Measurement of static and ELF magnetic fields in a large magnetic fusion plasma experimental facility

T. Uda[1], H. Obayashi[1], H. Nakayoshi[2], J. Wang[3] and O. Fujiwara[3]

1. Safety and Environmental Research Center, National Institute for Fusion Science, E-mail: udat@nifs.ac.jp
2. Nippon Kucho Service Co. Ltd.
3. Faculty Engineering, Nagoya Institute of Technology

Abstract: Environmental static magnetic field around the large helical device LHD, which is a nuclear fusion plasma experimental device using super conducting magnet system, was measured on the experimental period. Also EMF magnetic field was measured in the experimental facility, and personal exposure was monitored by volunteers of the NIFS. Although large magnetic leakage from the LHD was not detected in working area, it is important to monitoring continuously and to establish a suitable safety management system.

Key words: magnetic field, ELF, fusion plasma, health and safety

1 .Introduction

The Large Helical Device (LHD) of National Institute for Fusion Science (NIFS) has super conducting helical and poloidal coils system, that is the largest one in the world, and it started plasma experiments in March, 1998. Since then it had performed six plasma experimental cycles successfully. Although the static magnetic field of the LHD confines the plasma with high efficiency, magnetic field leaks out around the LHD. Safety issues are relating to leakage of not only static magnetic field but also variable frequencies of magnetic fields, which are from extremely low frequency of 60 Hz to extremely high frequency of 168 GHz. In a magnetic fusion facility, many electric and magnetic field generating devices are equipped as shown in figure 1. The major specification of LHD is presented in table 1. Except the super conducting coils system, many electric and magnetic devices are built. Major devices and frequencies are a motor-generator for power supply to neutral beam injection (NBI) of ELF, microwave generator of 2.45 GHz for discharge cleaning of plasma facing walls, plasma heating devices such as ion cyclotron resonance frequency of 25-100 MHz and electron cyclotron resonance frequency of 84-168 GHz. Although constructing materials of the LHD and related devices absorbs high frequency electromagnetic waves, leakage of them is concerned. Considering safety for occupational workers and visiting persons, we measured the magnetic strength around the LHD. Then protection of occupational exposure to electromagnetic fields was discussed considering the LHD and related devices.

Health effect by extremely low frequency (ELF) had been reported as children leukemia in epidemiological studies, and many health risk studies have been made and reviewed(1). Present risk considered in our live environment seems to be extremely low but it's better to consider health hazard for occupational workers, so we surveyed magnetic fields strength for electric appliances in working area around the LHD and its related devices. At the same time safety guideline that is applied only to our research institute NIFS is proposed with reference to the International Conference for Non-Ionizing Radiation Protection (ICNIRP) guidelines (2,3).

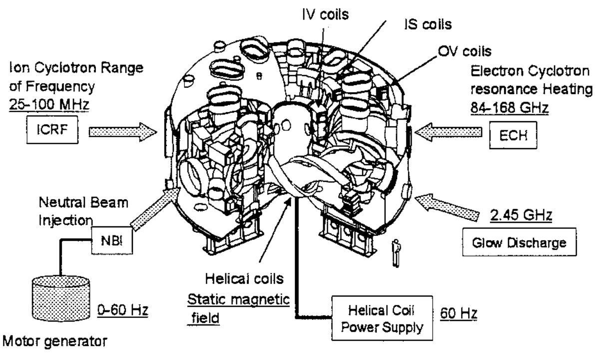

Figure 1. Large Helical Device LHD and electromagnetic fields concerned.

Table 1. Basic parameter of the LHD machine

	Phase I	Phase II
Machine configuration		
Helical coil major radius	3.9 m	
Helical coil minor radius	0.975 m	
Plasma radius	0.5-0.65	
Plasma volume	30 m^3	
l/m	2/10	
Magnetic field strength	3.0 T	4.0 T
Coil current density	40 A/mm^2	55.3 A/mm^2
Stored magnetic energy	0.9 GJ	1.6 GJ
Heating system		
ECH power	10 MW	10 MW
NBI power	15 MW	20 MW
ICRF power	3 MW	12 MW

2. Measurement method

Static magnetic field strength around the LHD was measured with commercially available gauss meters, GAUSS METER 9900 (F. W. BELL) and THM7025 (METROLAB), in the LHD experimental hall and outside of 2 m concrete wall for radiation shield. Specifications of these instruments are shown in table 2. We fixed measurement point outside of the LHD hall, where is 23 m far from the LHD center. The measurement height is 2.5 m from ground and LHD plasma center height is 5.5 m. So the fixed measurement point is 3 m lower from the horizontal center of plasma. Leakage of magnetic field strength was monitored continuously with the GAUSS METER 9900 at the fixed point.

