Biography: Professor Dr. Hasan Padamsee

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A Century of Smashing Atoms: Particle Accelerators, the Engines of Discovery

By:

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Professor Dr. Hasan Padamsee

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Introduction and Background:

Distinguished Professor Dr. Hasan Padamsee, **the recipient of the 2015 Robert R. Wilson prize for outstanding achievement in accelerator science**, was born and grew up in Bombay (present day Mumbai), India. His father was a wholesale glass ware sales person and mother was a homemaker, belonging to the Khoja (AgaKhani) Muslims community, and were very religious, according to Prof. Padamsee [1]. When he was a child, he had an interesting experience of being invited by one of his favorite English teachers, along with his friends, to his house to listen to a recording of Pygmalion and discuss life. This event made an enduring impression on his young mind and sparked his interest in studies, and even helped develop an interest in writing his own plays. Prof. Padamsee credits discussions with and explanations by his elder brother about major developments in physics such as Einstein's relativity as one of the main motivators for him to study Physics.

He attended St Mary's School and St Xavier's College in Bombay. In 1964, he was admitted to Brandeis University near Boston with a full scholarship under the Wien International Students Program and received his BS in Physics in 1967 [1]. He then started his PhD at Northeastern University, Boston, Massachusetts under Professor Carl A. Shiffman, specializing in solid state physics, and graduated in 1973 [2][3][4]. He published a paper titled “Quasiparticle phenomenology for thermodynamics of strong-coupling superconductors” along with Prof. Shiffman, launching a highly successful career in the field of superconductivity and particle acceleration [5].

When he finished his graduate degree, there was not a very high demand for physics PhDs at that time. While searching for jobs, he was temporarily offered a post-doc at the University of Lausanne in Switzerland. He also put his resume in the Physics Post-Doctoral Pool, hoping to get a position from a university or company. He explains how he got recruited by Cornell University in this uncertain phase of his career [1]:

“It was lucky at this time to have a job. But the word was that the supervisor was eager to grab credit for other's work. So I was hesitant to move my family to Europe. The main worry was whether I would be able to land a job in the US after I returned in 2 years? Then I got a surprise call from Cornell University Wilson Synchrotron Laboratory from a Professor McDaniel, who was the head of the Laboratory. (I later found out that McDaniel worked with Robert Wilson and Bethe on the Manhattan Project). He wanted to interview fresh PhDs with some knowledge about superconductivity. (I often tell the apocryphal story that he was looking for anyone who could spell the word!). His group was looking to develop superconducting microwave cavities to increase the energy of the synchrotron from 12 GeV to 25 GeV. I knew absolutely nothing about synchrotrons, particle accelerators and even less about microwave cavities. I had a week to go to

Ithaca (I mistakenly thought at first it was Utica!) for an interview. I dug up all the literature I could get my hands on from the library, including what was going on at Stanford (HEPL) and at Cornell. I learnt about some of the major issues and of course some of the buzz words. Luckily I also learned that the best performance came from cavities that were treated in an UHV furnace at 1800 C furnace (expensive). It was the first time I flew in 10 years (after my flight from London to Boston in 1964). The main person interviewing me was Dr. Maury Tigner, who kindly asked me to explain what my PhD was about. I must have given an understandable explanation because he asked some good questions. Then he casually asked me if I had any questions about the job. I immediately asked him if Cornell had an UHV furnace, because I thought that was the best way to get good cavity performance. (I was shooting in the dark.) I think I must have knocked him off the chair, because he and McDaniel were just discussing whether they should invest in such an expensive piece of equipment, and whether the heat treatment really did anything good. I don't remember the rest of the discussion. But when I returned to Boston, I got a call the next day from McDaniel, telling me they wanted to offer me the job!!! And that's how I got into particle accelerators."

While Prof. Padamsee is humble in narrating the story of how he entered this field, his initial research on heat treatment and related topics he had quickly done in preparation for this interview shaped a large part of his career and led to many of his most important contributions in this field.

