PRESENT STATUS OF KEKB PROJECT

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Abstract

The KEK B-Factory, KEKB, is an asymmetric-energy, two-ring, electron-positron collider for B physics. Eight-GeV electrons stored in a high-energy ring (HER) and 3.5- GeV positrons in a low-energy ring (LER) collide at an interaction point (IP), which BELLE detector surrounds. In order to facilitate detection of CP-violation effect at the bottom-quark sector, the machine is designed to reach a luminosity of 10^{34}cm^{-2}s^{-1}. Even with a high beam-beam tuneshift of 0.052 and a small β_y* of 1 cm at IP, necessary currents in the rings amount to 1.1 A at HER and 2.6 A at LER. KEKB adopts new schemes to reach the goal, such as ±11 mrad finite-angle collision at IP, non-interleaved-sextupole chromaticity correction to have large dynamic apertures, higher-order-mode-free normal conducting cavity called ARES and single-cell, single-mode, superconducting cavities to prevent coupled-bunch instabilities and combat heavy beam-loading, among others. The 2.5 GeV injector lianc has been upgraded to 8 GeV to facilitate the direct injection into the rings and increase the intensity of positrons. This five-year project started in 1994 and 1998 is the last year of the construction. The rings will be commissioned in the autumn of 1998.

1 BASIC FEATURES OF KEKB

Figure 1 shows a schematic layout of KEKB[1], which is an asymmetric-energy, two-ring, electron-positron collider housed in the 3 km TRISTAN tunnel. Eight-GeV electrons and 3.5-GeV positrons are stored in different rings; they circulate in opposite directions and collide at one interaction point (IP). The BELLE detector[2] surrounds the IP. The cross section of the tunnel is large enough to enable a side-by-side installation of LER and HER. The two rings change their inner-outer position at the IP and at a crossover point opposite to the IP, where LER and HER have different heights and electrons and positrons do not collide. The interchange of inner and outer position of the rings is necessary to make the two rings have the same circumference.

The injector linac has been upgraded from 2.5 GeV to 8 GeV in order to facilitate direct injection of electrons and positrons to the rings and to increase the intensity of positrons by raising the energy of electrons impinging on a positron-production target from 0.2 GeV to 3.7 GeV[3].

The main objective of KEKB is to detect the CP violation effect at the bottom-quark sector. If we move to the center-of-mass frame from the laboratory one, a 5.3-GeV electron and a 5.3-GeV positron collide and produce a pair of B meson and anti-B meson at rest at the Υ(4S) resonance. In the laboratory frame where an 8-GeV electron and a 3.5-GeV positron collide, the B and anti-B mesons move along the direction of the incoming electron, travel over a few hundred μm, and decay at different positions. By detecting the decay products, we can identify the B and anti-B mesons. This identification is essential for studying CP-violation, which is a subtle difference in behavior between particles and anti-particles.

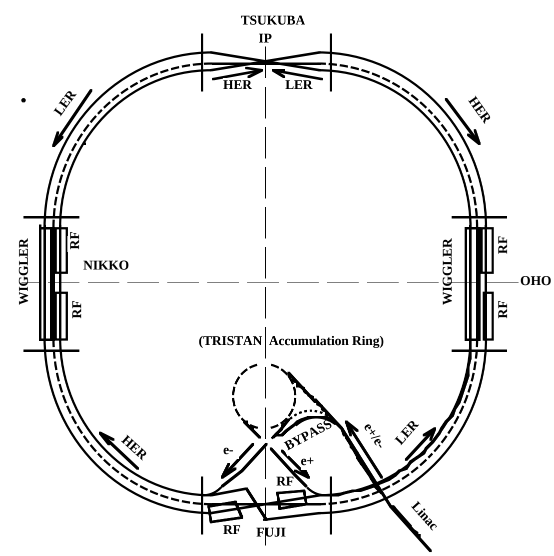

Figure 1 Layout of KEKB

KEKB aims to achieve a luminosity of 10^{34}cm^{-2}s^{-1}, which is necessary for the CP-violation detection. The luminosity (L) is given by

$$L = 2.2 \times 10^{34}\xi(1+r)\left(\frac{E \cdot I}{\beta_y^*}\right)_{\pm} \qquad (1),$$

where ξ is the beam-beam tuneshift, r the ratio between the vertical beam size to the horizontal beam size at the IP (usually r<<1 and is negligible), I the stored current in ampere, E the beam energy in GeV, and β_y* the β-value at the IP in cm. The ± sign means that this formula is applicable to both electrons and positrons. In order to reach a high luminosity, ξ and I should be maximized, and β_y* minimized.

