Ferdinand Freudenstein

Bernard Roth

Bernard Roth did his graduate work at Columbia University, where he was Professor Freudenstein's second PhD graduate. He has had a long career as a professor of Mechanical Engineering at Stanford University. Currently he is the Academic Director of the Hasso Plattner Institue of Design at Stanford, which is commonly known as 'the d.school'.

The Freudenstein equation, appearing for the first time in the doctoral dissertation of Ferdinand Freudenstein in 1954, is widely acknowledged to be a turning point in modern analytical kinematics. Professor Freudenstein (1926–2006) during his long career at Columbia University, together with his students, made outstanding research contributions in almost all areas of kinematics and mechanisms, and his direct and indirect influence can be readily seen in teaching, research and industrial practice in the area of mechanisms and machines. In this article the life and work of Ferdinand Freudenstein is revisited.

Introduction

Ferdinand Freudenstein is considered the father of modern kinematics in America. He made his mark early in his career with his PhD dissertation in which he developed what is known as *Freudenstein equation*. Over a 42-year career as a professor at Columbia University in New York City, he and his students produced outstanding research results in many areas of kinematics. Many of his PhD students went on to be distinguished professors at other universities, and they and their students educated several generations of new engineers, researchers and professors. At the time of his death in 2006 there were over 500 academic descendents belonging to the Freudenstein family tree. As of this date, there are six generations of academic descendents actively working in kinematics and related areas. The list of names, which is certainly incomplete, was at almost 575 in June of 2010. The list continues to be updated and can be found at http://my.fit.edu/~pierrel/ff.html. His progeny are teachers in many different countries, and his research results have shaped the teaching and practice of mechanism and machine theory throughout the world.

Keywords
Kinematics, mechanisms, linkages.

Kinematics

Kinematics is the study of the geometry of motion. Anything that moves has kinematic properties. If we measure the position of anything and its change of position, we are measuring kinematic properties. In today's world kinematics is important in the design and development of a huge variety of machines and living systems (for example robots, cars, trains, planes, satellites, bicycles, electro-mechanical devices, medical devices, toys, manufacturing equipment, construction equipment, people and animals). In the study of machines the application of kinematics is often encapsulated into a broader study known as mechanism and machine theory. In addition, since everything in our universe is moving, the study of how things move is in some way related to all fields of human endeavour and all aspects of the natural universe. Outside the realm of machines, we find great interest in studying the folding of proteins, the motion of gases, the flow of oceans, the movement of tectonic plates and other natural systems. Freudenstein's work was mainly framed to be applied directly to solid objects that make up classical mechanical systems and in particular the study of linked mechanisms. However, many of his descendants have taken his basic ideas into new areas of interest such as mechatronics (particularly robotics), micro-electro-mechanical (MEMS), biochemistry and bioengineering.

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Before Freudenstein, the research in mechanism kinematics in the United States of America (USA) lagged behind that in Europe (especially in Germany and Russia). He came along at just the perfect moment, when digital computers were first becoming available in universities and large corporations. He pioneered a movement that brought mechanism kinematics, which was still languishing in more-or-less the form developed in the 19th century, into a vibrant analytical and computational form appropriate to the modern era. Among his many contributions one can list:

- The modern basis for the kinematic design and analysis of mechanisms that move in two and three-dimensional spaces.
- Application of graph theory to the creative design of mechanisms.

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- A theory for the design of high-speed mechanisms.
- The introduction and application of sophisticated mathematical methods to mechanism design (e.g., Boolean algebra, optimal control theory, quaternions, dual numbers).

For a complete list of his hundreds of specific contributions, please see the extensive bibliography given in [1].

Youth

Freudenstein's personal life had full measures of both adversity and success. He was born into a comfortable life in Frankfurt am Main, Germany, on May 12, 1926. His father, George Freudenstein, was a creative and successful merchant and his mother, Charlotte Rosenberg, was from a family of prominent art experts and historians. His early life was full of family and community support, but in 1936, at age 10, he was forced to flee with his family from the Nazi generated anti-Semitism that was sweeping Germany. The family fled to Holland. However that soon proved unsafe, so after a short time they moved on to England. They lived in London during the blitz, moved briefly to Cambridge, and then spent several years in Llandudno, North Wales. During this period his family was split up. It was due to one of the many ironies resulting from World War II. When England and Germany went to war in 1939, his family members were classified by the British as enemy aliens and as a result the adult males, his father and older brother, were sent into exile in Australia.

Early in 1942, he with his mother and two sisters left Wales, on an old British cargo boat, for Trinidad. From there, after some delays, they were able to reach New York harbor in March of 1942. Ferdinand had a high school equivalency certificate from Wales and was able to enter college at New York University (NYU). He spent two years studying there and then, at age 18, joined the US Army. He was in the Army for about a year and a half, during which time he was able to graduate from the Army Specialized Training Program in Engineering, at Texas A&M

University. His Army service entitled him to the benefits of the 'GI Bill' which provided financial assistance for his study toward his first advanced degree in mechanical engineering: an MS from Harvard University. Ironically, although he was later to serve Columbia University as a highly honoured professor for 42 years, he was rejected when he applied to study there for his MS!

