PPPL HOTLINE
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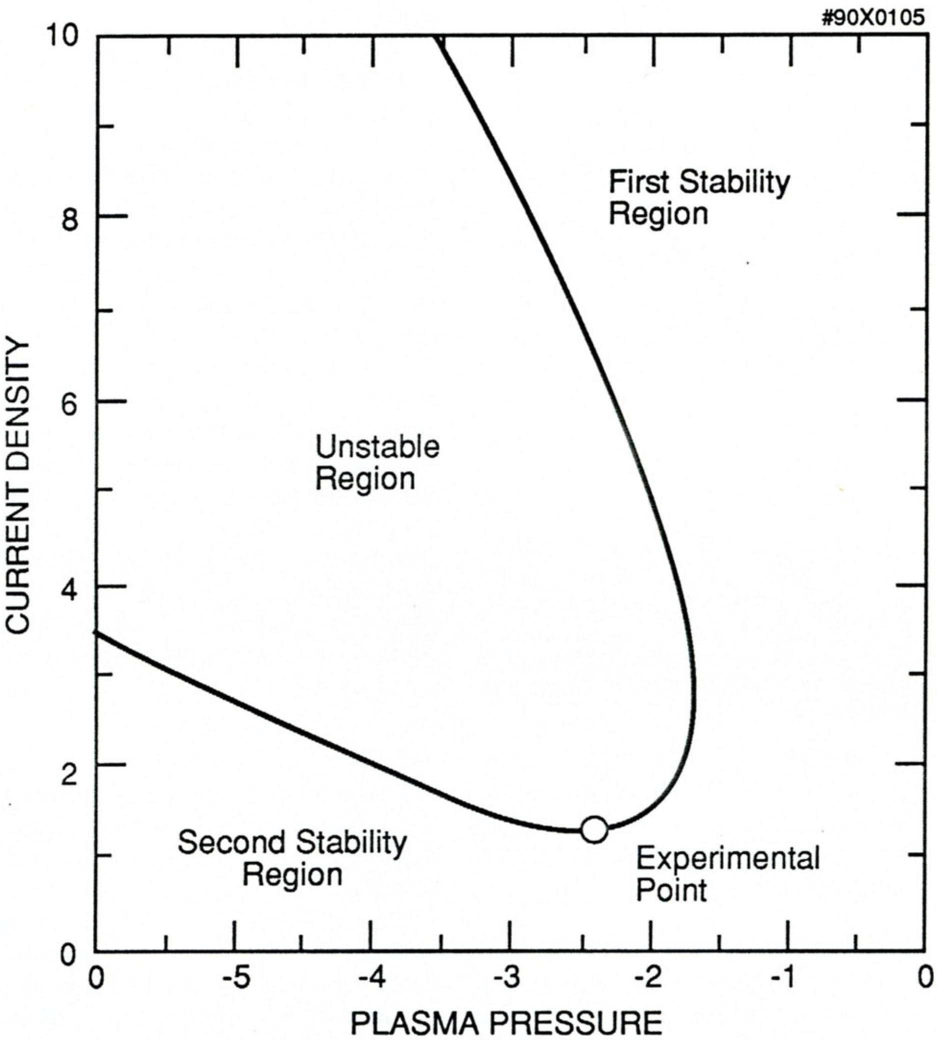
PBX-M Fiscal Year Roundup



By controlling the plasma current and pressure profiles, physicists will try to steer around the instabilities on their way to the second stability region. Enhanced-confinement, high-beta plasmas are predicted for the second stability regime.

by Carol Phillips

The PBX-M (Princeton Beta Experiment-Modification) physics and engineering teams recently completed a very busy and productive year in which they diagnosed and fixed problems that were hampering reliable machine operation, reached record high PBX-M betas of 6.8%, demonstrated the effectiveness of the passive stabilizer plates in suppressing plasma instabilities, and successfully tested and operated diagnostics that measure the current density profile.

PBX-M Project Head Ned Sauthoff said, "The measured high beta of 6.8% had an exciting feature. The plasma had very high ion temperature — for instance, ion temperatures at the center near 5 keV (58 million °C), and confinement times about 50% longer than predicted. This says that we had enhanced-confinement high-beta discharges, which is a big accomplishment." Producing enhanced-confinement, high-beta plasmas is one of the major goals of the PBX-M program.