Career Summary:

Upon graduation with his PhD from Northeastern, he joined Cornell University in 1973 as a research associate. One of the key turning points in his career came when the SRF group at Cornell, consisting of about 10 scientists, were recruited by the Continuous Electron Beam Accelerator Facility (CEBAF) at the Jefferson Lab to go to Virginia. Most of them accepted the offer, and Ron Sundelin, the leader of the group, was going to be the leader at CEBAF. Prof. Maury Tigner, the previous leader, had already left to lead the Superconducting Super Collider (SSC), and Prof. McDaniel already stepped down. Prof. Padamsee was offered a 50% raise to join as well. If he remained at Cornell, he would have been the only scientist apart from Joseph Kirchgessner, an important engineer with the SRF from the 1970's to 1987, and who chose to remain at Cornell. In making this important decision, Prof. Padamsee recounts [1]:

"The most difficult question in my mind was whether Joe and I could accomplish anything significant, given all the firepower had gone. I thought about it long and hard. To make a long story short, I followed the maxim: 'It is better to be the only fish in a small pond, than to be a small fish in a big pond.' Our new director Prof. Karl Berkelman really wanted me to stay because he believed that soon SRF would make a big contribution to improving the luminosity of Cornell Electron Storage Ring (CESR). CESR was the leading accelerator studying the newly discovered B-quarks. I agreed to stay knowing that Karl would support me, and he did in many ways as time went on. **The rest is history**."

Indeed, and we will explore that history further.

As a Cornell physics researcher, he worked in superconducting radio frequency (SRF) science and technology for applications to a wide variety of particle accelerators, and contributed forty years of research to the field of superconducting radio-frequency cavities. He was the project leader of the Superconducting Radio Frequency Group, pushing the advancement of accelerator technology for particle physics at the energy and luminosity frontiers. He also taught "Physics of the Heavens and the Earth" during spring semesters at Cornell University. He remained a part-time researcher and lecturer in physics until 2014, when he retired [6][7].

Throughout his career, Prof. Padamsee collaborated with many accelerator laboratories around the world, including the three acclaimed Department of Energy (DOE) national accelerator laboratories (Fermi National Accelerator Laboratory - FNAL, Thomas Jefferson National Accelerator Facility, and the SLAC National Accelerator Laboratory at Stanford University), the European Organization for Nuclear Research (CERN) in Geneva, Switzerland, which houses the Large Hadron Collider (LHC), the world's largest and most powerful particle accelerator, and Deutsches Elektronen-Synchrotron (German Electron Synchrotron DESY), one of the world's leading accelerator centers.

Key Scientific Contributions:

Prof. Padamsee's major scientific contributions to SRF include understanding the nature of thermal breakdown and curing it by using pure Niobium (Nb) with a high resistivity ratio. The most advanced methods in the early 1980s were only able to achieve a maximum accelerating gradient of about 5 MV/m, even with solutions for the multipacting problem that used a spherical/elliptical shape. He understood that this minimal gain was due to the breakdown of superconductivity at defects. Superconducting cavities spontaneously become normal conductors above an RF magnetic threshold. Imperfections such as contamination on the RF surface carry RF current by induction and heat up, so the temperature of the superconductor surrounding the defect rises. When it reaches the superconducting critical temperature, RF losses around the defect increase substantially, leading to thermal runaway and a "quench" of superconductivity over a large region. Getting rid of these imperfections, especially at a very large scale, is impractical. So, the best way to mitigate thermal breakdown is to use Nb with a higher thermal conductivity, which can be achieved through higher purity Nb [1].