In the present LHD plasma experiments the maximum plasma magnetic strength is about 2.9 T. Leakage of magnetic field strength is obtained as composition of measured magnetic strength X, Y and Z axes. In the early plasma experimental stage we measured the magnetic field in the LHD hall. The measurement points are located between 6.5 m and 19 m from the LHD center. This measurement was tried only one time, because usually workers are prohibited to enter the LHD hall on plasma operation in order to avoid unnecessary exposure to not only high magnetic field but also ionizing radiation.

Also measurement around an electron cyclotron resonance heating (ECH) device, which has a gyrotron made of super conducting magnetic coils, was made. Specification of the normal magnetic strength is 7 T at the center of the coil. Major magnetic features of the gyrotron are shown in table 3. The environmental magnetic field of ELF was measured with EFA-3 and EMDEX-II shown in table 2.

Table 2. Specification of magnetic field measurement instruments.

Model	Maker	Probe axial number	Frequency range	Measurement range
GAUSS METER 9900	F.W.BELL	3	DC~50kHz	1nT~10T
THM7025	Metrolab	3	DC	19.99-1999 mT
EFA-3	Wandel&Golterm	3	5Hz~30kHz	10nT~10mT
EMDEX II	ENERTECH CONSULTANTS	3	40Hz~800Hz	10nT~0.3mT

Table 3. Magnetic features of a gyrotron for ECH.

	Number	Location of coil	Normal magnetic field at the center of coil	Condition of magnetic field
Cavity coil	1	Length between the center of cavity and gun coil is 650 mm	7 T	dBz/dz≦1.25T/m in the place of ±10 mm from the coil center
Gun coil	2		0.28 T	Adjustable in ±10 A

4. Results and Discussion

4.1 Static magnetic field

Static magnetic field leakage was observed when electric current flowed in a single super-conducting coil and combined coils system of the LHD. For example, when electric current of 1 kA flows to an outer vertical (OV) coils, the maximum observed was 0.2 mT. That is about 5 times of natural magnetic field strength. When current loads simply to the helical coils, measured values at the fixed point are lower than that of obtained on the individual OV coils operation. Combination of the helical coils and outer vertical (OV) coils, inner vertical (IV) coils and inner shaping (IS) coils gives much less leakage of magnetic field, because the LHD coils system is designed to optimize the leakage magnetic field as low as possible. In figure 2, the 0-mode and b-mode show operation mode based on plasma placement control(4). Calculated values are compared in the same figure. The calculation code is HSD, which is developed for LHD coils design(5). The observed values agreed with the calculated values in less than 10 %.

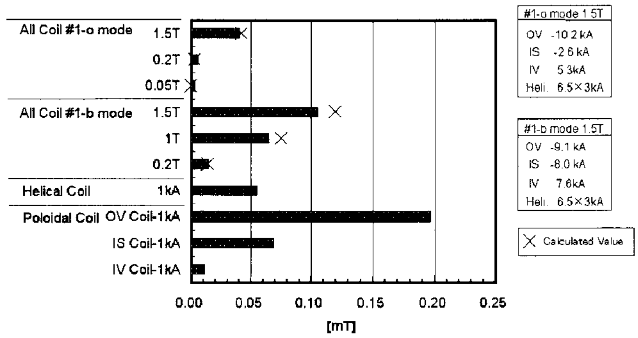

Figure 2. Magnetic field strength measured outside of the LHD hall in case of coil current loaded by one single mode or all combination modes.

Measured magnetic field strength at the fixed point outside of the LHD under experiment is shown as follows. Figure 3 shows relationships between distance from the LHD center and leakage magnetic field. In case of 1.5 T plasma operation, magnetic field was 70 mT near the cryostat, and outside of the radiation shield wall, it was 0.05 mT. Although the observed values differed from the calculated values up to 50% at maximum, we think that it tends to show nearly the same pattern.

