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INTRODUCTION

The Ray W. Herrick Laboratories developed as a cooperative enterprise between Purdue University and primarily American industry, and to a lesser extent the federal government. It grew out of the need of the air conditioning and refrigeration industry for university contact: first, to educate industry-oriented engineers with advanced degrees for their research and development laboratories, and second, to utilize the pool of talent that is available at a university of the professional stature of Purdue for research on industry-related questions.

Gifts from industry and grants from the government joined the investment of Purdue University in establishing the facility as part of the School of Mechanical Engineering. The faculty and the academic program provided the students with the proper education. Industry provided research projects of relevance. This cooperative venture nurtured the growth of the Laboratories to a community of approximately 90 people of faculty, staff, and students.

The Laboratories now provide an atmosphere of cooperation within the University itself. Faculty and students from all Schools of Engineering and the Sciences are willing to participate in research programs, if called upon. There are active research programs funded by a wide spectrum of industries: for example, the tire industry and the watch industry, in addition to programs funded by government agencies. However, a large portion of the research effort is concerned with compressors, which justifies and necessitates this special report on the compressor research activities to date.

This report attempts to summarize the research effort in compressors so far, give a listing of the many theses that were generated in this area, and provide information on the faculty who are most active in this area. For the prospective graduate student who would like to work in this challenging applied research area, this report outlines questions of application, support, etc. For the prospective industrial research sponsor, this report outlines the steps needed to get a research program started in this area.

Finally, this report outlines the activities of the Ray W. Herrick Laboratories in Compressor Research Conferences and Compressor Analysis and Design Workshops. This effort is considered to be important, both from the viewpoint of an international information exchange in this area, and from the viewpoint of the continuing education mission of Purdue University.
SUMMARY OF COMPRESSOR RELATED RESEARCH THESIS

The compressor research activity of the Ray W. Herrick Laboratories is summarized in the theses generated by its graduate students. The complete listing is given by the author, degree, title, and major professor.

In general, copies of theses may be obtained from several sources, such as ProQuest (http://www.proquest.com/products_pq/descriptions/pqdt.shtml). (However, some of the recent theses may still be confidential and will not be available until declassified. Another source would be the Interlibrary Loan Office, Purdue University Libraries, West Lafayette, Indiana, 47907. Their website is: http://www.lib.purdue.edu/access/ill/td/.

Early research focused on experimental procedures. For instance, the first strain gage measurements on a vibrating reed valve in an operating refrigerating compressor were conducted here. Since the early sixties, research has expanded into the area of mathematical simulation of total compressors, predicting valve reed vibrations and stresses, gas oscillations, acoustic radiation, etc. The advent of high speed compressors has made dynamic considerations mandatory, and research is therefore quite challenging to students in this area. Research has been done on air as well as refrigerating compressors. In general, the research can be thought of as serving three goals: Noise and Vibration Control, Thermodynamic Performance Improvement, and Increased Reliability.

The Ray W. Herrick Laboratories are internationally recognized as a research center in the compressor area.
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123. S. Ebling  
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Carbon Dioxide Compressor Load Stand  
8/2013  
E. Groll

124. S. Caskey  
MSME  
Cold Climate Field Test Analysis of an Air-Source Heat Pump with Two-Stage Compression and Economizing  
12/2013  
E. Groll
COMPRESSOR RESEARCH NOT REFLECTED IN THESES TITLES

In addition to the theses listed in the previous chapter, many more research reports on various aspects of compressors have been written, usually for research sponsors. As a rule, these reports are kept confidential, and are therefore not listed. Topics are often different from the theses topics, mainly since not everything found on a sponsored research program is eventually incorporated in a thesis. In some cases, although the student's support came from a sponsored research program, his thesis was written around a detailed question which was part of the research program and caught his fancy. For instance, the Laboratories have done extensive work on the noise control of large centrifugal compressors, but the graduate student on the project and his major professor decided that the student should write his thesis on the stiffening of shells.

Then there are theses in other areas whose findings have influence on compressor design. In addition to the ones that are listed here, there are many more in the areas of vibrations, acoustics, thermodynamics, fluid mechanics, heat transfer, control, etc. Also, considerable work that was or can be applied to compressors has been published by the Herrick faculty and students in journals and conference proceedings. Areas are, for instance, flow area modeling, impact stress analysis, valve reed similitude, instrumentation design, acoustics, etc., and some listings may be found in the Publications listing.
PAST AND PRESENT SPONSORS

Among past and present industrial sponsors of research related to compressors are:

- American Standard
- Aspera SpA, Italy
- Bell and Gossett ITT
- Bendix-Westinghouse
- Robert Bosch GmbH (West Germany)
- Carlyle Compressor Company
- Carrier Corporation
- Chrysler Corporation, Airtemp Division
- Copeland Corporation
- Cummins Engine Company
- Danfoss A/S, Denmark
- Mario Dorin SpA, Italy
- Dunham-Bush, Inc.
- E. I. duPont de Nemours and Company
- S.A. Embraco, Brazil
- Frick Company
- General Electric Company
- General Motors Corporation, Frigidaire Division
- Gibson Products Corporation
- GoldStar Company, Korea
- Joy Manufacturing Company
- L.G. Electronics
- Mitsubishi Electric Corporation, Japan
- Mitsubishi Heavy Industries, Ltd., Japan
- Nanjing Aotecar Refrigerating Co., Ltd.
- Necchi, S.p.A., Italy
- Panasonic (Matsushita), Japan
- Sanden Corporation, Japan
- Shanghai Hitachi Electrical Appliances Co., LTD
- Tecumseh Products Company
- Toshiba Corporation, Japan
- The Trane Company
- United States Army
- United States Air Force
- United Technologies Carrier Corporation
- Vilter Manufacturing Corporation
- Westinghouse Electric Corporation
- Whirlpool Corporation
- York Division, Borg-Warner Corporation
- Zanussi Eletromeccanica S.p.A., Italy