High Beta, Second Stability Regime, and Plasma Instabilities

For several years, theorists have been predicting the existence of an unexplored region of plasma stability, called the second stability regime. In this regime, it is believed that plasmas will be more stable and that enhanced-confinement and high-beta (typically, greater than 10%) will result. The challenge is to reach this second stability regime while avoiding the instabilities that limit beta in the first stability regime.

Physicists have identified several major types of plasma instabilities — external kinks, internal kinks, and ballooning modes — that must be controlled or bypassed if high beta and the second stability regime are to be reached. Four major techniques have been developed for PBX-M to control and manipulate these instabilities. They are:

- Placing passive stabilizer plates (also called close-fitting conducting walls) close to the plasma to stabilize external kinks.
- Indenting or "shaping" the plasma using a pusher coil to help stabilize the plasma against ballooning modes.
- Using lower-hybrid current drive, neutral beams, and current ramping to manipulate the plasma current density profile.
- Using Ion-Bernstein-Wave (IBW) heating to control the plasma pressure profile.

Progress in the first two areas was achieved during the past year, and an antenna for the Ion-Bernstein-Wave heating system was successfully tested. A 1-MW lower-hybrid current-drive heating system, which will allow control of the current

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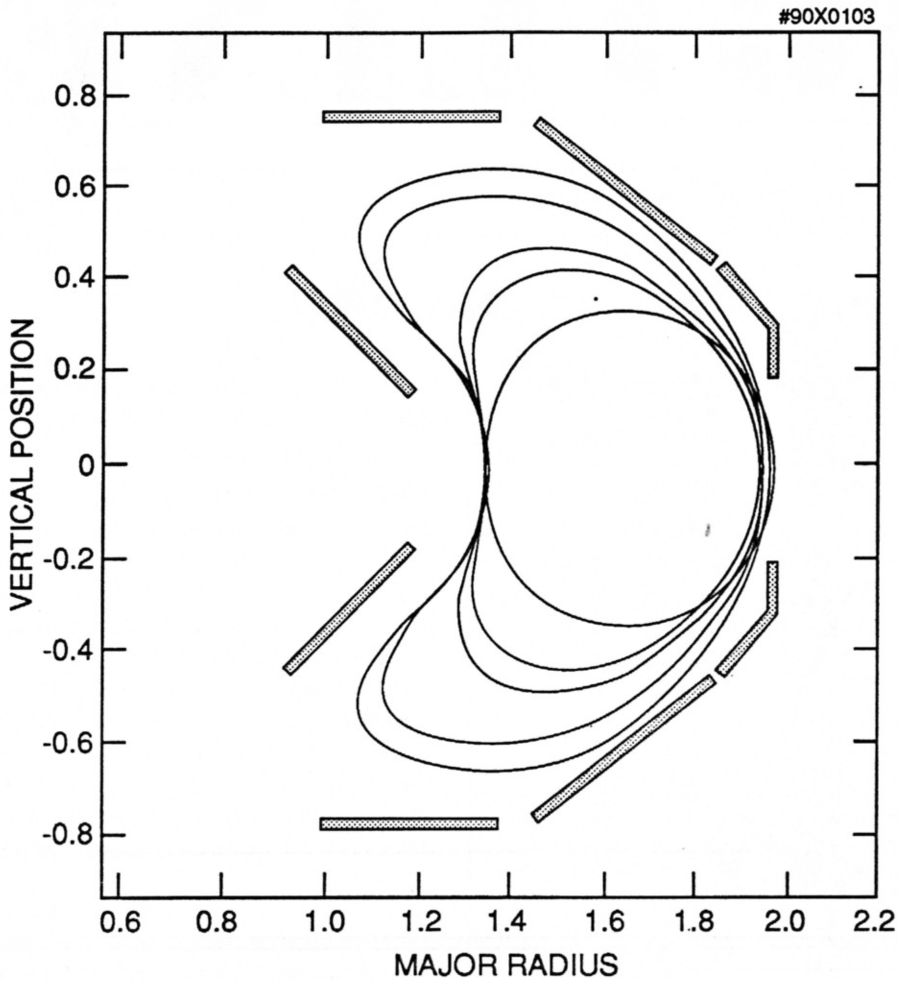

Installation of the passive stabilizer plates (gray bars) was the major improvement between PBX and PBX-M. Their effectiveness in controlling external kinks was demonstrated during the experimental run periods.

density distribution using radio-frequency power, is being installed on PBX-M during FY90 and will be augmented by a second megawatt in FY91.