Before 1984, the residual resistivity ratio (RRR), a measure of thermal conductivity, of commercial grade Nb available was between 20 and 30. Prof. Padamsee engaged in early efforts with Fansteel, an Nb producer, and Ames laboratory to improve the RRR of Nb. They used an improved ingot melting practice and were able to improve the RRR to 100 using 3-4 melt processes. Fansteel was then able to consistently produce Nb sheets of RRR 80 – 90. However, to reach even higher purity levels, the quality of the furnace vacuum had to be improved, rather than adding additional melt cycles. He then collaborated with the Wah Chang Corporation to achieve this, and was successful. Now, suppliers, who still use the methods of multiple and slow melting refined by Prof. Padamsee, are able to produce niobium sheets with RRR of 250 – 400. The higher RRR this process produced allowed for accelerating gradients to rise to about 10 MV/m, twice than before! Beyond this, the main limiting factor to higher gradients became the field emission of electrons. Gradients of even 25 - 30 MV/m have been achieved with RRR of

500- 600 if field emission did not take over. Later discovery of electropolishing (EP) and baking brought down the need of RRR to about 300 [1].

Prof. Padamsee's solution has led to significant improvements in the quality of niobium and performance of SRF cavities. Prof. Sergei Nagaitsev, head of Accelerator Science Programs at Fermi lab, acknowledged that "Without his contributions, SRF technology would not be ready today for the most modern accelerators that are under construction and development" [8].

In other efforts to obtain high RRR Nb for cavities before the industrial approach had matured, Prof. Padamsee patented his invention in the United States in 1984, named "PURIFICATION OF NIOBIUM". It is a method of purifying Nb containing an impurity having a significant diffusion rate above about 1000° C. It accomplishes this by depositing, through vapor, a film of yttrium (Y) on the surface of the Nb. The Nb is put in a vacuum with pressure greater than about 10^{-4} torr and at an elevated temperature above about 1000° C, preferably 1200° C to 1400° C, for a time sufficient to cause the impurities to bind with the yttrium film [9]. Specifically, this method removes oxygen well and to a lesser extent, nitrogen.

Using yttrium as opposed to titanium for the process allows for purification to happen quicker, at lower temperatures to get the same effect. When the purification process is complete, the yttrium film and yttrium oxide layer produced on top can be removed with nitric acid. The niobium surface can be further treated to remove a few micrometers or more of niobium for more surface sensitive applications [10]. Prof. Padamsee's method has several other advantages as well. Since relatively lower temperatures can be used to get the same effect, there is less risk of deformation in the Nb. Also, the vacuum requirements are not as strict with this method, allowing simpler technologies like diffusion pumped furnaces to be used. This process can be used with other purification processes like decarburization to further improve the purity [11].

Using another method, UHV degassing at 2000°C, he was able to purify 1'' diameter cavities, and obtained RRR values up to 1200 – 1400. The test results from these cavities verified that higher RRR valued Nb leads to higher quench fields [1].

Other Significant Scientific and Academic Contributions:

Prof. Padamsee joined CERN as a visiting scientist for one year in 1980-81, conducting research on composite Niobium on Copper, and dissecting cavities to analyze the nature of defects that cause quench. Later at Cornell he launched in 1990 the TeV Energy Superconducting Linear Accelerator (TESLA) which morphed into the TESLA collaboration headed by DESY, and subsequently into the International Linear Collider (ILC). After teaching SRF courses extensively at the U.S. Particle Accelerator School (USPAS) and CERN, he authored two widely used text books in SRF published by Wiley [7][12].

