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The Advanced Beam-Cooling Program at Fermilab: First Experimental Demonstration of Optical Stochastic Cooling

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The reduction of random motion in particle beams, known as beam cooling, has dramatically extended the science reach of many accelerator facilities, with applications ranging from high-energy colliders to the accumulation of antimatter for tests of CPT symmetry and gravity. One of the primary research frontiers in beam cooling is the realization of advanced cooling concepts that have system bandwidths of tens to hundreds of terahertz and achievable cooling rates that exceed the state of the art by up to four orders of magnitude. Here we describe the successful experimental validation of Optical Stochastic Cooling (OSC), which constitutes the first demonstration of any advanced cooling concept. This demonstration is part of a broader advanced beam-cooling research program at Fermilab that also includes high-energy electron cooling and future efforts in laser cooling of ions. The OSC method, first proposed nearly three decades ago, is derivative of S. van der Meer's stochastic cooling (SC), which was instrumental in the discovery of the W and Z bosons at CERN and the top quark at Fermilab. In SC, a circulating beam is sampled and corrected (cooled) using microwave pickups and kickers with a bandwidth of a few GHz. OSC replaces these microwave elements with optical-frequency analogs, such as magnetic undulators and optical amplifiers, and uses each particle's radiation to sense and correct its phase-space errors. The OSC experiment, which was carried out at Fermilab's Integrable Optics Test Accelerator (IOTA), used 100-MeV electrons, a radiation wavelength of 950 nm and achieved a total damping rate approximately 8-times greater than the natural longitudinal damping rate due to synchrotron radiation. Coupling of the longitudinal and transverse planes enabled simultaneous cooling in all degrees of freedom. The integrated system demonstrated sub-femtosecond stability and a bandwidth of ~20 THz, a factor of ~2000-times higher than conventional microwave SC systems. Additionally, detailed experiments were performed demonstrating and characterizing OSC with a single particle in IOTA. This first demonstration of SC at optical frequencies serves as a foundation for more advanced experiments with high-gain optical amplification and advances opportunities for future operational OSC systems at colliders and other accelerator facilities.

In-person participation

Yes

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