As a young man, Ferdinand was a fine pianist and an accomplished player of the xylophone. He also was a good tennis player and enjoyed athletics. He had unusual powers of concentration that allowed him to concentrate on his studies even under the adverse conditions that accompanied the family's long transition from Frankfurt to New York. Ferdinand's father had wanted his son to join him in business, but Ferdinand had a desire to be a pure mathematician; mechanical engineering was a family compromise.

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Choice of Specialty

After receiving his MS, Freudenstein worked as a Development Engineer in the Instrument Division of the American Optical Company in Buffalo, New York. He was there for approximately two years, and then left to study for his PhD at Columbia University. This work experience helped to solidify a strong youthful fascination with machines. Later in life he recalled having had a very early interest in machines and mechanisms. He always remembered an experience from when he was about 12 years old: "I recall being fascinated in a London movie house by the Charlie Chaplin film Modern Times. It was a devastating satire on industrial life and one scene, in particular, captivated my mind. It showed Charlie, a hapless factory worker, being sucked into the mechanism of a huge machine and being moved about in a prone position by enormous turning wheels. For weeks after that movie, I dreamed about Charlie moving around in that machine." His long-time interest was further stimulated by subsequent summer jobs as a development engineer at Ford Instrument and American Machine and Foundry, and as a Member of Technical Staff, at Bell Laboratories.

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Freudenstein

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At Columbia University he encountered one major obstacle: there was no one on the faculty who did research in kinematics of mechanisms. Fortunately, Professor H Dean Baker, a specialist in combustion, agreed to be Freudenstein's thesis supervisor, and to allow him to work on mechanism kinematics, even though Baker himself knew very little about the subject. For the rest of his life, Ferdinand was extremely grateful for what he considered as an act of great kindness and generosity on Baker's part.

Early Achievement

After Ferdinand received his PhD, he was appointed to an assistant professorship in Columbia University's Mechanical Engineering Department. His career up the academic ladder was meteoric. In less than three years he was promoted to Associate Professor. Then one year later he became the Chairman of the Department of Mechanical Engineering, a post he held for six years. After only two years as an Associate Professor, he was promoted to the rank of Professor (1959).

In the same year, at the age of 33, he married Leah Schwartzchild. Their first child, David, was born on February 3, 1961, and their second child, Joan, was born on February 6, 1964. The young family took up residence in the Riverdale section of the Bronx, where they purchased a comfortable three-story brick house on a quiet residential street. Ferdinand lived in that house for the rest of his life.

At the end of the 1950's and the beginning of the 1960's, Ferdinand's Kinematics Program at Columbia started to get world-wide recognition. It became known as the best place to study mechanism kinematics in the United States. He attracted prominent colleagues from abroad, some of whom he collaborated with on research projects.

Loss and Adjustment

In the midst of all Ferdinand's professional success, tragedy struck when his wife Leah died in May 1970. This created a huge

challenge for Ferdinand who had not had any real experience with domestic details such as cooking and running a household. Fortunately, he was a quick learner. For the next ten years, he ran the household and was both mother and father to his children. At the same time he remained a highly productive and world-renowned Columbia professor.

In May 1980, ten years after the death of his first wife, Ferdinand married Lydia Gersten. Lydia was a teacher who was widowed, had grown children and was caring for her elderly mother. Lydia and her mother moved into the house in Riverdale. Lydia took over the domestic management of the household, and became a close and loving partner in Ferdinand's life. Over the next years, Ferdinand's children grew up, Lydia's mother died, and Lydia and Ferdinand became the sole occupants of the house. Their marriage flourished for nearly twenty-six years, until Ferdinand's death, and was the great gift in the last half of his life.

Two years after he re-married, Ferdinand was made Stevens Professor of Mechanical Engineering. He held this chair for two years, and then in 1985 was made Higgins Professor, a chair which he held until his retirement. In addition to these honors, he was elected as a member of the prestigious National Academy of Engineering, an Honorary Member of International Federation for the Promotion of the Mechanism and Machine Science (IFToMM) and a Fellow of the New York Academy of Sciences; he became an Honorary Life Fellow of the American Association of Mechanical Engineers (ASME). He accumulated a long list of other awards for his research and teaching.

Throughout his career Ferdinand was involved as an industrial consultant. He very much valued these contacts and the insights they afforded into 'real-world' engineering problems. His main consulting activities were with Bell Telephone Laboratories, Designatronics, IBM, The Singer Company, Foster Wheeler, Gulf and Western, and General Motors. The General Motors consulting activities went on for over fifteen years. Several of his consulting activities led to technical publications in the open

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literature. In addition, he served as an expert witness on several cases involving engineering issues.

