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RADIO-FREQUENCY ENERGY IN FUSION POWER GENERATION

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ABSTRACT

The history of radio-frequency (rf) energy in fusion experiments is reviewed, and the status of current efforts is described. Potential applications to tasks other than plasma heating are described, as are the research and development needs of rf energy technology.

INTRODUCTION

Early studies of controlled thermonuclear fusion, around 1953, proposed methods of heating that generally included radio-frequency (rf) power in the very low frequency (VLF) region. Such systems as the "B-Oscillator" and the "Test MOPA," for use in magnetic pumping, operated in a frequency range of 100-200 kHz. In 1957, T. Stix of Princeton University proposed and demonstrated that a high frequency (HF) rf system would couple energy efficiently to the plasma at the ion cyclotron resonance frequency. Experimental results conducted with rf source capabilities of 1 MW on the B-65 at 12 MHz and the B-66 at 16 MHz indicated that rf energy was a strong candidate for reactor heating. Problems of confinement and impurity influx plagued plasma studies for the next decade. These anomalies limited rf heating studies to power levels of a few hundred kilowatts, even though significant developments were made in megawatt rf power sources up to and including the very high frequency (VHF) range.

At fusion laboratories the world over, starting about 1975, major commitments were made to heat plasmas by means of ion cyclotron resonance heating (ICRH), electron cyclotron resonance heating (ECRH), and hybrid schemes with high power rf sources. Success in varying degrees has been achieved. As experiments and theoretical calculation continued, other roles for rf heating were devised. Each method of heating and/or plasma control requires a particular part of the spectrum for proper operation.

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The ion cyclotron range of frequencies (ICRF) lies in that portion of the rf spectrum that includes such services as the AM broadcast band [medium frequency (MF), 300-3000 kHz], the international communications and broadcast band (HF, 3-30 MHz) and the VHF television/FM broadcasting band (VHF, 30-300 MHz). Many years of development and operation in these frequency ranges by commercial and government interests enabled the fusion program to move to relatively high power levels without a major equipment development program. However, this fortuitous circumstance is no longer applicable, and much research and development in component parts, such as vacuum tubes, will be required to construct rf systems to meet the needs of present and future machines.

The primary role that ICRF heating will play in the tokamak reactor will be in heating the plasma at the fundamental and second harmonic regimes. For the first fusion reactor, this mode of heating will require rf power levels in the 100-MW range. At this time, existing rf systems for plasma machines are capable of only 5 MW. In addition to resonance heating, the ICRF power sources will be used for plasma current drive. This scheme is particularly practical in large reactor vessels, where physical spacings will allow for arrays of waveguide launchers in a fast wave configuration.

The lower hybrid range of frequencies (LHRF) covers that portion of the rf spectrum which is used for ultrahigh frequency (UHF) television and microwave heating (UHF, 300-3000 MHz). The primary role envisioned for LHRF is "current drive." The rf energy is used to provide excitation to electrons in a unidirectional mode so that a net current flow in the plasma will allow continuous operation of the tokamak reactor. LHRF may also be used for plasma heating. However, further investigation is required to prove that this method of heating is practical. Power levels of 10-50 MW are envisioned for current drive of a full-size reactor. Post-World War II development of high power gridded tubes and ~0.5-MW klystron amplifiers has provided the means to satisfy power

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