The parameter ξ is a measure of the beam-beam force between colliding bunches, and usually takes a value between 0.03 and 0.05. At KEKB, we assume a rather challenging value of 0.052 for ξ. The parameter β_y* is a measure of beam focusing at the IP. The minimum attainable value of β_y* is determined by a chromaticity produced by final focus quads. The allowable minimum value is around 1 cm. If we insert L=10^{34}cm^{-2}s^{-1}, ξ=0.052, β_y*=1 cm, and E=3.5 GeV and 8 GeV in the formula (1), we find that we should store 2.6 A in the positron ring and 1.1 A in the electron ring. The main issue of KEKB is, therefore, how to store such large currents in the rings and to achieve stable collisions between the beams under the high beam-beam tuneshift.

These large currents are distributed into 5000 bunches per ring; except for a few % of the whole buckets (bunch gap), every bucket in a ring is filled with the beam. The bunch gap is necessary for ion clearing. At KEKB, single-bunch current is well below the threshold of single-bunch instabilities; only coupled-bunch instabilities are of concern.

It is advantageous to inject beams into the rings with the same optics as those for the collision mode. This requires that the dynamic aperture of the ring be large enough for injection even with a small β_y* of 1 cm. A non-interleaved-sextupole chromaticity correction scheme is adopted to have enough dynamic apertures at injection and at collision[4]. The KEKB optics design allows us to change emittances and momentum compaction factors independently over 1.0x10^{-8}m<ε_x<3.6x10^{-8}m and -1x 10^{-4}<α_p<4x10^{-4}, respectively. To increase flexibility of tuning, every quad is equipped with vertical and horizontal steering magnets and a beam position monitor and every sextupole with a remote-control mover.

Measurement of the vertical beam size in the ring is most essential to tune the beams. Double-slit interferometric beam size monitor is now being developed for KEKB. This type of monitor system are working satisfactory at AURORA[5], KEK PF[6] and KEK ATF.

Wigglers are used to shorten the damping time of LER down to that of HER. The total synchrotron radiation power amounts to 4 MW or higher per ring; copper vacuum ducts are used to sustain high heat from the radiation.

Table 1 summarizes the main parameters of KEKB.

Table 1. Main Parameters of KEKB.

Ring		LER		HER	
Energy	E	3.5		8.0	GeV
Circumference	C		3016.26		m
Luminosity	L		1 x 10^{34}		cm^{-2}s^{-1}
Crossing angle	θ_x		± 11		mrad
Tune shifts	ξ_x/ξ_y		0.039 / 0.052		
Beta function at IP	β^*_x/β^*_y		0.33 / 0.01		m
Beam current	I	2.6		1.1	A
Natural bunch length	σ_z		0.4		cm
Energy spread	σ_d	7.4 x 10^{-4}		6.7 x 10^{-4}	
Bunch spacing	S_b		0.59		m
Particles/bunch		3.3 x 10^{10}		1.4 x 10^{10}	
Emittance	$\varepsilon_x/\varepsilon_y$		1.8 x 10^{-8}/ 3.6 x 10^{-10}		m
Synchrotron tune	ν_s		0.01 ~ 0.02		
Betatron tune	ν_x/ν_y	45.52 / 45.08		46.52 / 46.08	
Momentum compaction factor	α_p		1 x 10^{-4} ~ 2 x 10^{-4}		
Energy loss/turn	U_o	0.81† / 1.5††		3.5	MeV
RF voltage	V_c	5 ~ 10		10 ~ 20	MV
RF frequency	f_{RF}		508.887		MHz
Harmonic number	h		5120		
Longitudinal damping time	τ_E	43† / 23††		23	ms
Total beam power	P_B	2.6† / 4.5††		4.0	MW
Radiation power	P_R	2.1† / 4.0††		3.8	MW
HOM power	P_{HOM}	0.57		0.15	MW
Bending radius	ρ	16.3		104.5	m
Length of bending Magnet	l_B	0.915		5.86	m

† without wigglers †† with wigglers

2 COUPLED-BUNCH INSTABILITIES AND CAVITIES

Large stored currents excite strong coupled-bunch instabilities due to higher-order modes (HOMs) and the fundamental mode of cavities. A straight-forward way to avoid coupled-bunch instabilities due to HOMs is to use cavities where no HOMs are excited by the beam. KEKB uses two kinds of HOM-free cavities: normal conducting cavities, called ARES[7,8], for LER and HER, and superconducting cavities (SCC) for HER[9].