Personal Characteristics

Ferdinand Freudenstein was a kind and soft-spoken individual. He was extremely modest. He avoided controversy and academic politics. He was an accessible professor, and was always pleased to assist his professional colleagues at Columbia and throughout the world. He was rather informal, and often signed his letters F.F. or F^2, and suggested his PhD students call him F^2 (pronounced *ef-square*).

His benevolent influence was felt, both directly and indirectly, by practically everyone who taught or did research in the field of kinematics for machines and mechanisms. He wrote a great number of evaluation letters for his many students and their academic descendants, as well as for individuals whom he knew primarily through their research publications. Because of his prominence, many people sought to use him as a reference, and the letter writing became a great chore, but he felt it was his duty to the profession and he undertook it without complaint.

He was an unusual mix of being very theoretically oriented and yet be very concerned about real-world practical applications of his work. At heart he loved mathematics and mathematicians. The highest compliment one of his research students could get from him was being told "you think like a mathematician". He could easily read technical material in German, French and Russian and spent a lot of time in the library reading mathematics books and journals. One amusing incident came from his library habit. A student had given him a handwritten draft of a PhD thesis to review. It was before computers were in wide use for typing theses, so this was the only copy. At one point Ferdinand could not find the draft and he expressed his great concern to the student. The student was not at all disturbed thinking that Ferdinand, out of guilt, would author a far better replacement. After the second day Ferdinand went back to check around his

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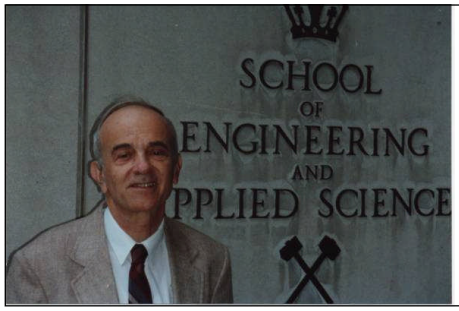
usual seat in the library. He could not find it and Ferdinand kept getting more disturbed while the student seemed to be getting more pleased at the prospect of Ferdinand authoring a replacement. It eventually turned out that it was indeed left in the library, but the librarian had neglected to tell Ferdinand. It ended happily: the student graduated content with his original mediocre work and survived to write this article.

His Influence on Kinematics and Beyond

An interesting event occurred at an American Society of Mechanical Engineers (ASME) meeting in San Francisco in 1972 where Freudenstein's was the scheduled luncheon speech. At one point, as part of the introduction the moderator requested: "all the people in the room who are either part of the Freudenstein academic family tree or feel that their work has been strongly influenced by their relation with him please rise from your seats." At that moment, almost all of the approximately two hundred people in the room rose to their feet. Similar requests were made subsequently at other meetings over the years, and the results were the same. It always created a powerful emotional response to witness this physical demonstration of Freudenstein's great influence on the field.

The Latter Years

In 1991, on the occasion of Ferdinand's 65th birthday, Professor Arthur Erdman, a Freudenstein academic grandchild, organized a conference in Brainard, Minnesota. The event produced an exceptional book titled *Modern Kinematics*: *Developments in the*



Ferdinand Freudenstein at Columbia University shortly before his retirement.

Last Forty Years [2]. The conference was an academic family reunion, filled with excellent science and engineering. Ferdinand and Lydia enjoyed it tremendously.

The following year Ferdinand was awarded the coveted Egleston Medal for distinguished engineering achievement from Columbia University. However, soon after that he started to show signs suggestive of Alzheimer's disease. His once brilliant and incisive mind was starting to forget, and in normal conversation he often repeated himself without realizing he had done so. Ferdinand was able to keep up his work and teaching at a reduced scale until in 1996, at the age of 70, Ferdinand retired from his position at Columbia University with the title of Higgens Professor Emeritus.

Ferdinand had always planned to write a definitive book on mechanism kinematics after he retired from teaching. This pleasure was denied to him by his illness, and is a great loss to the world. His illness progressed slowly and he was able to maintain his family life for several years after retirement. Inexorably, however, his difficulties became progressively more debilitating. Throughout his illness he was cared for at home by his wife Lydia, who devoted her entire attention to his care and comfort. He passed away peacefully in his Riverdale home on March 30, 2006.

Address for Correspondence
Bernard Roth
Mechanical Engineering
Department
Stanford University, USA
Email:broth@stanford.edu
roth@robotics.stanford.edu

Suggested Reading

[1] **Bernard Roth, Ferdinand Freudenstein (1926-2006), in *Distinguished Figures in Mechanism and Machine Science: Their Contributions and Legacies*, Marco Ceccarelli (Editor), Springer, 2007.**

[2] **Arthur G Erdman (Editor), *Modern Kinematics: Developments in the Last Forty Years,* John Wiley & Sons, 1993.**