OPERATION SCHEME AND STATISTICS OF KEKB

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Abstract

The KEKB B-Factory(KEKB) started a collision experiment in 1999 and finished in June, 2010. The total operation time of KEKB from fiscal year 2000 was 55657 hours. The breakdowns of operation are physics run 73.8%, machine study 6.8%, machine tuning 4.8%, beam tuning 5.9%, trouble 5.3%, maintenance 2.1% and other 1.3%. The total integrated luminosity was 1041 fb^{-1} and the maximum peak luminosity was 21.083 $nb^{-1}s^{-1}$. To increase the peak and integrated luminosity, the continuous injection scheme, the crab cavities and the skew sextupole magnets were effective. We finished over ten year operation of KEKB in June, 2010.

INTRODUCTION

The KEKB B-Factory (KEKB) [1, 2] started a collision experiment in 1999 and finished in June, 2010. We have started works for the KEKB upgrade toward SuperKEKB. During the operation period of KEKB for about 10 years, the Belle detector collected 1041 fb^{-1}. The maximum peak luminosity was 21.08 $nb^{-1}s^{-1}$ which is more than double of the design luminosity of 10.0 $nb^{-1}s^{-1}$. In the KEKB operation, several new trials have been introduced. In this report, the continuous injection scheme, the crab cavities and the skew sextupoles are described. We introduced the continuous injection scheme which enabled data acquisition during the beam injection in 2004. We installed crab cavities in February, 2007. The crab cavities are used in a usual physics operation and it was proven that they operate very stably under the condition of the high current beams. We installed skew sextupole magnets in March, 2009 and the e+/e- simultaneous injection scheme was realized. There were many difficulties and problems during the KEKB operation for about 10 years. Figure 1 shows the history of the KEKB operation.

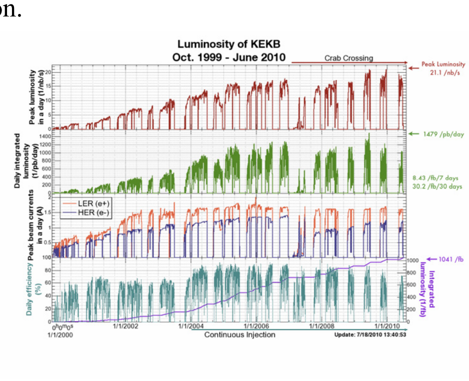

Figure 1: Ten year history of the KEKB operation.

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INJECTION METHOD

When the beam was injected, data acquisition had been temporarily stopped until 2003. Electrons (HER) and positrons (LER) were injected after a physical experiment had been done for about one hour, and data acquisition was resumed afterwards. We introduced a continuous injection mode (CIM) that enables the beam injection during the data acquisition in 2004. In the CIM method the injections of HER and LER had been switched every about ten minutes. Afterwards, we succeeded in shortening the switch interval greatly. We could switch at intervals of about five minutes in 2008. An HER and LER simultaneous injection (which means pulse-to-pulse switching for linac pulse) was realized in April, 2009. Beam injection schemes are shown in Figures 2.

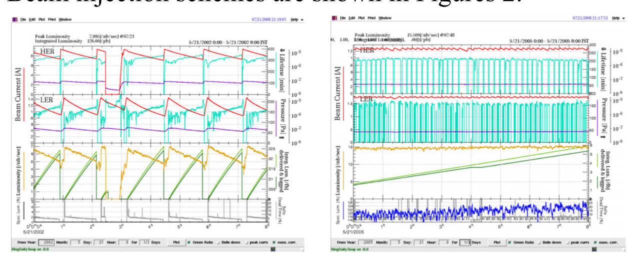

Figure 2: Before (left) and After (right) introducing the CIM method.

Figure 3 shows the beam parameters with the simultaneous injection. The beam currents of HER and LER can be kept at almost constant values at any time by the simultaneous injection. The temperature changes of the vacuum chambers that receive the influence of the synchrotron radiation from the beam have become small. The luminosity change has also become small. They were advantageous for the luminosity tuning.

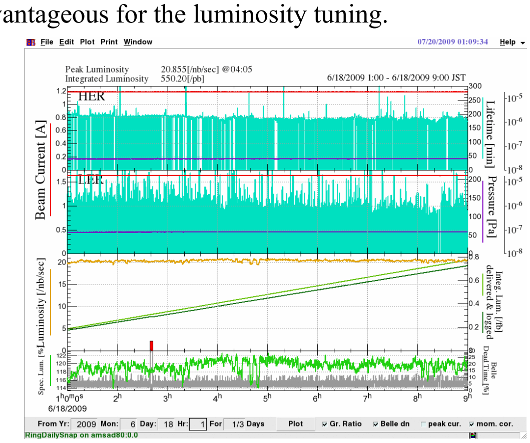

Figure 3: Beam parameters with the simultaneous injection.

