

Compressor Commissioning at RIT Demonstrates Real-World Design, Test & Research Experience

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In 2007, collaboration between the Rochester Institute of Technology (RIT) and Dresser-Rand (D-R) was initiated for the donation of an industrial-sized compressor for the purpose of on-campus educational and graduate research applications. The project has since led to a series of multidisciplinary senior design team projects culminating with the installation and commissioning of a brand new ESH-1 reciprocating compressor in 2010. This successful effort has been followed by a student summer internship, two additional senior design teams, and two graduate student thesis research projects. Through frequent interaction between the faculty and students at RIT with engineers and managers at D-R the project has been immensely successful in presenting students at all levels with “real-world” design and research challenges.

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Introduction

The Rochester Institute of Technology in Rochester, NY, is a nationally respected leader in professional and career-oriented education with an approximate enrollment of 16,000 students of which 3,000 are graduate students. The Kate Gleason College of Engineering is one of the largest colleges at RIT totaling 2,000 undergraduate and 500 graduate students with both B.S. and M.S. degrees are offered by the college.

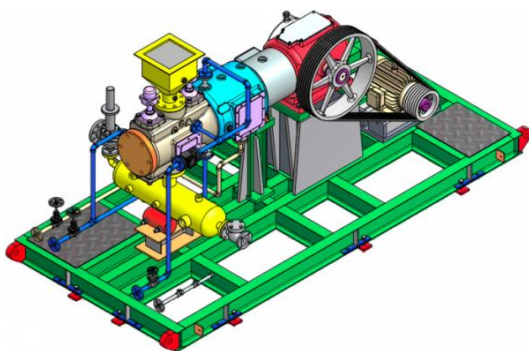


Figure 1 – Dresser-Rand ESH-1 Reciprocating Compressor

Dresser-Rand is a multinational corporation and recognized world-leader in gas compression technology with a R&D headquarters located in Olean, NY. They provide a wide range of technology, products, and

services used for developing energy and natural resources including reciprocating compressors.

The relationship between the RIT and Dresser-Rand has a long and distinguished history. D-R is one of upstate New York’s largest manufacturing organizations and utilizes a very large range of engineering talent. Three of Dresser-Rand’s primary manufacturing and R&D facilities are located about 100-miles from RIT and as a result they accept dozens of coop students annually in mechanical, industrial, and electrical engineering. Many of these students are offered positions with the company upon graduation given their unique “in-college” training experience.

It was determined prior to 2008 that expanding the relationship between RIT and D-R would be advantageous to both organizations. If Dresser-Rand hardware could be available on the RIT campus it could provide hundreds of students the opportunity to work with an actual industrial piece of equipment that covers an extremely wide range of engineering disciplines: from thermodynamics to vibrations to instrumentation; all having very strong design and analysis challenges. Moreover, D-R would be provided with graduating engineers knowledgeable with their compression equipment for possible hire.

The first effort for this donation was in 2008 with a 6-stage compressor that was previously in service aboard the aircraft carrier, U.S.S. Enterprise. Due to issues with declassification of the equipment this option was dismissed. The project languished for a year before

Dresser-Rand graciously offered a brand-new single stage, dual acting reciprocating compressor (**Figure 1**). The ESH-1 compressor specifications are shown in **Table 1**.

Model		Dresser-Rand ESH-1	
Diameter	6"	Max. Pressure	50 psia
Stroke	5"	Max Temp	320°F
Weight (lbs.)	~8,000	Flow Capacity (ACFM)	34
Speed (rpm)	360	Compressor (BHP)	7
Estimated value		\$90,000	

Table 1 - Compressor Specifications – Gas: air

The unit was scheduled to arrive at RIT during 2009 but it was delayed due to legal and intellectual property concerns. However, due to dedication by the company and the university these hurdles were overcome and the compressor arrived at RIT in 2010.

