A publication of the International Cryocooler Conference

# CRYOCOOLERS 9

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# Preface

The last two years have witnessed an explosion in interest in pulse tube cryocoolers following the achievement by TRW of high efficiency long-life pulse tube cryocoolers based on the flexure-bearing Stirling-cooler compressors from Oxford University, and have seen the initiation of development of long-life, low-cost cryocoolers for the emerging high temperature superconductor electronics market. Hydrogen sorption cryocoolers achieved their first operation in Space this year, and closed-cycle helium Joule-Thomson cryocoolers continue to make progress in promising long-life space applications in the 4 K temperature range. On the commercial front, Gifford-McMahon cryocoolers with rare earth regenerators are making great progress in opening up the 4 K market, and new closed-cycle J-T or throttle-cycle refrigerators are taking advantage of mixed refrigerant gases to achieve low-cost cryocooler systems in the 65 - 80 K temperature range. Tactical Stirling cryocoolers, now commonplace in the defense industry, continue to find application in a number of cost-constrained commercial applications and space missions, but are shrinking in numbers as the defense industry goes through a period of consolidation.

Building on the expanding stable of available cryocoolers, numerous new applications are being enabled; many of these involve infrared imaging systems, and high-temperature superconductors in the medical and communications fields. Application experiments, designed to explore, troubleshoot and resolve product integration issues, continue to occur on an ever widening front, particularly in the fields of infrared imaging and spectroscopy, gamma-ray spectroscopy, and high-temperature superconductor applications. An important lesson is that integrating cryogenic systems requires care and thoughtfulness in a broad range of engineering and scientific disciplines. In this regard, the vibration sensitivity of many of the infrared and medical imaging applications has led to the recognition that cryocooler-generated vibration and EMI is a critical performance parameter for these applications. In response, several of the application experiments involve the measurement of vibration and EMI susceptibility, and the development of advanced closed-loop active vibration control systems.

This book draws upon the work of many of the international experts in the field of cryocoolers, and is based on their contributions at the 9th International Cryocooler Conference, held in Waterville Valley, New Hampshire, in June 1996. The program of this conference consisted of 124 papers. Of these, 106 are published here in *Cryocoolers 9*. Although this is the ninth meeting of the conference, which has met every two years since 1980, the authors' works have only been made available to the public in hardcover book form since 1994. This book is the second hardcover volume of what we hope will be a series of professional texts for users and developers of cryocoolers. Prior to 1994, proceedings of the International Cryocooler Conference were published as informal reports by the particular government organization sponsoring the conference — typically a different organization for each conference. A listing of previous conference proceedings is presented in the Proceedings Index, at the rear of this book. Most of the previous proceedings were printed in limited quantity and are out of print at this time.

Because this book is designed to be an archival reference for users of cryocoolers as much as for developers of cryocoolers, extra effort has been made to provide a thorough Subject Index that covers the referenced cryocoolers by type and manufacturer's name, as well as by the

scientific or engineering subject matter. Extensive referencing of test and measurement data is included in the Subject Index under a wide variety of performance topics. Examples include refrigeration performance data, complete cryocooler characterization test data, vibration and EMI measurements, and qualification and life test experience. Application and integration experience is also highlighted by specific index entries. To aide those attempting to locate a particular contributor's work, a separate Author Index is also provided, listing all authors and coauthors. Contributing organizations are listed in the Subject Index to assist in finding the work of a known institution, laboratory, or cryocooler manufacturer.

The content of the book is organized into 15 chapters by cryocooler type, starting with Stirling cryocoolers, pulse tube cryocoolers, and associated research. Next, Brayton, Joule-Thomson and sorption cryocoolers are covered in a progression of lowering temperatures. Gifford-McMahon cryocoolers and low-temperature regenerators in the 4 to 10 K range are covered next, followed by a glimpse into the future with miniature solid-state refrigerators receiving increased interest in the laboratory. The last three chapters deal with cryocooler integration technologies and experience to date in a number of representative applications. The articles in these last three chapters contain a wealth of information for the potential user of cryocoolers, as well as for the developer.

It is hoped that this book will serve as a valuable source of reference to all those faced with the challenges of taking advantage of the enabling physics of cryogenics temperatures. The expanding availability of low-cost, reliable cryocoolers is making major advances in a number of fields.

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