Early Years of Commercial Cathodic Arc Vapor Deposition: Hot Deals during the Cold War

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Abstract
Much has been published over the last 30 years covering the growth and applications of commercial Cathodic Arc Vapor Deposition. From the U.S.S.R. and U.S.A., to around the globe, several methods were developed and continue to evolve, producing an incredible array of physical vapor deposition (PVD) coatings and uses.

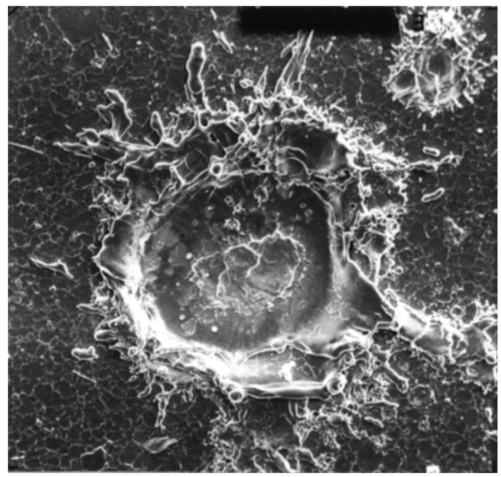
We will present a review of the devices behind Cathodic Arc plasma generation, the companies and the people contributing to these developments, early skirmishes and turf battles, along with interesting anecdotes and practices from the "old days". Among the techniques and types, we will discuss: random arc, steered arcs, point sources and large area sources that existed prior to 1986.

Keywords
Cathodic; arcs; tool; coatings; titanium; nitride; PVD; history.

Background

A history of the Cathodic Arc from the 18th century forward is well documented in the book, **Cathodic Arcs, From Fractal Spots to Energetic Condensation** [1]. The research performed at the National Science Center, Kharkov Institute of Physics and Technology in the Soviet Union (KIPT), played a primary role in developing what we know today as the PVD process of cathodic arc vapor deposition, known as Bulat technology (Sablev et al. patent) [2]. Because of the number of companies that exist today supplying cathodic arc equipment and processes, and the research that still needs to be done to present their work, we have limited the timeline to 1986.

Cathodic arc vapor deposition is based on a high current (>40 amps), low voltage (<100 volts) discharge producing fully ionized plasma that often contains multiple ion charge states. Cathodic arc ion energies are higher than sputtering or evaporation, but lower than ion implantation. Plasma is produced instantaneously from a solid cathode into metal ion plasma and is not a sputtering or evaporation process. Metal coatings can be produced using a noble gas background, or coatings (such as titanium nitride) can be produced using a reactive gas background, such as nitrogen. There are many forms of cathodic arc processes including DC, pulsed, laser and filtered to name a few.



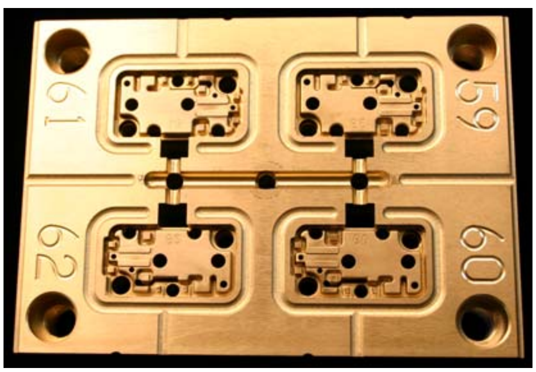
Cathode spot crater Photo: B. Jüttner

Cathodic arc plasma Photo: Multi Arc

Coating Applications

Typical uses for coatings produced with cathodic arc are: tribological applications for wear and corrosion protection of cutting tools, medical tooling and implants, plastic injection molds and components, automotive engine and transmission components, etc. Decorative coatings are produced for plumbing facets, door hardware, automotive trim and lighting, etc. These PVD coatings have saved billions of dollars in reducing wear and have greatly reduced environmental impact of waste materials by replacing hazardous wet-plating processes.

High-temperature wear/lubricity coatings: weapons. Photo: Vergason Technology



Wear/release coatings: plastic injection molding. Photo: Vergason Technology

Wear/chemically-inert coatings: medical tooling. Photo: Vergason Technology

We will review some of the smaller steps, along with the people and companies involved that moved the technology from the USSR to the US and started the commercial success.