ARES is an acronym of Accelerator Resonantly coupled with Energy Storage. The schematics of ARES is shown in Fig. 2. It consists of three cells: an accelerating cell, an energy-storage cell, and a coupling cell between these cells. HOMs are extracted from the cavity by four wave guides attached to the accelerating cell, and absorbed by SiC absorbers equipped at the end of the wave guides. Beam pipes attached to the cell are grooved to make a few transverse HOMs that cannot be extracted by the wave guides propagate towards the beam pipes. The large-volume, low-loss, energy-storage cell effectively increases the stored energy of the cavity system.

Figure 3 depicts the superconducting cavity for KEKB. Two large-bore beam pipes are attached to both ends of the cavity cell. The diameters of the beam pipes are chosen so that the frequencies of all modes, except for the fundamental one, become higher than the cut-off frequencies of the pipes. HOMs propagate towards the beam pipes and eventually become absorbed by ferrite dampers attached to the inner surface of the pipes. One beam pipe has a larger diameter than the other and connected to the cell via an iris; this is necessary to extract a few transverse HOMs as the grooved beam pipe works for ARES.

Both ARES cavity and superconducting cavity have large stored energies, which make them strong against heavy beam-loading; no coupled-bunch instability due to the fundamental mode of the cavities is excited.

Two ARES cavities and a SCC were tested with high-current beams at the accumulation ring (AR) in 1996, the ARES cavities up to 500 mA and the SCC up to 573 mA[10].

By the commissioning of the rings, 12 ARES will be installed in LER and 12 ARES and 4 SCC in HER. In one or two years, the number of cavities will increase to the final number of 20 ARES in LER and 12 ARES and 8 SCC in HER to support the full currents in the rings.

3 INTERACTION REGION, FINITE-ANGLE COLLISION AND CRAB CAVITY

After an electron bunch and a positron bunch collide at the IP, these bunches should be quickly separated in order to avoid parasitic beam collisions at n x $S_b/2$ apart from the IP, where n is an integer and S_b is the bunch spacing (59 cm at KEKB). KEKB adopts a horizontal finite-angle crossing of ±11 mrad. The finite-angle crossing scheme has an advantage of eliminating the use of separation dipole magnets that produce synchrotron lights close to the IP. Figure 4 shows the layout of the KEKB interaction region.

A pair of superconducting final-focus quads are installed inside the BELLE detector and under its 1.5-T solenoid field[11]. Each quad has a superconducting anti-solenoid in front of it. These antisolenoids produce a solenoid field opposite to the detector solenoid so as to cancel out the integrated solenoid field along the beam trajectory. This is advantageous to an asymmetric-energy collider where electron and positron beams rotate by different angles by a detector solenoid if this cancellation does not exist. This superconducting quad-antisolenoid system has been already completed and showed a satisfactory performance.

At a finite-angle collision, particles in a bunch receive different transverse kicks from the opposing bunch according to their longitudinal position in the bunch. This dependence makes the longitudinal and transverse oscillation of the bunches couple to each other and excites synchrobetatron resonances. Although extensive simulations done at KEKB show no decrease of luminosity and no increase of beam tails due to the finite-angle crossing[1], we are considering adopting a crab-crossing scheme as a backup solution to solve any unforeseeable problems due to the finite-angle crossing and have started development of crab cavities[12].

In a crab-crossing scheme[13], incoming bunches are tilted by half a crossing angle by crab cavities and collide head-on in the center-of-mass frame at the IP. Outgoing bunches are tilted back again by other crab cavities.