CRAB CAVITIES

The crab cavities were installed in February, 2007. The purpose is to realize virtually the head-on collision. Figure 4 shows the effects of crab cavities with a finite crossing angle. Before the crab cavities were installed, the peak luminosity 17.60 $nb^{-1}s^{-1}$ had been recorded with the HER/LER beam currents of 1340/1662mA. After the crab cavities were installed, the peak luminosity 16.10 $nb^{-1}s^{-1}$ had been recorded with the HER/LER beam currents of 934/1605mA. In May 2009, the peak luminosity 21.08 $nb^{-1}s^{-1}$ was recorded with the HER/LER beam currents of 1188/1637mA. The improvement of the luminosity was chiefly brought by the installed of skew sextupole magnets. In addition, the increase of the HER beam currents contributed to this.

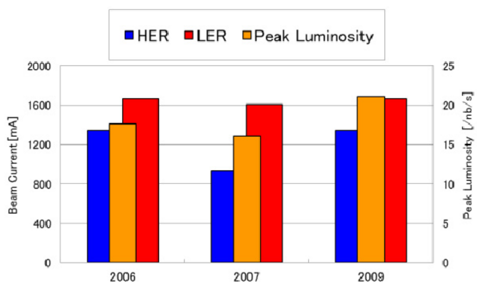

Figure 4: The effects of crab cavities.

SKEW SEXTUPOLE MAGNETS

It has been shown by the beam-beam simulations that the momentum dependence of the x-y coupling at the IP would degrade the luminosity if remaining values are larger [3]. To correct these chromaticities of the x-y coupling at the IP, 14 pairs of skew sextupole magnets (10 pairs for HER and 4 pairs for LER) were installed in March 2009. The effects of the newly installed magnets were remarkable. The peak luminosity was increased by 15 or 17% by these magnets. Figure 5 shows the luminosity and other related parameters on May 2nd 2009, when the sextupole magnets were used in the beam operation for the first time. In the single day, the peak luminosity was increased from 16.3 $nb^{-1}s^{-1}$ to 18.5 $nb^{-1}s^{-1}$ owing to the tuning using the magnets.

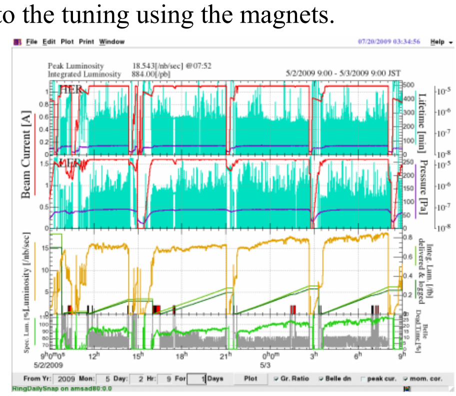

Figure 5: The luminosity changed on May 2nd 2009 when skew sextupole magnets were firstly used.

OPERATION PERIOD AND DETAILS

KEKB had been operated for about nine months (excluding two months of summer and new year) every year from fiscal year 2000 to fiscal year 2007. The maximum operation period was 275 days (6552 hours) in fiscal year 2004. Operation period in fiscal year 2008 and fiscal year 2009 were about 150 days, because of a budget restriction. Operation period of fiscal year 2010 was 49 days. Figure 6 shows the operation days and hours of each fiscal year.

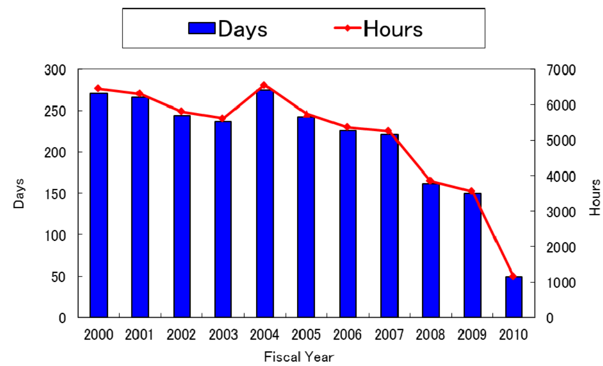

Figure 6: Operation period.

The main purpose of the KEKB operation is the physical experiment. The study for the accelerator performance improvement has been also done (beam tuning, machine tuning, and machine study). Figure 7 shows the breakdown of KEKB operation time in each fiscal year. The portion of the physics experiment was over 70% almost every year. One shift every two weeks (8 hours) was spent on maintenance time for the equipments. The beam tuning time was reduced gradually from the start of operation until fiscal year 2005. There was a big trouble of the Belle detector in fiscal year 2005. In fiscal year 2006 and 2007, a long time was devoted to the study of crab crossing and the portion of the physics experiment was decreased down to 50%.

