PREPRINT UCRL- 77264

Lawrence Livermore Laboratory

Conf- 751125--19

BASEBALL II-T, A NEW TARGET PLASMA STARTUP EXPERIMENT

MASTER

A. Chargin, B. Denhoy, A. Frank, and S. Thomas

November 14, 1975

This paper was prepared for submittal to the Proceedings of the Sixth Symposium on Engineering Problems of Fusion Research, November 18 through 21, 1975, San Diego, California.

BASEBALL II-T, A NEW TARGET PLASMA STARTUP EXPERIMENT*

A. Chergin
B. Denhoy
A. Frank
S. Thomas

Lawrence Livermore Laboratory, University of California
Livermore, California 94550

Summary

This paper is a brief description of modifications and additions to the existing Baseball II experiment. These changes will make it possible to study target plasma buildup in a steady-state magnetic field. This experiment, now called Baseball II-T+ will use a pellet generator to deliver ammonia pellets into the center of the magnetic mirror field where they will be heated with a 300-J, 50-ns, CO_2 laser. The plasma created by this method will have a density of approximately 10^{13} cm^{-3} and a temperature of about 1 keV. This target plasma will be used for neutral beam injection startup studies with a 50-A, 20-keV neutral beam. Later, the beam power will be increased to study buildup. With ion injection energies of up to 50 keV, it may be possible to achieve $n\tau$ as high as 10^{12} cm^{-3} s. The new components necessary to achieve these goals are described here.

Introduction

The Baseball II-T experiment was undertaken to develop startup plasmas consistent with steady-state operation of mirror field confinement. The experiment has been planned in three phases: a) development of technology required to produce a target plasma, b) demonstration of startup in a steady-state magnetic field by neutral beam injection onto a target plasma, and c) increasing neutral beam injection to achieve and maintain a dense, high-temperature plasma for a time longer than transient effects of vacuum pumping and particle losses.

Pellet heating with a laser was selected as the most likely method to succeed in target plasma production. This decision was based partly on good progress made by United Technologies Research Center; however, the Baseball pellet generation and delivery, as well as laser wavelength, are different from the UTRC method.[1] Neutral beam sources, nominally 50 A at 20 keV, developed by Lawrence Berkeley Laboratory (LBL) will be used to demonstrate startup.[2,3] Sources at 40 keV are currently under development at LBL, and these will be used to sustain the plasma in later experiments. The magnetic confinement will be accomplished in the existing Baseball II superconducting magnet facility with minimal modifications.[4]

*This work was performed under the auspices of the U.S. Energy Research & Development Administration, under contract No. W-7405-Eng-48.

+ "T" was added to designate target plasma startup.

Magnet System Adaptation

Because the Baseball II magnet was originally designed for a different set of scientific parameters, not all of its features are compatible with the laser-pellet target plasma production. The magnet geometry makes it difficult to deliver large-diameter laser beams, i.e. 20 cm, within 50 cm of the center and then focus them into a very small focal zone. The only reasonable way to accomplish this is to use 90° and 105° off-axis parabolic mirrors for laser focusing.[5] These mirrors are within the top and bottom magnet lobes respectively. They focus the beam in a vertical plane from opposing directions onto a central target. The laser beams arrive approximately horizontally through the environmental chamber wall, and then they are turned and focused by the off-axis parabolic mirrors. The Baseball LHe circulation system in these regions had to be cut and modified to accommodate the laser beam. The wall of the 8-ft stainless steel vacuum chamber was cut in place, and two new 16-in. ports were fitted for laser entry. Both LN_2 and LHe heat-shield liners were modified accordingly.

The existing Ti sublimation system was incompatible with the new plasma regime, as well as with the reflecting surfaces of the mirrors. Also, the vacuum requirements for the new experiment imply Ti sublimation before every shot. Therefore, the mirror surfaces must be protected and covered by remote control. The 12 sublimators and their cable circuits are designed for rf power to facilitate operation in a high magnetic field. Each sublimator is a 2.5-kW unit, but no more than two will operate at any one time. This heat load is taken on the LN_2 liner surrounding the coil. Figure 1 shows the overall experiment layout.