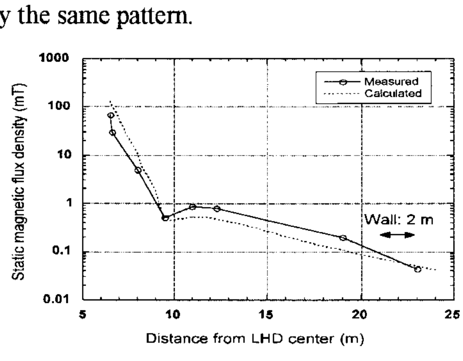

Figure 3. Relation of distance from the LHD center and leakage magnetic strength.

The reason of disagreement between calculated values and observed ones will be dependent on roughness of calculation of leakage magnetic field, because the LHD helical coils has complicated structure, magnetic field is not uniform circle. The other reasons may be systematic error of the measurement instrument and estimation error of the distance. Beside this measurement, GAUS METER 9900 had been used.

Figure 4 shows relationships between magnetic field strength of the fixed point and plasma magnetic strength that is increased up to 2.5 T in stepwise. This result shows that leakage magnetic field strength has a linear relation to plasma magnetic strength. With the monitoring results, it becomes clear that the environmental magnetic field strength in the working area is extremely low and it is not over 200 mT even near the LHD vessel. But when the LHD is operated with 3 T, which is the goal of the LHD machine in the first phase, it will be larger than 200 mT at 7 m from the LHD center. Value of 200 mT is the basic regulated strength supposed by ICNIRP for occupation.

Figure 5 shows leakage of LHD plasma magnetic

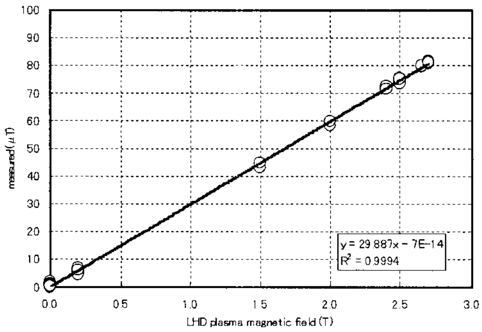

Figure 4 Relation of LHD plasma magnetic strength and measured leakage magnetic strength.

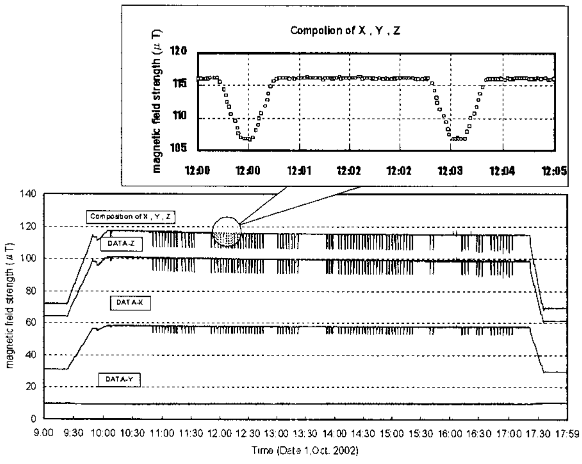

Figure 5 Leakage of magnetic field of typical plasma experimental day.

field strength at the fixed point in the representative plasma experimental day. The constant swaying may be caused by electric current generated in the toroidal plasma.

History of magnetic field strength since 1998 to 2003 is shown in figure 6. As a major issue of the super conducting magnetic coils, it decreases quickly with quenching or with abnormal event occurrence. According to our experiences magnetic field strength at the fixed monitoring point was spontaneously increased to about 0.9 mT. At the same time some steel materials were magnetized. But devices constructing materials in the LHD experimental hall is not magnetized because they are made of stainless steel.

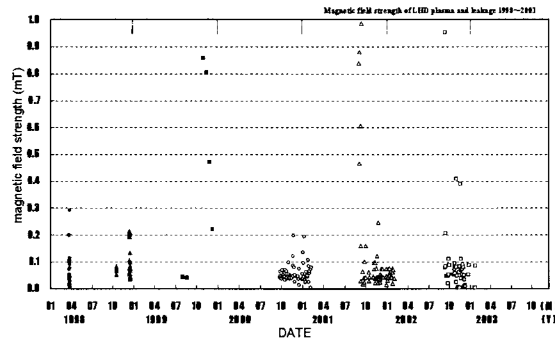

Figure 6 History of magnetic leakage monitoring in 1998-2003 outside of the LHD hall.