The function of a crab cavity is to give a sidewise kick to the bunches. This is accomplished by utilizing the TM110 mode, one of the higher-order modes of the cavity. Quadrupole magnets between crab cavity and the IP translate these kicks into sidewise position displacement at the IP and the bunch gets tilted. The cell of the crab cavity has a squashed shape to degenerate two orientations of the TM110 mode: one orientation is used as the crab mode. A coaxial beam pipe is attached to one side of the crab cavity cell to extract not only HOMs but also the fundamental mode. The TM110 crab mode is confined by a choke attached to the coaxial beam pipe.

The first full-size prototype crab cavity cell showed an excellent surface peak field of 33 MV/m, which is higher than the required field by factor 1.5.

4 PHOTOELECTRON AND FAST ION INSTABILITIES

Two new transverse coupled-bunch instabilities, the fast-ion instability (FII)[14,15] and the photoelectron instability (PEI)[16], may be serious to KEKB. Simulations predict that the growth time of these instabilities at KEKB is one msec or shorter[17,18]. Since the vertical beam size is small compared to the horizontal one, only vertical oscillations are excited by these instabilities.

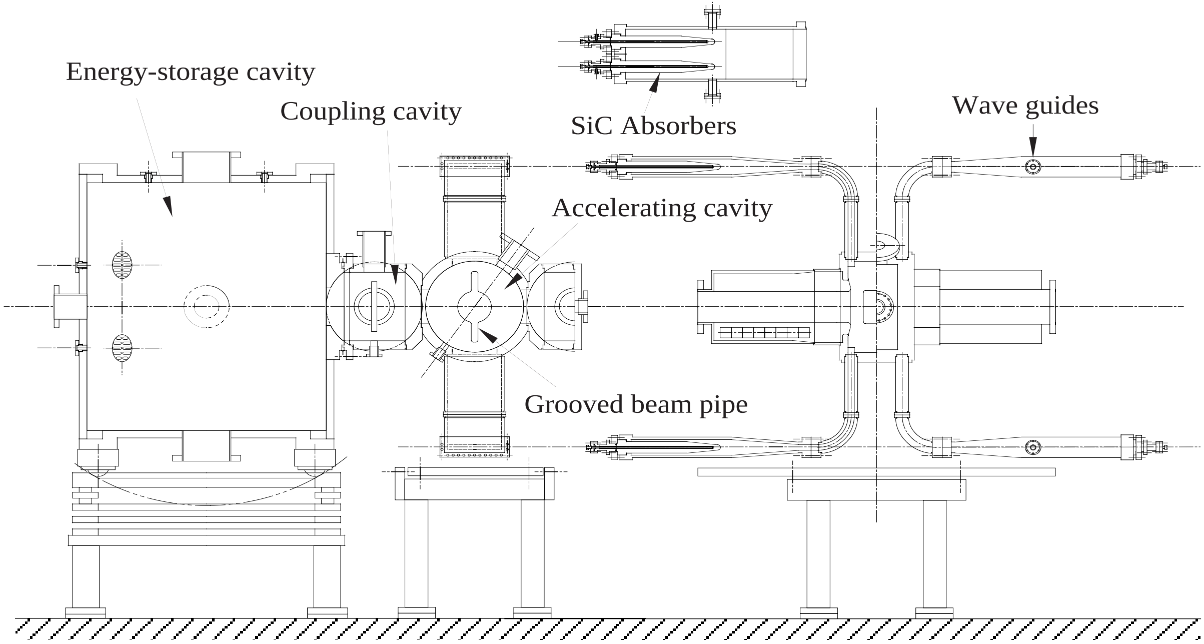

Figure 2 ARES for KEKB

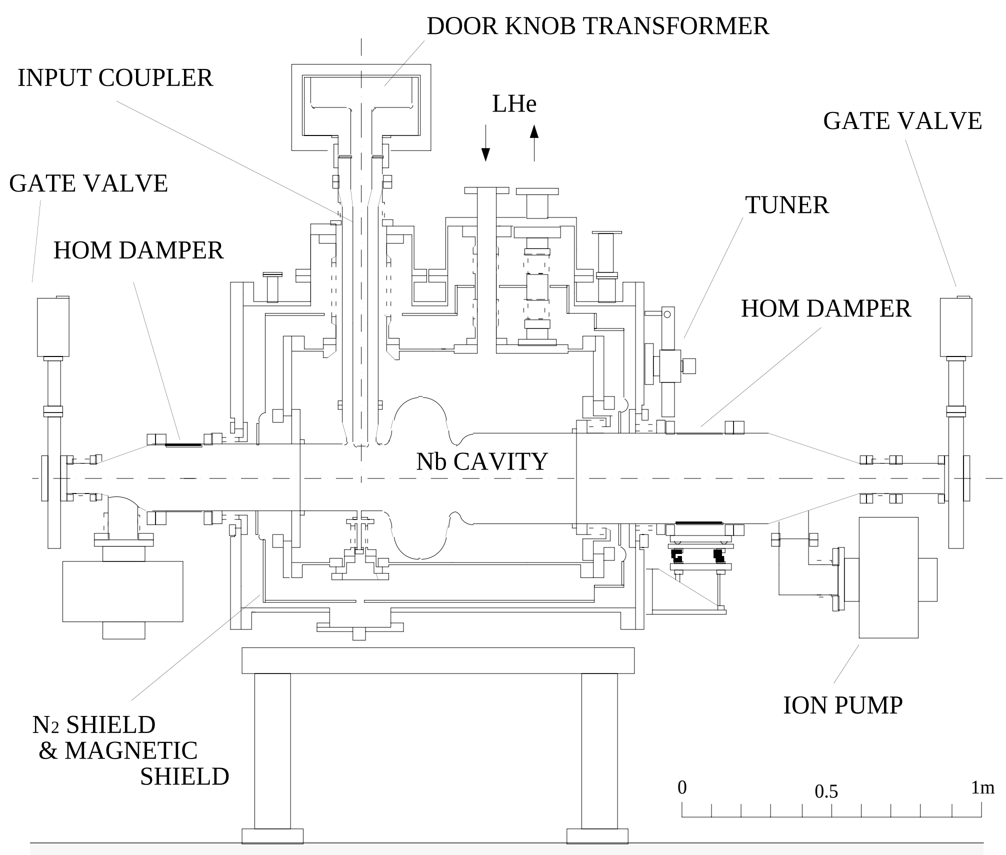

Figure 3 Superconducting cavity for KEKB

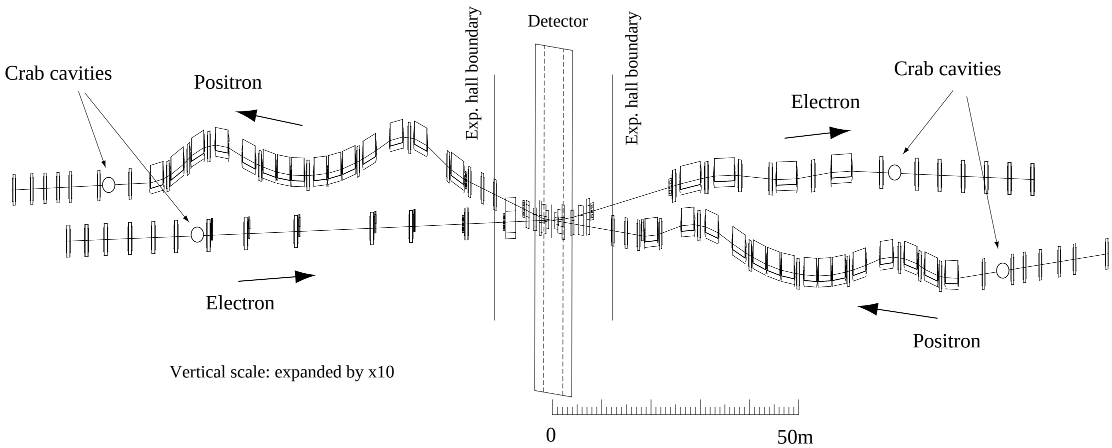

Figure 4 Layout of the KEKB interaction region

FII is an ion-related, vertical coupled-bunch instability, and of serious concern for HER. Ions created in a single passage of a bunch train excites the instability even though these ions are cleared out during a bunch gap. One of the features of the instability is that bunches in the tail of the train have a larger oscillation amplitude. All three experiments concerning this instability, at LBL ALS[19], at KEK AR[20], and at PLS PAL[21], observed this phenomenon.

PEI is a serious concern for LER. Electron clouds are formed around the beam by secondary electrons produced by synchrotron lights hitting the inner surface of the vacuum ducts; this clouds work as a wake source and excite coupled-bunch instability. PEI was first observed at the KEK Photon Factory Ring[22] and confirmed at BEPC of IHEP by IHEP-KEK collaboration[23].