Political Directives

During the finalization of the SALT I Agreement in May 1972, US President Richard Nixon and Soviet Premier Alexei Kosygin signed a five-year agreement between the two countries to cooperate in the fields of science and technology (also known in the US as the Apollo Soyuz Test Project or ASTP). This agreement was officially titled: Agreement Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes. One major goal of this agreement was to rendezvous U.S. Apollo and Soviet Soyuz spacecrafts in earth orbit during 1975 [3]. President Nixon's speech included the need for co-operation and reciprocation between the two countries in their efforts to conquer disease, improve the environment, and to expand bilateral trade and economic links [4]. Interesting note: Soviet Leader Brezhnev was a metallurgist.

US President Nixon and Soviet Premier Kosygin. Photo: Keystone, Hulton archive, Getty Images

Dual-Use Concerns

Of concern to both countries during the ASTP, was the potential that technology marketed as unclassified for "civilian" applications, could have a dual-use in classified military applications. An example of this, described in a paper by FBI Special Agent William H. Smits, Jr., titled Significance of the Question of High-Technology Transfer to the Soviet Union and Soviet-Bloc States, was the friction reducing "squirm drive" gear to be used in the civilian Chevrolet S-10 truck, that could also be used in helicopter rotor drives and rotary knuckles of robots. This type of dual-use put the device on an export controlled list for shipments to the USSR. Other concerns were voiced before the historic 1972 signing from the US embassy in Moscow, over the knowledge potentially gained from the space program which could be used for space-based weapons [5]. Even with all the issues of technology protection and its potential ill use, major achievements by the USSR and the US were realized, as planned, in July 1975 with the docking of the Apollo and Soyuz space crafts in Earth orbit [6].

Cosmonaut Leonov and Astronaut Stafford historic handshake. Photo: NASA

Dual-Use of Arc Technology

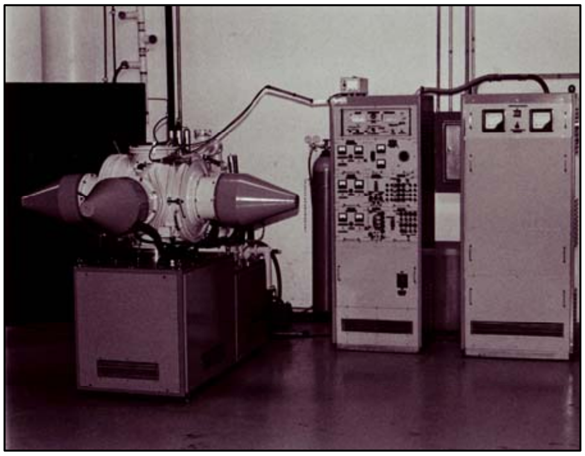
The KIPT has widely reported about the developed civilian applications of cathodic arc coatings, such as wear resistant coatings on metal cutting tools, hard coatings on materials operating in aggressive environments, coatings for machine components, etc. On page 53 in his book, author Anders mentions the mass production of Bulat-3 cathodic arc sources also being built in plants in Tallinn, Estonia [1]. The Dvigatel plant located in Tallinn was originally built for rail-car production and was developed by the USSR into one of its largest enterprises for top-secret military production. Secret Bulat technology was used to make metal and other parts extremely durable and chemically resistant at this plant which fulfilled equipment orders for the nuclear and space industries [7]. Nikolai Baibakov, the head of GOSPLAN, the State Planning Committee responsible for the economic planning in the Soviet Union, reported in the Soviet Press article "The Economic Strategy of the Communist Party of the Soviet Union (CPSU) Today", that Bulat technology was a "plasma accelerator", indicating a potential dual-use of the technology [8].

Dvigatel plant in Estonia
Photo: Abandoned Places

From Russia with Love

Joseph Filner, a US trader that worked to market metals from the Soviet Union, was told by the Soviet GOSPLAN, that he would lose his nickel and platinum selling interests if he did not buy the Bulat license. Filner set up a joint venture (JV) between his company Noblemet, and TRW's Greenfield, a US company that manufactures drill bits and similar cutting tools. The new JV, Noblefield, set up in late 1979, bought the license to bring the Bulat technology of hard, wear resistant thin film coatings for cutting tools to the US. The deal was signed on 24 December 1979 and two days later, on Boxing Day, 26 December, the USSR invaded Afghanistan which influenced TRW to pull out of the deal. Filner lamented his problems of the deal to a Control Data Corporation (CDC) executive, Robert Schmidt, in a bar in Moscow. CDC was keenly interested in the technology and entered into the joint venture with Noblefield. CDC had a business incubator in St. Paul, Minnesota where the newly formed company in August 1980, Multi Arc Vacuum Systems Inc., was to get its start. Henry Brandolf, a consulting technical advisor to Multi Arc, tested all the coated drills and found out that the drills at the outside edge of the fixture were cooler and performed extremely well. Brandolf told Filner that the technology was as advertised, and, based on three successfully coated drill bits, the Bulat technology was accepted and the rest of the license fee was paid.