The first Book, "**RF Superconductivity for Accelerators**", co-authored by his students Jens Knobloch and Thomas Hays, was originally published in 1998. It introduces some of the key ideas of RF Superconductivity, and presents a comprehensive overview of the field. The book covers the basic concepts of microwave cavities for particle acceleration, with a summary of the historical foundations of radio frequency superconductivity, and the fundamentals of superconductivity and the electrodynamics of superconducting surfaces. It describes in detail the observed behavior and performance of superconducting cavities, a cavity fabrication technology, illustrating the interplay between theory and practical technology. General issues connected with beam-cavity interaction and related critical components are also covered that are of great interest to those concerned with the detailed technology of superconducting accelerating cavities. Finally, the book discusses applications of superconducting cavities to frontier accelerators of the future. It covers the application of superconducting cavities to high-current storage rings (so-called B factories), to intense proton accelerators for pulsed neutron sources and nuclear waste transmutation, and to high-energy linear colliders. Prominence is given to the attractive features of the superconducting TESLA (TeV Energy Superconducting Linear Accelerator) collider proposal, which he initiated. The highlight of the book is its explanation of multipactor and field emission. It is highly useful for those working in the high-gradient frontier because these effects are also prominently observed in room-temperature copper accelerating structures and other RF components operating at high field level [13][14][15].

"RF Superconductivity: Science, Technology, and Applications", is the second book on RF Superconducting, written by Prof. Padamsee and published in 2009, by which time he was widely recognized as one of the leading experts in this field. This book highlights the latest advances in the key technology for future accelerators. It discusses the fundamentals as well as recent developments and promising future applications, and is useful for newcomers and experts. Researchers in accelerator physics will also find much that is relevant to their discipline. The book covers topics including new cavity geometries, RF surface resistance and critical fields, multipacting and field emission, and tuners. A wide range of interesting future applications are discussed, including next generation light sources, energy-recovering electron linear accelerators (called energy-recovering linacs, or ERLs) for nuclear physics, nuclear astrophysics, high-intensity proton linacs, and the ILC [16][17][18][19].

Since the early 2000s, Prof. Padamsee has published several papers and gave presentations describing the state of the art of SRF technology, potential applications and promising future developments, providing expert guidance to researchers and scientists.

In 2001, Prof. Padamsee published a topical review on "The science and technology of superconducting cavities for accelerators", in the Superconductor Science and Technology journal by the Institute of Physics Publishing [20]. He describes that rapid advances in the performance of superconducting cavities have made RF superconductivity a key technology for accelerators in a wide variety of related fields, including high-energy particle physics, nuclear physics, neutron spallation sources and free-electron lasers. The review describes the progress in understanding the gradient and limitations in superconducting cavities, and new techniques developed to overcome them. Significant progress has been made in reducing the spread in gradients arising from the random occurrence of defects and emitters due to new ways of treating the cavities. He states that it is important to aim for higher RRR in large-area cavities, where there is a high chance of defects and contamination. High-pressure rinsing greatly reduces the number of field emitters. High Pulsed Power RF Processing (HPP) destroys accidental field emitter contaminants. This technique will be necessary to achieve the high intrinsic gradient potential of SRF cavities.

In a presentation given to the US Department of Energy Office of Science in 2008 [23], Prof. Padamsee described new advances and theories in the field of particles acceleration and noted that the predictions by the “Eilenberger (BCS) Theory” gave hope for achieving approximately 120 MV/m for perfect Nb_3Sn and 200 MV/m for perfect MgB_2. However, he believes this is not the right path to follow for the next generation of accelerators, due to the complexity of the new materials. Instead, he holds that 40 – 60 MV/m can be achieved with Nb, and predicts 65 MV/m can be achieved in the near future with the best shaped cavities [1][24][25].

At the IPAC'15, the sixth International Particle Accelerator Conference, sponsored by the Institute of Electrical and Electronics Engineers (IEEE), the American Physical Society (APS) and hosted by Thomas Jefferson National Accelerator Facility (Jefferson Lab), Prof. Padamsee gave a talk on “SRF Accelerators Flourish In a Golden Age – Past, Present and Future Success of SRF” [26][27]. He placed SRF science in historical as well as philosophical context, discussing the fifty years of advances in SRF science and possibilities for the future.