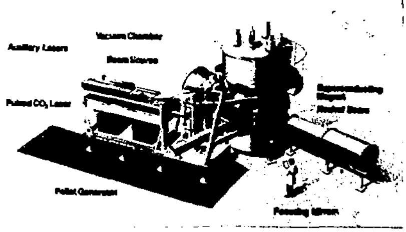

Fig. 1. Overall experiment layout.

As the requirements for the new experiment developed and many of the tasks needed to accomplish the experiment could be identified, a schedule plan was made that includes milestone, financial, and manpower plans. A CPM-type computer code was used to plan and update project activities.[6] During the first half of the project, the computer program was very useful. However, during the second half, no further updating was done because the computer program output and the actual project schedule corresponded reasonably well, and the number of remaining tasks diminished so that their interrelationship was obvious without the computer.

Pellet Generation

Pellet generation is influenced by several factors: vapor pressure, size, composition, purity, fabrication, delivery, and guidance. Ideally, the pellet would be made of pure deuterium. However, developing technology for pellet fabrication, delivery, and guidance would be difficult and expensive with deuterium. Therefore, almost all of the development to date has been accomplished using ammonia.[7] Ammonia liquifaction is simpler than deuterium, and it can also be pumped on LN_2 surfaces instead of LHe. All of the basic techniques applied to making an ammonia pellet generator also can be applied to deuterium with the addition of more complicated but nevertheless standard cryogenic methods. For the initial experiments, it appears possible to obtain satisfactory target plasmas with ammonia. However, it is expected that a deuterium pellet would result in higher energy, longer lifetime, and higher-density target plasma. The deuterium pellet development will be undertaken in the future.

The pellet size necessary to produce an adequate target plasma is dependent upon several parameters: required plasma volume, necessary ion density, efficiency of laser ionization of pellet atoms, and efficiency of laser energy transfer to ions. The needed plasma volume is a sphere large enough to intercept the injected neutral beam. In Baseball II, this sphere should be approximately 6 cm in diameter. The mechanism of the target plasma formation is such that it is not possible to predict accurately the final target plasma volume. Therefore, the pellet generation scheme should be capable of producing pellets over a range of sizes of 50 to 200 μm or 10^{15} to 10^{17} atoms per pellet. In the target plasma, an ion density of 1.4×10^{13} cm^{-3} with a temperature of approximately 1 keV is expected.

Figure 2 shows schematically the method of pellet generation which is essentially that of C. D. Hendricks.[8] The pellet gun generates a stream of charged liquid droplets, any of which can be electrostatically deflected and sent downstream through a Venturi-type orifice. The liquid droplet freezes in flight shortly after it is formed. The orifice serves as a separation between low- and high-vacuum regions as well as a barrier for the streaming gas since it is not aligned with the stream. The droplets are generated at a rate of 10,000 s^{-1} with an initial speed of 10 ms^{-1} which increases to 35 ms^{-1} as the pellet passes through the orifice. Because of Baseball II access limitations, the pellet trajectory is along a horizontal axis perpendicular to the neutral beam injection direction. Along the pellet trajectory, three readings of pellet location and speed are taken, and one deflection plate is energized to a fixed voltage. This gives enough data to compute accurately the predicted pellet trajectory near the focal zone. The necessary correction to

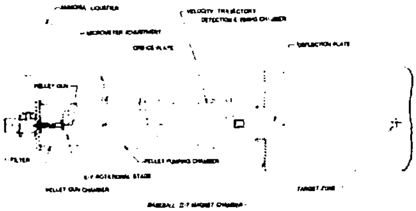

Fig. 2. Schematic of pellet generation.

the trajectory is also computed and the approximate voltage applied to the final deflection plates to insure pellet passage through the focal zone.

Laser System

The selection of the laser system was based on the principle of ablative burn-through of a pellet.[9] Commercially developed CO_2 lasers were available with the required specification of 300 J in a 50-ns pulse. This laser beam is split to hit the pellet from opposite directions to reduce any rocketing effects. Since the Baseball II undergoes optically significant dimensional changes during cooldown and cannot be vibrationally isolated, it is an unsatisfactory mounting base for laser optics. A cantilevered support structure was built for guiding the two beams, supporting the focusing mirrors, and resisting vacuum load. The CO_2 laser, the structure, and the pellet generator are mounted on a common 18- by 6-ft granite table, vibrationally isolated from the ground, and inside a temperature-controlled ro... Therefore, the coil itself does not need to be precisely aligned with the laser system, although the pellet will enter the laser focal zone approximately in the center of the magnetic well.