October through December 1988

During the first few months of FY89, PBX-M experienced problems with electrical arcing and failures of the insulation inside the vacuum vessel. This caused damage to machine components and unreliable machine operation.

"We didn't completely understand the problem, although we were pretty sure voltages from plasma disruptions were responsible, so we decided to improve the insulators which support the passive stabilizer plates and instrument these plates to measure the voltages and currents. We could then gather data for design criteria to fix the machine," Sauthoff said.

The PBX-M engineering team was responsible for modifying the machine so that physicists could identify and study plasma disruption effects and for designing modifications to correct the problems. These activities were critical if PBX-M was to operate reliably.

January through June 1989

Measuring voltages caused by plasma disruptions was the main engineering physics goal during the January through March experimental run period. Henry Kugel and Michio Okabayashi lead the experimental physicists in measuring the voltages and currents, and theoretical predictions and assessments were made by Steve Jardin and Charles Kessel. "We determined that the voltages were moderate, about 1,000 volts, and this allowed us to do rather simple fixes," said Sauthoff. Chuckling, he added, "there were some wide differences between the measured voltages and the predicted ones, and Steve is still scratching his head over this. Understanding the difference is important for projecting requirements for future machines like the Compact Ignition Tokamak and the International Thermonuclear Experimental Reactor."

The effectiveness of the passive stabilizer plates, the major improvement between PBX (Princeton Beta Experiment) and PBX-M, in controlling external kink instabilities was also investigated during this run, and the current was raised to explore high-β_T.

A high-beta plasma was achieved operating at modest toroidal fields, $B_T \sim 1$ T (= 10 kG), and high neutral-beam power, 5 MW. The maximum beta was 6.8%, tying the record set a few weeks earlier by DIII-D (at General Atomics in San Diego). "The good confinement and high temperatures in these plasmas were especially interesting and demonstrated enhanced performance," Sauthoff said.

From April through June, PBX-M was shutdown so that engineers and technicians could upgrade the insulation in the vacuum vessel and thus increase the reliability of the machine. In addition, one of six possible antennas for the ion-Bernstein-wave-heating system was installed, and a one-channel prototype for a new plasma fluctuation profile diagnostic, the Beam Emission Spectrometer (BES), was tested successfully.

July through October 1989

This run period was focused on control of the plasma current distribution using rapid change of the plasma current, neutral beams, and pellet injection.

Theorists have determined that at a particular plasma current and magnetic field, the beta that a plasma of a given size can achieve is limited by the onset of instabilities. This is called the "Troyon Limit," and it defines the boundary of the first stability regime. However, PBX-M physicists obtained betas which were four times this limit, and detailed analyses of these plasmas showed that they were at the threshold of the second stability regime. "The results confirmed that PBX-M is on the right track. When all the planned tools [passive stabilizer plates, pusher coils and divertor, ion-Bernstein-wave heating, and lower-hybrid current drive] are available in FY91/92, even higher performance should be achievable," Sauthoff said.