RIT's Multidisciplinary Design Program

The Multidisciplinary Senior Design (MSD) Program is an experience that all engineering undergraduate students are required to take during their senior year at RIT. It provides a team-based, capstone design experience where students define, analyze, design, and implement solutions through the application of skills and coursework from earlier in their undergraduate careers. The projects are intended to be open-ended and utilize talent across many engineering disciplines. The course is designed to simulate, across two academic quarters (22-weeks, MSD-I & -II), a typical design process a student would see in a "real-world" engineering environment. The projects are sponsored by a wide range of industries and government organizations.

In preparation of the planned compressor delivery in 2008, and again in 2009, two separate senior design teams (**P08452**¹ & **P09452**²) were formed and tasked with the installation and commissioning of the compressor. As mentioned neither of these units arrived at RIT. This demonstrates one of the real challenges of working with industry when in academia. The student's calendars do not get pushed back when the delivery gets delayed. However, as a faculty guide there is an attempt to coordinate industry availability and student schedules to provide a well-conceived design experience in everything from feasibility to timeline to cost. Thus, for these two teams the project was more simulated, but they did accomplish many design goals that proved valuable. While the compressor was absent the test cell that would house it was available for analysis. With the specifications of the unit they knew the mass and

dimensions for structural analysis, heat rejection needs to size the coolant system, electrical service needs for the drive motor, and even acoustical considerations for operators in the test cell. Equally important they provided a first attempt at implementing industry standard safety protocols, such as lockout/tag out on the electrical supply and hearing/eye protection.

A third team in 2010 greatly benefited from this strong foundation when the compressor actually arrived. **P10452**³ was a four engineer team tasked with the actual installation of the compressor. The following section outlines only a portion of the design process undergone by this team.

Installation & Commissioning of the D-R Reciprocating Compressor at RIT

The goal of the MSD program is to expose the students to the design process. Students typically have the urge to develop a solution to a problem, build it, and then spend an inordinate amount of time trying to make it work. The program seeks to demonstrate to them that there is a process to designing a product whether it is a white paper design or the installation of a compressor. **Figure 2** is a diagram of the journey the students take during MSD-I and illustrates a typical design process as often seen in industry.

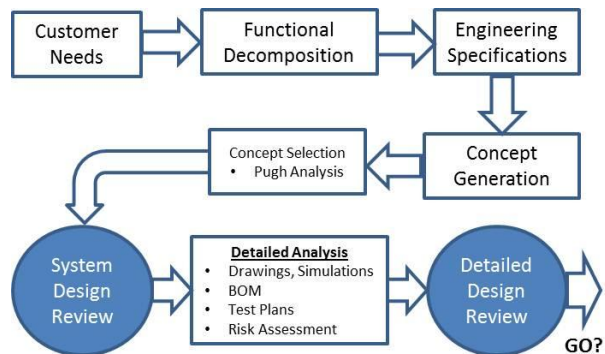


Figure 2 - RIT's MSD Phase I Design Process

The process starts with *Customer Needs*. In this case the needs are easy to interpret. Install the compressor in the test cell and ensure safe operation. (There were others such as install preliminary measurement capability to baseline the compressor operation at beginning-of-life).

Next, is the *Functional Decomposition* of each need (**Figure 3**). The blocks to the right indicate all areas that require addressing by the design. This helps the students break an unwieldy problem into more manageable subprojects. It also aids assigning tasks to different engineers and provides a sense of ownership.

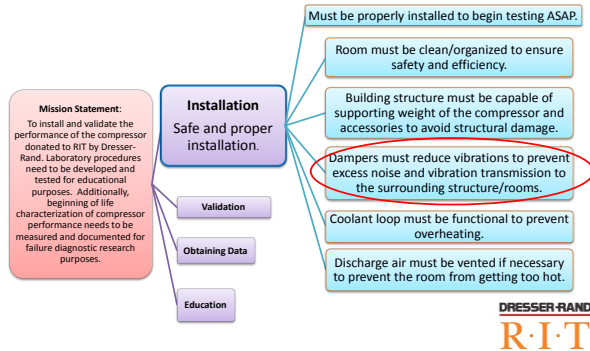


Figure 3 - Functional Decomposition of the Installation Need

Engineering Specifications are where students attempt to convert often “soft” requirements from the customer into hard and testable values. They derive each engineering specification from a specific list of customer needs and assign a relative level of importance based on customer interaction. This results in an acceptable range, or nominal value, that must be testable at the conclusion of the project. If the specification cannot be tested, or requires extensive effort to test, then there should be push back by the design team to determine the origin of the customer need and if it can be clarified or modified.