He predicts that the most significant discovery in this field in the future and its impact and applications as follows [1]:

“If the best procedures and best cavity geometries are used there is good evidence to expect gradient to rise to 65 MV/m with Nb. Nb_3Sn still has a very long way to go. But everyone wants to follow their own hunches, so all this may not happen in a straightforward way. The best and most reasonably economic path is the ILC based on SRF cavities operating at 40 MV/m with future energy upgrades possible with 60 MV/m.”

Prof. Padamsee continues to be actively involved in the field, even after retiring, and participated in a colloquium at the Ohio State University in January 2019, speaking about the International Linear Collider (ILC), the core superconducting acceleration technology and the physics potential for the Higgs. He was a member of the Global Design Effort (GDE) that published the Technical Design Report (TDR) in 2013, and since then the accelerator proposal has evolved to start as a high intensity Higgs-physics machine at 250 GeV, instead of the original design energy of 500 GeV [28][29].

Prof. Padamsee has also mentored many graduate students over the course of his career. Many of his doctoral students have also made key contributions of their own within SRF fields. Some of his graduate students include; Dr. Olexander S. Romanenko, affiliated with the Fermilab [1][30][31][32], Dr. Jens Knobloch, at Berlin Electron Storage Ring Society for Synchrotron Radiation (BESSY) [1][33][34], Walter Hartung, Senior Physicist at The Facility for Rare Isotope Beams (FRIB) at Michigan State University (MSU) [1][35][36], Dr. Gregory R. Werner, who is a Senior Research Associate at the Center for Integrated Plasma Studies (CIPS) at the University of Colorado, Boulder [37][38], Dr. Grigory V. Eremeev, affiliated with the Thomas Jefferson National Accelerator Facility and now with Fermilab [39][40][41][42]. He has also mentored many undergraduate students, including Janice Wynn and Walter Hartung (also a graduate student of his), who received the Presidential Scholar Award (top 25 of the graduating class). They both named Prof. Padamsee as their mentor [1].

Recognitions:

Over his career, Prof. Padamsee has received many awards and recognitions for his contributions and influence in the field of RF Superconductivity. A select few are highlighted below.

Dr. Padamsee was appointed **Fellow of the American Physical Society** (APS) in 1993 for leadership in accelerator science through insights in applied superconductivity that have significantly improved acceleration gradients of superconducting RF cavities [43].

In 2012, he received the **IEEE Particle Accelerator and Science Technology (PAST)** awarded by the Particle Accelerator Science and Technology (PAST) committee, one of the technical committees of the IEEE Nuclear and Plasma Sciences Society, dealing with the science and engineering of particle accelerators [44].

He has won the **2012 Bakish Award** for "Best Paper presented by a researcher, scientist or engineer at this year's electron-beam conference", awarded by the Cornell Laboratory for Accelerator-Based Sciences and Education (CLASSE) for his talk "Niobium Based Accelerators for Nuclear Energy and Reducing Nuclear Waste". The Award Selection Committee chose Dr. Padamsee's paper based on the content and also for his long-standing support of the ebeam research community. [45]

In 2014 Fermilab appointed Prof. Padamsee as **Head of the Technical Division** to oversee the development of SRF for the Linac Coherent Light Source –II at SLAC, as well as for Proton Improvement Program (PIP-II) at Fermilab [7].

Dr. Padamsee has received the prestigious **2015 Robert R. Wilson Prize** for “Outstanding achievement in accelerator science” and "for his leadership and pioneering world-renowned research in superconducting radiofrequency physics, materials science, and technology, which contributed to remarkable advances in the capability of particle accelerators." [7]. Sergei Nagaitsev [46], head of Fermilab’s Accelerator Division and chief accelerator officer, who chaired the selection committee said, “The main criteria we were looking for were a high impact in both particle and accelerator physics and unquestionable respect in both communities” and “the award is well-deserved”. Dr. Padamsee acknowledged that “The people who have gotten this award in the past are people who have done wonderful things. I feel humbled to be in their company” [8].