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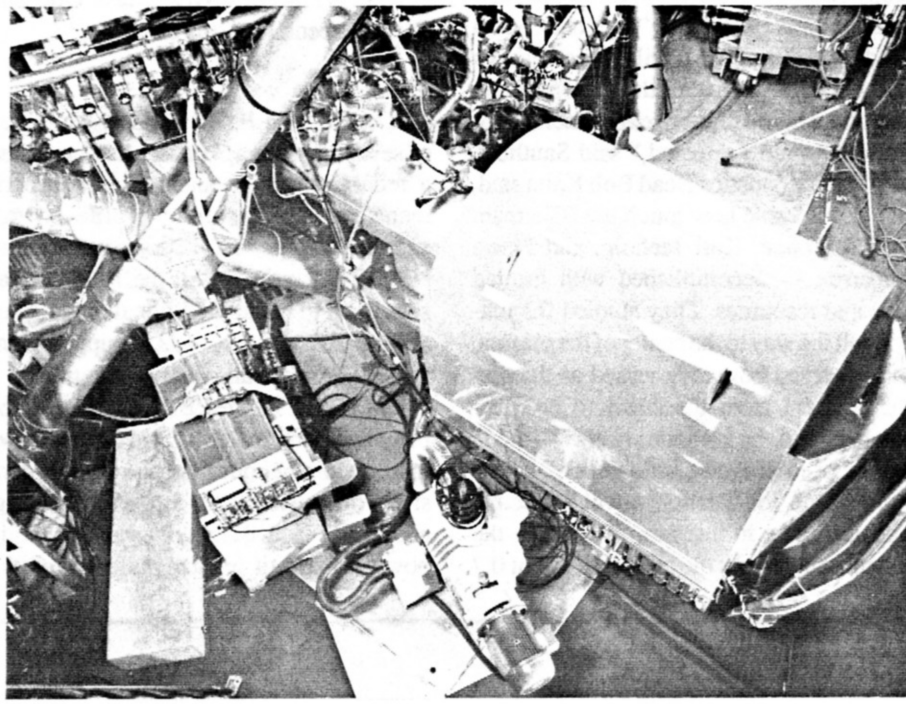
Also during this period, diagnostic measurements of the plasma current density were made to study plasma stability. (Diagnostics are instruments used by physicists to measure how well the plasma is performing and to assess how well their methods towards controlling the plasma are working.) Being able to accurately measure and control the plasma current density profile is very important to achieving the goals of PBX-M. Accordingly, three diagnostics employing different techniques were developed to measure the current density and to provide valuable cross checks between measurements. All were successfully employed during the summer run.

The Motional Stark Effect (MSE) polarimeter was developed by Fred Levinton of the Jaycor Corporation of San Diego, California; it measures the plasma magnetic field direction. The X-Ray Pinhole Camera diagnostic, developed by Ray Fonck and graduate student Ed Powell, measures the plasma magnetic surface contours. The Fast Ion Detector Experiment (FIDE) diagnostic, developed by Bob Kaita and graduate student Don Roberts, measures the fast ion orbit shifts. Both the FIDE and MSE diagnostics use an 80-keV neutral probe beam, which was developed jointly by PPPL and the Culham Laboratory in England.



Top view of the 80-keV neutral probe beam on PBX-M.

Plasma fluctuations are important plasma characteristics which need to be measured to understand the plasma performance. They are "waves" in the plasma which are driven by the instabilities and may drive transport (the motion of energy or particles within the plasma); the measurements of fluctuations tell the physicists how well the instabilities are being suppressed or how virulent they are.

During the summer run, an upgraded, four-channel Beam Emissions Spectro-

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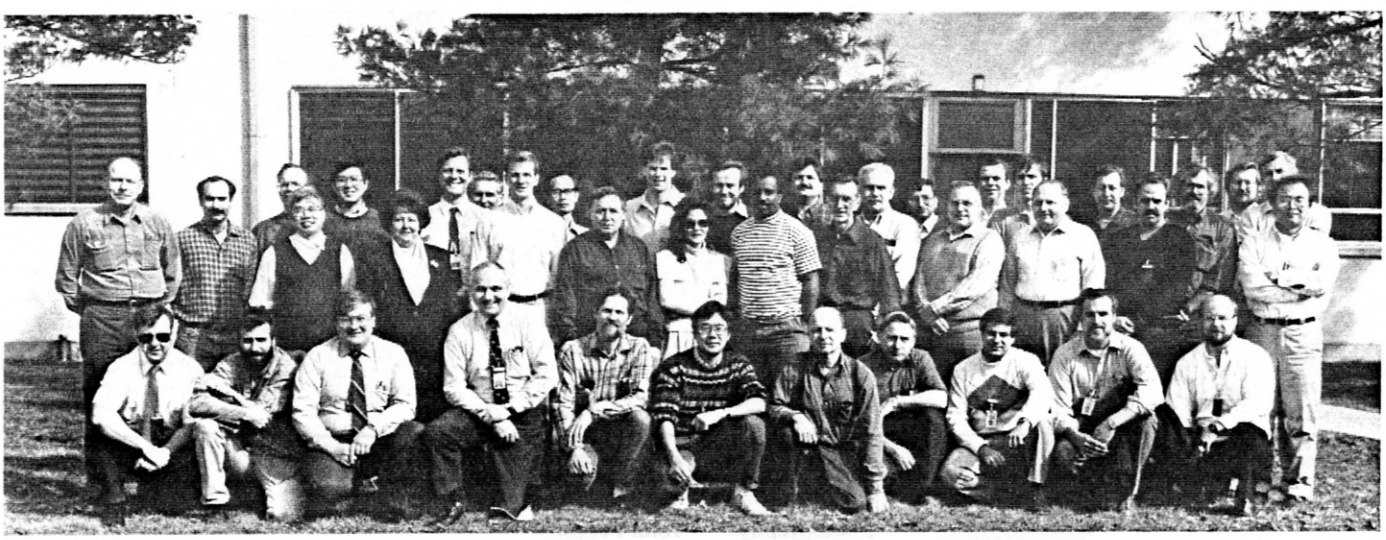