For this example, one of the six functions identified as part of the installation of the compressor was vibration suppression (circled in **Figure 3**). Through interviews performed by the team with technical experts at D-R there were concerns expressed regarding potentially damaging vibration due to the inertial effects of the motion of the unbalance mass during the operation of a single-stage compressor. Since the compressor sits on a reinforced 6-inch concrete slab above a basement the vibration transmission to the floor could be damaging to the structure of the building. It was decided that a vibration engineering specification of transmissibility less than one would be necessary.

This forced the team to make a very important decision. The previous year’s team that simulated the installation of the compressor hired a professional engineer to do an analysis of the arrangement. The PE took into account the mass of the unit and the associated vibration to make a determination that while two steel beams needed to be placed in the ceiling of the basement below the compressor additional vibration dampening was not needed. However, the team elected to add an extra level of safety, and design a vibration mitigation strategy. This was not an ethical decision by the team because they had the correct analysis done. It was a decision based on cost. The project had the financial support to purchase the additional hardware necessary. While this was mild instance of engineering

economics it did show the team that extra safety and available funding can trump engineering analysis.

The decision to implement a vibration mitigation strategy necessitated the next phase of the design process, *Concept Generation*. During concept generation the students are encourage to brainstorm as many ideas as possible since the first one is often not the optimal one. **Table 2** illustrates only a partial list of the ideas generated. The Pugh Analysis technique for *Concept Selection* shown is used in Six Sigma projects to compare the benefits of alternative solutions.

Criteria	Weights	Concepts				
		(Reference) Bolt directly to floor	Place on top of cement slab and rubber mat - no bolts	Mount to LORD vibration dampers	SLM Machinery Mounts	Mount with shocks/springs
Dampen vibrations transmitted to floor	9	0	1	1	1	1
Clear building structure in basement	1	0	1	0	0	-1
Secure compressor to floor	9	0	-1	0	0	0
Easy to install	1	0	0	-1	-1	-1
Durability of Unit	3	0	1	1	1	1
Reduce Noise	3	0	1	1	1	1
Relatively Low Cost	3	0	-1	1	-1	-1
Support Weight of Compressor	9	0	0	0	0	0
Sum -'s		0	4	4	3	3
Sum 0's		8	2	3	3	2
Sum +'s		0	2	1	2	2
Net Score		0	4	17	11	10
Rank		7	5	1	2	3

Table 2 - Concept Selection (Pugh) Mounting System

From this analysis the passive lattice-style mounts are the most effective solution. It is expected that prior to the system design review, or definitely before the detailed design review, that a detailed analytical analysis be performed to prove that the engineering specification likely will be met.

The *System Design Review* is the most important “gate” the students pass. It is a multi-hour presentation to the customer and technical experts (D-R engineers, RIT faculty discipline experts, etc.) as to the design approach from *Customer Need* to *Concept Selection*. This gate review allows for push-back by the customer or the request for clarification by the technical experts.

The *Detailed Design Review* follows (a brief 3-weeks later for RIT’s MSD program) to present a “Go or No Go” design solution to meet all customer needs. If the design is approved MSD-I concludes and MSD-II initiates for the second 11-week quarter focused on executing the fabrication and test portion of the project. For the compressor mount example **Figure 4** shows the conceptual CAD design and the final installed lattice mount.