Other Related Contributions:

Above and beyond his scientific and technical expertise in the field of physics and particle acceleration, he has made significant efforts to explain physics to students from other majors and relate it to fields in humanities. Prof. Padamsee says “I like to find ways to share the adventures of discoveries and the excitement of physics with the lay audience” [1].

To this end, Prof. Padamsee published a book “Unifying the Universe – The Physics of Heaven and Earth” that presents a non-technical approach to physics for the lay-science enthusiast. This popular textbook is intended for non-science undergraduate students taking their first physics class, and was inspired from the conceptual course he taught for twenty years at Cornell University. It relates physics and the humanities, with connections to art, poetry, history, and philosophy. The book explores how the process of scientific thought is inseparably linked with cultural, creative, and aesthetic aspects of human endeavor, exposing the readers to new ways of looking at the world. The book addresses current and exciting new topics in the field, such as exo-planets, the accelerating Universe, dark matter, dark energy, gravitational waves, super-symmetry, string theory, big bang cosmology, and the Higgs boson. It also talks about quantum physics, including quantum entanglement and quantum computing [47][48][49]. He has several YouTube videos that demonstrate many of the concepts from this book. The book has received high praise from reputable physicists, including Professors Brian Greene from Columbia University and David Lee, Nobel Laureate in physics, from Cornell.

Prof. Padamsee is also a playwright! He says “I also write plays based on science and the interesting personalities. I have written two plays which have been performed, one is called CREATION'S BIRTHDAY - A BIG BANG BEGINNING, and the other is called QUANTUM LOVERS…The second play is about Contradictions in Love and the Quantum via the Love story between Einstein and his first wife Mileva.” [1].

He published the first play via a crowdfunding campaign in Indiegogo, a platform to fund ingenious, work-in-progress products and ideas [50]. A synopsis of this enthralling play illustrates Prof. Padamsee’s interest in cosmology and macrophysics, even though he is an expert in microphysics!

This play demonstrates the clash between science and religion’s views of the origin of the universe as Edwin Hubble unlocks the mystery of creation in the early part of the 20th century. Hubble triumphs, overcoming a strictly religious father, a belittling thesis advisor, and World War I. He partners with Milton Humason, a former janitor, and Father George Lemaitre, a physicist-priest, and challenges Einstein’s claim that the universe is stable and non-expanding. They reveal the flaw in Einstein’s work, without which Einstein’s theory also leads to an expanding universe. The discovery of the Bing Bang creation brings the religion-science conflict to a climax, and Hubble reveals another major consequence: the date of creation’s birthday [51].

Summary:

As an excellent researcher in the field of solid state physics, Superconducting Radio Frequency (SRF) and particle accelerators for almost fifty years, Prof. Padamsee has created a lasting legacy through a patented key invention, a number of books including two reputable and widely used text books on RF Superconductivity for Accelerators, and many review articles in encyclopedias. He has published more than 650 papers in the field of solid state physics including more than 350 scholarly papers in the field of particle accelerators. He has presented in hundreds of reputable national and international scientific forums in this field including conferences, colloquiums, invited talks at special meetings, and others [52][53][54].

Illustrating his high-standing and legacy in this field, Prof. Padamsee has received a number of highly reputable awards and recognitions from national as well as international organizations. He has collaborated with and worked directly at the top research organizations in the field of particle accelerators in including the top three US labs funded by the DOE, Fermilab, Jefferson Lab, and SLAC at Stanford, as well as CERN, the premier international research facility in particle accelerators. At Cornell University and at several other research organizations, he has mentored a number of PhD and graduate students, who themselves have become researchers at these and other research organization, universities, and academic institutions.

Prof. Padmsee's legacy is fully highlighted by the Wilson Prize he received for "**Outstanding achievement in accelerator science**" with this citation from the selection committee: "**For his leadership and pioneering world-renowned research in superconducting radiofrequency physics, materials science, and technology, which contributed to remarkable advances in the capability of particle accelerators.**" Such words are not to be taken lightly!

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