Except for the LHD, there are many kinds of magnetic field producing devices. Example is a gyrotron, which is a major plasma-heating machine by electron cyclotron resonance heater ECH. The gyrotron of the ECH has a super conducting magnet, of which strength is 7 T at the center of coil. Leakage of magnetic field is measured with a gauss meter. The relation of measured value and distance from the coil center is shown in figure 7. Although entrance of workers in the ECH device is regulated by the leakage of magnetic field, high electric voltage and X-ray radiation is more important safety issues.

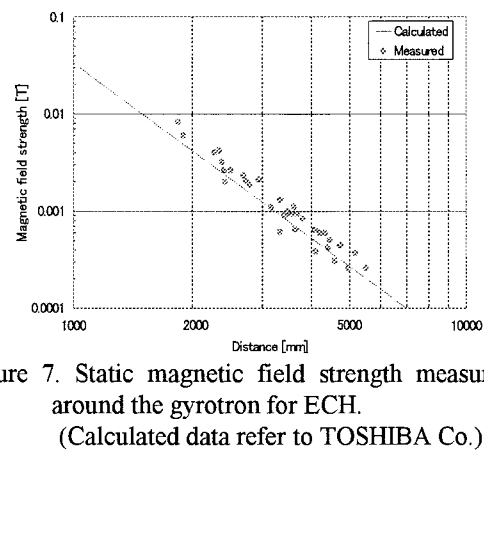

Figure 7. Static magnetic field strength measured around the gyrotron for ECH.
(Calculated data refer to TOSHIBA Co.)

4.2 Variable frequency electromagnetic field

In the magnetic fusion experimental facility, there are many devices generating various electromagnetic frequencies as already shown in figure 1. The major issues are not only static magnetic field but also variable magnetic fields, of which frequencies are from extremely low frequency (ELF) of 60 Hz to high frequency of 168 GHz. There are many kinds of environmental magnetic fields around the LHD and related devices. Concerning occupational safety issues, not only static magnetic field but also variable electric and magnetic fields should be measured.

(1) ELF electromagnetic field:

Major devices are electric power source for super conducting magnetic coils system and a motor generator for power supply to the NBI device. The ELF magnetic field strength around the electric equipments in the laboratory was distributed between 0.2-40 μT. The average ELF level in office is about 0.1 μT.

We measured the exposure level with the cooperation of 23 voluntary workers who are researchers, technicians and office workers. The volunteers were carrying EMDEX-II ELF monitor in 24 hours. Then average exposure level was 0.18μT, and almost all the monitors were less than 0.22μT. But a few volunteers were exposed to 6-12 μT. It is found that beside the experimental devices there are some electric exposure sources like transportation and home electric equipments. For example, the magnetic strength measured outside of the laboratory was 0.5 μT in an electric car, 1.3 μT in a automobile, and 300 μT on a electric carpet.

(2) High frequency electromagnetic field:

There are many types of microwave generator for plasma heating such as ICRF (Ion Cyclotron Range Frequency) and ECH (Electron Cyclotron resonance Heating), and for discharge cleaning of plasma facing walls. The frequencies are varied from 25 MHz to 2.45 GHz and 168 GHz.

Measurements of the high frequency electromagnetic field are made by Fujiwara et al. as collaboration. The results are reported in their paper(7).

5. Occupational protection

According to this measurement, workers entrance area should be regulated to less than 200 mT, and public visitors to the facility should be regulated to less than 40 mT and less than 0.5 mT for people with cardiac pacemakers. We made safety control by self-regulation rule based on the recommendation reported by ICNIRP. In our experience the static magnetic field strength is less than occupational regulation level. Although the measured magnetic strength is less than the occupational level, overall exposure including various electromagnetic frequencies should be measured and concerned. The experimental rooms installed such magnetic devices are regulated to enter for the non-occupational people by putting up notices of warning information at the entrance door of room or building.

6. Conclusion

Magnetic field leakage was observed in a large magnetic plasma fusion experimental facility of LHD. Considering occupational safety, it is regulated to enter the workers in the LHD hall and the leakage level outside of the hall is small enough. Also variable magnetic fields were measured, and it was found that the leakage level is so small. However it is important to continuously measure the environmental magnetic field to establish the safety management system for the magnetic fusion facility.

7. Acknowledgement

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