The focusing optics are two parabolic mirrors 24 by 35 cm, at off-axis angles of 90° and 105° with focal lengths of 50 and 65 cm respectively.[10] They are designed to be cooled to 80 K, and their dimensional changes are taken into account. These, as well as six other large turning mirrors, were made of OFHC copper. An annealing schedule was set up for all mirrors during various stages of fabrication.

In order to monitor alignment, an interferometer was set up with a He-Ne laser. This is a useful feature for real-time confirmation of alignment. For triggering the CO_2 power laser, an argon timing laser is used to detect the pellet approaching the focal zone. Figure 3 shows the schematic of the major optical components. The dimensional stability criteria for the mechanical design are more stringent for the interferometer and the timing laser than for the CO_2 laser. Floor vibrations were dampened with servo-controlled pneumatic isolators supporting the 45,000-lb laser system assembly. The support structure on top of the granite table was designed with the aid of a finite element computer program to insure dynamic characteristics that would not amplify the small vibrations transmitted through the isolators.[11]

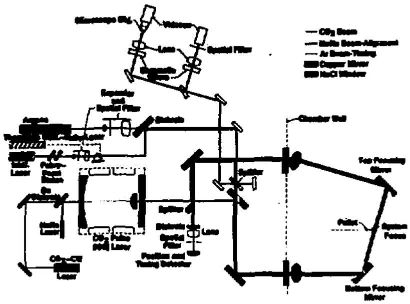

Fig. 3. Schematic arrangement of Baseball II-T laser beams.

Since the building high-bay area where the Baseball II is located fluctuates significantly in temperature, humidity, and air particulate content, an environmental enclosure was constructed around the laser system. This room can be maintained at a temperature of 72 ± 1/2°F and at relative humidity of 30 ± 5%. The dust level is reduced to 100 $ppft^3$ of 5-μ particulate and 10,000 $ppft^3$ of 0.5-μ particulate. Because the windows for CO_2 laser wavelength are made of sodium chloride, the humidity needs to be locally lowered in the areas of the windows to about 10%.

Neutral Beam Injection

For the initial phase of the experiment, a 50-A, 20-keV neutral beam source will be used to facilitate target plasma diagnostics and to provide indication of beam trapping. The source is of standard design built by LBL and is used successfully in several projects.[2] The actual module installed has been tested to 60 A at 16.5-keV output using hydrogen. The total beam power and beam energy distribution are measured directly on the same diagnostic device. The power is measured calorimetrically on a calibrated copper plate. The energy distribution is measured by allowing a negligible portion of the beam to pass through an array of small holes in the calorimetric plate. These small beamlets produce secondary electrons on a detector at the end of each hole. By studying the proportionality of signals, the energy distribution can be easily obtained.

The source is mounted in a 5-ft-diam tank with a LN_2 liner and Ti sublimation. The liner is made of 316 stainless steel with unique double-wall construction which allows the inner wall to be as thin as 0.020 in. For Ti sublimation purposes, the heat transfer through the 0.020-in. wall is very good, and temperature fluctuations can be held to less than 5 K. The technique of spotwelding the thin sheets for double-wall construction of heat transfer surfaces was developed by Mueller Co.*

For the buildup phase of the Baseball II-T experiment, a new neutral beam injector system is proposed. Figures 4 and 5 show the layout of the system. The current plan is to use five 50-A, 20-keV source modules and one 40-keV source module. There will be two 9-ft-diam source tanks, each housing three source modules. The primary pumping will be by volume dilution of the pulsed gas loads into the source tanks. However, Ti gettering on LN_2 surfaces inside each source tank is planned as well as on LN_2 surfaces surrounding the magnet walls. To allow for quasi-steady-state operation with the 40-keV beam, the LHe cryopumping surface will be increased to 20 m^2 inside the magnet environmental chamber. With this scheme, the vacuum conditions should allow operations for 100 ms with the 40-keV beam. A product $n\tau$ of 10^{12} cm^{-3} may be achieved.

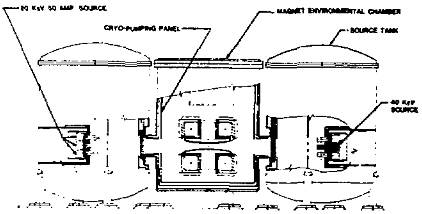

Fig. 4. Proposed multiple-beam injection, vertical cross section.

