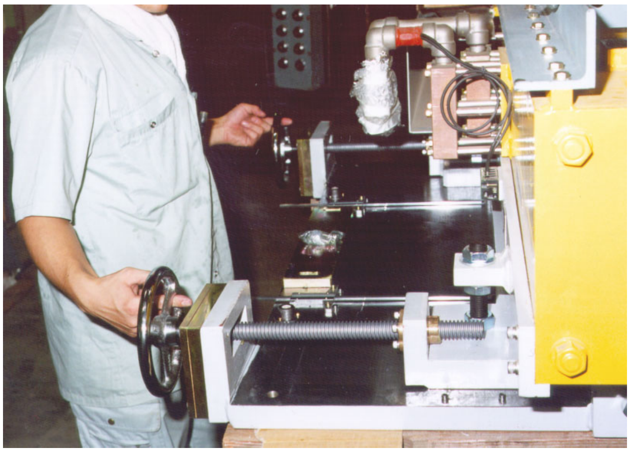

Fig.4: Improved slide base to remove from the beam line.

6 WHERE ARE OUR MAJOR PROBLEMS WITH REGARDS TO MAINTENANCE

Spares : Depend on the Budget
Expertise : Almost is generalist but not expert.
Planning : Difficult to make a scheduled maintenance due to tight operation schedule and budget
Radiation : Depend on the place but equipment breaks occur frequently in high radiation area etc,
Budget : Tight budget does not allow us to prepare the whole of spare parts and maintenance. Especially, the maintenance budget was cut in order to make a construction fee for fast extraction system during three years, 1996-1998. It recovered once, but has been decreasing continuously and will become to zero at 2006, since the PS will be shut down at the completion of the J-PARC. Table 6 shows the minutes of the operation and budget.
Equipments : Deterioration depend on old product and/or radiation damage
Personnel : Old age persons (46 years old average)
How do you take advantage of times when the machine is down unexpectedly? Maintenance work starts as fast as possible and volunteers are mobilized and outsourcing order under director.
How are decisions made when repairs are considered (committee, small group, individual, etc.)?
1) Considered in small group
2) Order to director for help of mobilization
Extra-budget : supported by Division head, Department Director, Director General, and societis supported by IPNS (Institute of Particle and Nuclear Studies).

6 ACKNOWLEDGMENTS

We would like to express our gratitude to Mr.K.Okazaki for his help collecting data.

7 REFERENCES

[1] H.Sato et.al, WAO1998, Vancouver, May 1998, P48.
[2] T.Kawakubo and H.Sato, Presented in this workshop.
[3] T.Suzuki, Presented in this workshop.
[4] H.Sato et.al, PAC2001, Chicago, June 2001, P1426

Table 6: Minutes of the Operation and Budget

		1997	1998	1999	2000	2001	2002
Booster Intensity (E12)		1.5	1.5	1.8	1.8	1.8	2.1
Main Ring Intensity (E12)		3.0 Slow	3.5 Slow	6.0 Fast	6.0 Fast	3.5 Slow	7.0 Fast
Budget 1)	PS	84	46	74	124	100	86
	MR	54	35	115	147	131	112
Operation Time (hours)		4800	3900	6100	5800	5879	5800 2)

Notice: 1) Normalized by an average for three years before (1994-1996)
2) Plan in FY2002
3) Until end of December