The most effective way to combat FII and PEI is to use strong, bunch-by-bunch feedback systems with a damping time faster than 1 msec[24]. For PEI, weak solenoid field of 30 Gauss can confine the electron cloud very close to the wall of the vacuum duct and reduce the strength of the wake. A winding machine is now under development for KEKB.

5 PRESENT STATUS AND COMMISSIONING PLAN

The project was approved by the Japanese government in 1994 as a five-year project; JFY1998 is the last year of its construction. In May-June the fully upgraded linac has been commissioned and successfully accelerated electrons to 8 GeV and positrons to 3.5 GeV. Positrons were transported halfway to LER through a new transport line. Equipment of the rings are being installed in the tunnel and ground buildings: three quarters the total number of magnets have been already installed. The commissioning of the rings will start from the autumn of 1998 and the BELLE detector will be rolled-in early 1999.

6 REFERENCES

[1] KEKB B-Factory Design Report, KEK Report 95-7, August 1995.

[2] A Study of CP Violation in B Meson Decays, KEK Report 95-1, April 1995.

[3] Design Report on PF Injector Linac Upgrade for KEKB, KEK-Report 95-18, March 1996 (in Japanese).

[4] K. Oide and H. Koiso, Phys. Rev. E47, 2010, 1993.

[5] T. Mitsuhashi, et al., Proc. of 11th Symposium on Acclerator Science and Technology, p.441, SPring 8, 1997.

[6] T. Mitsuhashi, et al., “Spatial Coherency of the Synchrotron Radiation at the Visible Light Region and Its Application for the Electron Beam Profile Measurement”, to be published in Proc. of 1997 Particle Accelerator Conference, Vancouver, May 1997.

[7] Y. Yamazaki and T. Kageyama, Particle Accelerators 44, 107, 1994.

[8] T. Shintake, Particle Accelerators 44, 131, 1994.

[9] T. Furuya, et al., Proc of 5th European Particle Accelerator Conference (EPAC96), pp.2127-29, 1996.

[10] Y. Funakoshi, “High Beam Current Experiments for the KEKB Conducted at the TRISTAN Accumulation Rings” to be published in Proc. of 1997 Particle Accelerator Conference, Vancouver, May 1997.

[11] K.Tsuchiya, el al., Proc. of the 5th European Particle Accelerator Conference (EPAC96), pp.2287-2289, 1996.

[12] K. Oide and K. Yokoya, Phys. Rev. A40, 315, 1989.

[13] K. Hosoyama, Proc. of the 7th Workshop on RF Superconductivity, p.671, 1995.

[14] T.O. Raubenheimer and F. Zimmerman, SLAC-PUB-95-6740, 1995.

[15] G.V. Stupakov, et al., SLAC-PUB-95-6805, 1995.

[16] K. Ohmi, Phys. Rev. Lett. 75, 1526, 1995.

[17] K. Ohmi, Phys. Rev. E.55, 7550, 1997.

[18] K. Ohmi, Proc. of the International Workshop on Multibunch Instabilities in Future Electron and Positron Accelerators (MBI97), pp.163-169, KEK, July 1997.

[19] J. Byrd, et al., Phys. Rev. Lett. 79, 79, 1997.

[20] H. Fukuma, et al., “Experimental Observation of the Ion-Related Coupled Bunch Instability in a Bunch Train in TRISTAN AR”, to be published in Proc. of 1997 Particle Accelerator Conference, Vancouver, May 1997.

[21] K. Kwon. et al., Proc. of the International Workshop on Multibunch Instabilities in Future Electron and Positron Accelerators (MBI97), pp.32-41, KEK, July 1997.

[22] M. Izawa, et al., Phys. Rev. Lett. 74, 5044, 1995.

[23] Z.Y. Guo, et al., “The Experimental Study on Beam-Photoelectron Instability in BEPC”, to be published in Proc. of 1997 Particle Accelerator Conference, Vancouver, May 1997.

[24] E. Kikutani and M. Tobiyama, “Strategy for Developing Very Fast Bunch Feedback System for KEKB”, to be published in Proc. of 1997 Particle Accelerator Conference, Vancouver, May 1997.