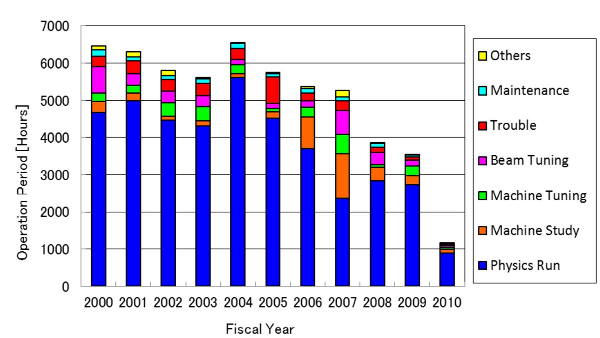

Figure 7: The use of available time for KEKB in hours.

In fiscal year 2008 and 2009, almost no dedicated machine study time was used for crab crossing. However, the machine study for SuperKEKB, which is the upgrade project of present KEKB, increased and so the portion of the machine study is larger compared with before the installation of the crab cavities.

INTEGRATED AND PEAK LUMINOSITY

To increase the integrated luminosity, it is important to decrease the frequency of the beam abort, to decrease the failure rate of the machine, and to decrease the dead time of the detector by the beam noise. Figure 8 shows the history of the annual integrated luminosity and the average daily luminosity.

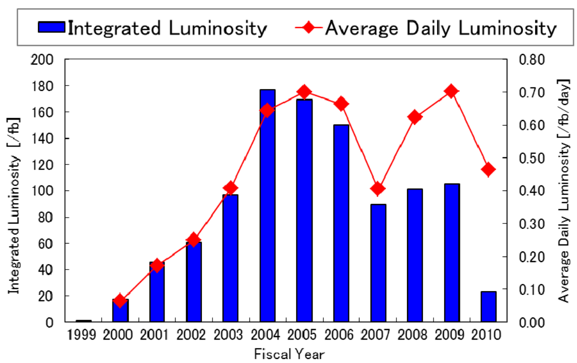

Figure 8: The history of the annual integrated luminosity and the daily average luminosity.

The integrated luminosity and the average daily luminosity were increased gradually with the beam current increase from the start of operation until fiscal year 2003. Afterwards, the integrated luminosity and the average daily luminosity were nearly doubled by introducing CIM and increasing the peak luminosity in fiscal year 2004. The integrated luminosity for three years from fiscal year 2004 was rather high and Belle accumulated about 700 fb^{-1}.

The operation time of fiscal year 2007 was about seven months. The crab cavities were installed in February, 2007. We conducted various machine studies.

The operation time of fiscal year 2008 was about six months. The integrated luminosity was 101.06 fb^{-1} and the maximum peak luminosity was 16.381 $nb^{-1}s^{-1}$. The average daily luminosity of 0.6 $fb^{-1}day^{-1}$ is lower than 0.68 $fb^{-1}day^{-1}$ in fiscal year 2005. However, it increased rapidly.

The operation time of fiscal year 2009 was about six months. The integrated luminosity was 105.43 fb^{-1} and the maximum peak luminosity was 21.083 $nb^{-1}s^{-1}$. The average daily luminosity of 0.7 $fb^{-1}day^{-1}$ was achieved, which is higher than 0.68 $fb^{-1}day^{-1}$ in fiscal year 2005.

BREAKDOWN TIME

The breakdown time due to the troubles has been decreasing, even if we take the decrease of the operation time into account. The vacuum trouble has increased from fiscal year 2000 to fiscal year 2002 with the current increase. It has decreased gradually afterwards. Fiscal year 2005 was an exceptional year, when the trouble of Belle detector accounted for a large portion. The failure rate was 5.3% in the whole operation time of eleven years. Figure 9 shows the history of the troubles.

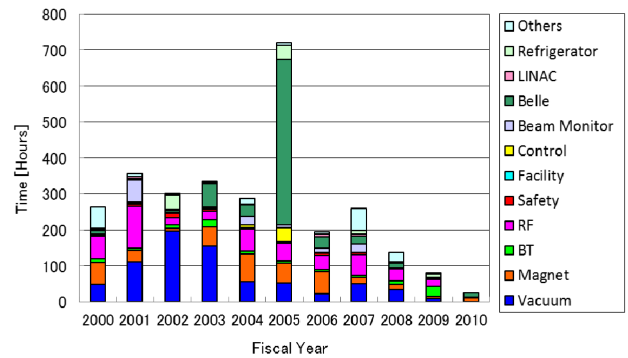

Figure 9 : The history of the troubles.

SUMMARY

The total operation time of KEKB from fiscal year 2000 was 55657 hours. The breakdowns of operation time are physics run 73.8%, machine study 6.8%, machine tuning 4.8%, beam tuning 5.9%, trouble 5.3%, maintenance 2.1% and other 1.3%. The total integrated luminosity was 1041 fb^{-1} and the maximum peak luminosity was 21.083 $nb^{-1}s^{-1}$. To increase the peak and integrated luminosity, the continuous injection scheme, the crab cavities and the skew sextupole magnets were effective. We finished over ten year operation of KEKB in June, 2010.

ACKNOWLEDGMENTS

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[2] http://kekb.jp.
[3] Y. Funakoshi et al., "RECENT PROGRESS OF KEKB", Proceedings of PAC07, Albuquerque, New Mexico, USA.