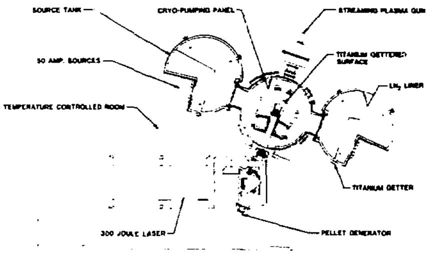

Fig. 5. Proposed multiple-beam injection, plan view.

Current Status

The magnet system adaptation has been accomplished and successfully tested. The pellet generator produces pellets reliably. However, the guidance and delivery systems need further improvement because only a small fraction of the pellets pass through the focal zone. This fraction should be sufficiently increased with the addition of another computer to facilitate faster trajectory calculations.

* Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U. S. Energy Research and Development Administration to the exclusion of others that may be suitable.

The CO_2 laser system and other auxiliary lasers are installed and tested. One off-axis parabolic mirror has been delayed in fabrication, causing the current checkout operation to be done with one-sided focusing instead of the intended two. One 50-A, 20-keV source has been installed and is now operational. The first tests of target plasma generation will be done soon. The final phase of the experiment is in the preliminary design stage awaiting funding approval. Assuming timely funding, the multiple-beam system could be built and installed in approximately one year. Then the experiment could be started on sustaining the plasma in a steady-state magnetic field.

Acknowledgments

This paper was prepared by the mechanical engineering staff of the Baseball II-T project. However, many other people contributed toward the progress of this project, which is headed by C. Damm, Project Physicist. Other physicists associated with the project are J. Foote, A. Futch, R. Goodman, A. Hunt, J. Osher, and G. Porter. The electrical engineering staff members are A. Bogdanoff, D. Matsuo, and A. Waugh. From the three technician groups, the main contributors were, respectively, R. Johns, T. Stack, and J. Strong.

References

1. A. F. Haught, et al., "Laser Initiated Target Experiment (LITE)," in 5th IAEA Conf. on Plasma Physics and Controlled Nuclear Fusion Research, Tokyo, 1974.
2. W. R. Baker, et al., "Intense Neutral Beam Research and Development," in 5th IAEA Conf. on Plasma Physics and Controlled Nuclear Fusion Research, Tokyo, 1974.
3. A. K. Chargin and C. J. Anderson, "Solving Problems of Neutral Beam Injectors at LLL," in Proc. 5th Symp. on Engineering Problems of Fusion Research, Princeton University, Princeton, N.J., 1973.
4. C. D. Henning, R. L. Nelson, A. K. Chargin, B. S. Denhoy, and F. Marschbarger, "Engineering the Baseball Magnet System," in Proc. 4th Symp. of Engineering Problems of Fusion Research, Naval Research Laboratory, Washington, D.C., 1971.
5. A. Frank and A. Chargin, Laser Focusing Optics for Baseball II-T, an Approach Trade-Off Study, Lawrence Livermore Laboratory Engineering Note, ENE 74-27 (1974).
6. T. A. Kozman and A. K. Chargin, "Project Planning and Project Management of Baseball II-T," in Proc. 6th Symp. on Engineering Problems of Fusion Research, San Diego, 1975.
7. B. S. Denhoy, "Frozen Ammonia Micro Pellet Generator for Baseball II-T," in Proc. 6th Symp. on Engineering Problems of Fusion Research, San Diego, 1975.
8. J. M. Schneider and C. D. Hendricks, "Source of Uniform-Sized Liquid Droplets," Rev. Sci. Instrum. 35, 1349 (1964).
9. J. Osher and G. Porter, Laser-Pellet Heating Studies for Plasma-Target Production, Lawrence Livermore Laboratory Rept. UCRL-77137 (1975).
10. A. Frank, A. Chargin, and N. Brown, "Laser Startup Optics for Baseball and Future Mirror Machines," in Proc. 6th Symp. on Engineering Problems of Fusion Research, San Diego, 1975.
11. S. Thomas, A. Chargin, B. Denhoy, and B. Johnson, "Vibrational, Thermal, and Alignment Considerations of the Laser System for Baseball II-T," in Proc. 6th Symp. on Engineering Problems of Fusion Research, San Diego, 1975.