Many sponsors have had or have research programs with the Ray W. Herrick Laboratories that stretch over many years, involving as many as four students at a time.
HOW TO INITIATE SPONSORED RESEARCH

The prospective sponsor should contact the Director of the Herrick Laboratories or one of the members of the faculty and ask for a preliminary meeting. At this meeting, the sponsor can state his interests, and the degree of his desired involvement can be discussed. After this meeting, the Herrick Laboratories faculty will write an informal technical research proposal, which will be discussed with the sponsor at one or more subsequent meetings. An informal budget will be presented at that time. After an informal agreement on the proposal and budget has been reached, the proposal will be formally processed through Purdue University offices for administrative approvals. The approved technical proposal and budget will then be forwarded to the sponsor by the Purdue Research Foundation, along with an agreement form for execution by the sponsor.

To accommodate needs for confidentiality, it is possible to withhold publication of a thesis for up to two years after contract termination.

While continuing sponsorship of research stretching over several years is desirable, both from the viewpoint of the Herrick operation and the maximum benefit to the sponsors, budget commitments do not have to exceed one year. Contracts are usually fixed price contracts.

Often the prospective sponsor is unsure what would constitute an acceptable research project. It is suggested that he contact the Ray W. Herrick Laboratories anyway, as there are few worthwhile projects that cannot at least generate a master's thesis. The faculty will take the responsibility to add to the project any necessary additional academic requirements. In these cases, this means that the sponsor received information above and beyond what he has contracted for.

A NOTE TO OUR FOREIGN FRIENDS

A foreign visitor is usually surprised that the compressor research operation of the Herrick Laboratories is completely different from what he is accustomed to. He will be dismayed because the faculty may be unable to answer a question on some specific design detail of some specific brand of compressor, but will be agreeably surprised about the depth of knowledge in particular scientific areas applying to compressor design; for example, heat transfer or vibrations. He will also be surprised to find faculty members involved not only in compressor research but, for instance, also in combustion oscillation. The reason is simply the different characters of the higher education systems in the United States. Chairs for piston machinery, or even fluid machinery, in general do not exist. No single professor has the mission to be the expert in a given applied area such as compressors. Rather, there are professors specializing in the engineering science disciplines. They will, if needed, apply this specialized knowledge to industrial design. These disciplines are
thermodynamics, fluid mechanics, heat transfer, vibrations, stress analysis, automatic control, acoustics, etc. This applies in general also to the course content of the academic curriculum.

It is felt that the advantages of this system outweigh the disadvantages. The Ray W. Herrick Laboratories program in compressor research is an attempt to preserve the advantages and eliminate the disadvantages by a cooperative approach to applied research. Thus, the specialists in acoustics, vibration, thermodynamics, etc., bring their full knowledge to bear on every research project, even if it is only in an informal consultation capacity.

A NOTE TO PROSPECTIVE GRADUATE STUDENTS

In general, the graduate student who works on a sponsored project can expect an appointment as a half-time Graduate Research Assistant. Master's degree candidates are expected to write a thesis related to their project research. This thesis can also be the final report to the project sponsor. In addition, the student is expected to write progress reports to the sponsor during the course of his research. Material in the progress reports can be incorporated in the thesis. The Ph.D. candidate is, of course, required to write a dissertation.

Students often ask what constitutes an acceptable thesis. A suggested minimum requirement for a Master's thesis is that the student utilize graduate-type coursework and produce results that are of a certain importance to the compressor industry. Publishability in refereed professional journals is not required, but many of our Master's degree graduates have published their work subsequently. However, a Ph.D. thesis has to contain material that is publishable in professional journals, be of a sufficient degree of difficulty to prove the candidate's qualification, and has to be in its subject matter of high interest either to the compressor industry or to one of the engineering science disciplines. Publications of former Herrick Laboratories Ph.D. candidates can be found in almost all major journals. This testifies to the quality of the Herrick Laboratories programs.

In all fairness, it has to be pointed out that applied research, in this case on compressors, is in some cases more difficult than what is often called basic research; since sooner or later the applied question leads to a basic investigation also. It is certainly more time-consuming, since the student is expected to become both broad and deep in outlook. He will also enter into a relationship of responsibility with the sponsoring company, and has to handle most communication with the sponsor himself. The rewards are a good and tough engineering education, no matter if on the Master's level or on the doctoral level. Graduates of the Ray W. Herrick Laboratories do, as a rule, very well for themselves in industry or government positions. A large percentage of the Ph.D. candidates have entered successful academic careers in major universities.
Students who are interested in joining the Ray W. Herrick Laboratories should formally apply to the Graduate School of Purdue University by writing to the Graduate Office of Mechanical Engineering, Purdue University, West Lafayette, Indiana 47907, U.S.A., and indicate their interest in the Laboratories on the application form.

**JOURNAL AND CONFERENCE PUBLICATIONS**
**BY HERRICK FACULTY AND STUDENTS**


Purdue Compressor Technology Conference, pp. 69-73, Purdue University, West Lafayette, IN, July 1980.


279. C.R. Bradshaw, S.V. Garimella and E.A. Groll, “A Comprehensive Model of a Miniature-Scale


Faculty of Compressor Research Group:
Dr. Eckhard Groll
Dr. James E. Braun
Dr. W. Travis Horton