Personnel from many areas of the Laboratory were involved in operations on the PBX-M. Standing (l to r): Bob Diernbach, Fred Levinton, Dick Yager, Tong-Wen Jaeng, Masa Ono, Madge Mitas, Ned Sauthoff, Walt Maciolek, Don Roberts, Yunuen Qin, Frank Polom, Sr., Ed Powel, Janet Felt, Stefano Bernabei, Ron Hatcher, Gary Drozd, Les Gereg, Pete DePeter, Munier Awad, Bill Persely, Jim Dickinson, Eric Thorsland, Stan Schweitzer, Harry Krotz, Fred Wasylenko, Joe Carson, Tom Kozub, Henry Kugel, and Michio Okabayashi. Kneeling (l to r): Dick Shoe, Ray Pressburger, Phil Heitzenroeder, Dan Kungl, Dan Bollenbacher, Nobu Asakura, Herb Fishman, Rich Palladino, Bob Raimond, Rich Frankenfeld, and Bill Davis. Staff also involved with PBX-M, but not available at the time of the photo are: Virginia Baunach, Ron Bell, Morrell Chance, Gordon Chiu, T.-K. Chu, Mary Corneliussen, Nick Dereka, Jim Faunce, Jerry Gething, Gary Gibilisco, Tom Gibney, Glenn Greene, Steve Jardin, Charles Kessel, Alex MacAulay, Janard Manickam, Bob Mika, Dave Moser, Steve Paul, Sherry Preische, Ken Quadland, Mike Reusch, Phyllis Roney, Bob Santoro, John Semler, Tom Sereni, Steve Sesnic, Hiro Takahashi, Keith Voss, and George Vetoulis.

scopy (BES) system to measure the fluctuations was installed. "We had put a window in during the April/June shutdown and were able to install the system in the wee hours of the night so experimental operations weren't affected," said Sauthoff. PBX-M Diagnostics Head Bob Kaita said, "It's remarkable how much the BES team — Ray Fonck, Kurt Jaehnig, and Pierre Duperrex — accomplished with limited time and resources. They studied fluctuations all the way to the center of the plasma, and observed how they varied as the discharge went from the standard confinement regime, or L-mode, to the H-mode regime of improved confinement."

A single ion-Bernstein-wave antenna was used, late in this run, to validate the antenna and assess the effects of about 0.7 MW of 41 MHz waves; Masa Ono and Glenn Greene lead this effort.

The Future

The PBX-M FY89 program consisted of several successful phases that produced a reliable machine and included experiments exploring current profile control and access to the high-beta second stability regime. Early in FY90, the PBX-M was shutdown to install additional diagnostics and heating systems and to upgrade in-vessel hardware and instrumentation.

During FY90, the PBX-M teams will be busy installing lower-hybrid current drive to allow direct control of the current density profile using radio-frequency heating, additional ion-Bernstein-wave heating power to permit greater plasma pressure profile control, and the capability for applying voltages to the passive stabilizer plates to study the effect of edge electric fields.

"The PBX-M will become operational again at the beginning of FY91 when funding arrives," Sauthoff said. "We will then begin studying the effects of plasma cross-section shaping and active current density and plasma pressure profile control on stability and confinement. The PBX-M team looks forward to applying its flexible control and unique diagnostic tools to studying their influences on plasma fluctuations and confinement, leading to the development of a more advanced toroidal configuration which will improve the attractiveness of the tokamaks as a fusion reactor," he said.

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