Figure 4 - LORD Vibration Isolation Mount: (left) CAD design, (right) actual

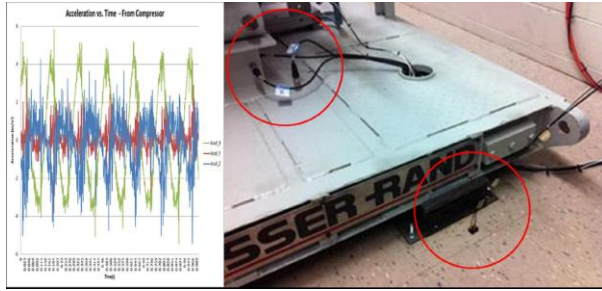


Figure 5 - Test Validation of Transmissibility

MSD-II tends to be the more exciting of the two quarters for the students because they get to see their design come to fruition. Hopefully they understand the importance of the design process that led them to this solution. Once the design is implemented testing for compliance with the engineering specifications begins. For the vibration mount example this means demonstrating transmissibility between the compressor and the floor is less than one. **Figure 5** shows placement of two tri-axial accelerometers with measurement data. The largest transmissibility ratio measured was 0.028 in the vertical direction at the operating frequency of 6Hz which concurs with analytical results.

There is a final design review at the conclusion of MSD-II to demonstrate the design/prototype to the customer and show that the needs have been met or the gaps identified.

Beyond the Installation

The following is a list of accomplishments achieved in less than one year since the commissioning of the compressor.

1. The team (**Figure 6**) proudly demonstrated the technology and their efforts at RIT's annual innovation and creativity festival, IMAGINE RIT, in May 2010 with an estimated attendance of 30,000.
2. An independent study developed an educational vibrations lab.
3. Two members of the team took employment with D-R in their Accelerated Management Program.
4. A RIT coop student during the summer of 2011 designed and installed a rack mounted DAQ system with 16 AI and 16 thermocouple channels.
5. Two new senior design teams for academic year 2011-12 were funded by Dresser-Rand.
 - a. **P12452**⁴ - Design of a vibration dampening system to reduce longitudinal motion by 50%, and the design of a pumpless thermosiphoning coolant system (4 Engineers)
 - b. **P12453**⁵ - Installation of instrumentation and a donated D-R Envision™ Health Monitoring DAQ system valued at \$45,000. (3 Engineers)

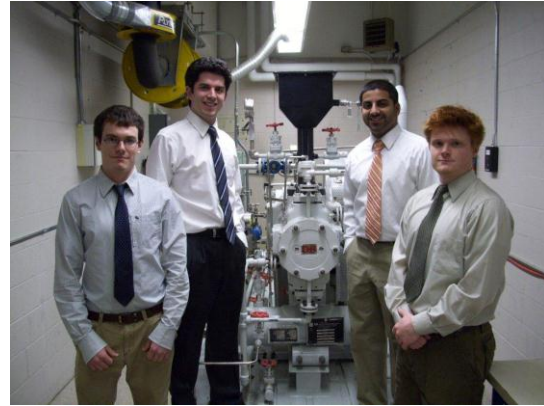


Figure 6 - 2010's MSD Team with the Compressor (E. Kendall, J. Blamer, P. Bagchi, M. Purvis)

6. Two members of this year's teams are continuing with graduate research (and Dr. J. Kolodziej) on health monitoring techniques for crankcase bearings and discharge valves for reciprocating compressors. Both projects have been proposed to D-R for 2012-13.

It is evident from the continued commitment from Dresser-Rand⁶ and the strong support of RIT the collaboration between industry and academia will be fruitful for years to come. It is truly a "win-win" in that RIT provides a "real-world" experience for its students through laboratories of fundamental undergraduate courses, coop experiences on campus, future MSD team projects, and graduate level thesis topics. In exchange D-R can identify engineers with experience on their equipment for potential hire, as well as, state-of-the-art research leading to valuable intellectual property to be implemented on their compression equipment.

Acknowledgement

In addition to the effort by the authors many others have contributed to the success of this program. A special recognition is given to the following: student members of all the compressor MSD teams; Lord Corporation for the donation of the vibration isolation lattice mounts; and many from Dresser-Rand and RIT that made this compressor donation possible.

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