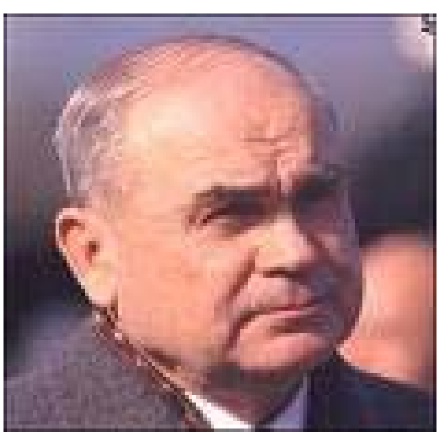
It was in the fall of 1980 that Filner contacted and hired Peter D. Flood to run and grow the company, which grew from $0 to 5 million dollars in sales by 1984. Flood estimated that the license (royalties) was paid off in 1988 with payments totaling around 4 million dollars. The original license covered only equipment sales, not coating services, which would lead to future difficulties [9].



Bulat machine Photo: Multi-Arc

High Level Soviet Political Support

Nikolia Baibakov, worked with four Soviet leaders starting with Stalin [10], and was very proud of the Bulat technology and mentioned in his 1982 report of **The Economic Strategy of the CPSU Today**, "That is why measures have been drafted sharply to increase the application of these methods, particularly the vacuum-plasma technique of applying durable coatings. Thus we plan extensively to introduce Bulat units, with a plasma accelerator based on a titanium electrode as their main working element." Author Anders reports in his book, that by the late 1980s, about 4000 cathodic arc coating systems were manufactured and in operation throughout the USSR [1].



GOSPLAN Director Nikolia Baibakov
Photo: Telegraph UK

Where Did Joseph Filner Come From?

Filner had a very interesting life. It is worth looking into the man who played a large role for bringing Bulat technology to the US.

Joseph Filner Photo: The Pittsburgh Press

Joseph Filner was born in Pittsburgh, Pennsylvania, in 1914, as son of Polish immigrants. He drove delivery trucks for his parent's bakery and became involved as an organizer for the bakers' union and later with the Teamsters, Steelworkers and other industrial unions.

In 1942, the mid point of World War II and the start of the McCarthyism period, Filner was the secretary of Pittsburgh communist party, and an Air Raid Warden Instructor in Defense Counsel Zone 2. He paid a $500 fine and spent one year in the Allegany workhouse for conspiracy and perjury stemming from the Communist election petition scandal of 1940, while pledging "I have felt it is my solemn duty to do everything in my power to serve my country."[11]

The Pittsburgh Press

This Edition Contains 9 SECTIONS A TOTAL OF 108 PAGES

Six German Armies Smash Forward; Peril To Oil-Rich Caucasus Grows

COMMUNISTS GET GO-BY ON DEFENSE OATH

HOUSE DRAFTS TAX BILL OF 6½ BILLIONS

Nurse Who Survived Bataan Tells Of Japanese Horrors

NAZIS RUSH AID TO ROMMEL IN TROOP PLANES

Egypt Battle Is Renewed After 9-Day Lull; Yanks In Guinea

SPAIN MAY GET KING, NAZIS HINT

The Pittsburgh Press 12 July 1942

It is also interesting to note that the headline in the 12 July 1942 Pittsburgh Press carrying an article about Filner stated: "Six German Armies Smash Forward; Peril to Oil-Rich Caucasus Grows". Under the direct threat of death from Stalin, it was Baibakov's responsibility to protect these energy reserves and find a way to get the fuel to Leningrad that was under siege, which he successfully accomplished.

Filner enlisted in the Army and he helped lead US patrol forces up Italy, and on 29 April 1945, the Army 45 Infantry Division, 180th Regiment that he belonged to, was one of the first to arrive at Dachau Concentration Camp in Germany for its liberation.

Dachau camp prisoners cheer their American liberators, April 29, 1945.

Photo: US Holocaust Memorial Museum

Filner returned to Pittsburgh after the war and again worked at his parent's bakery. He realized how important stainless steel would be to American industry and founded Stainless and Alloy Corporation of America. The business and his scope expanded internationally, and he also founded and operated several other businesses including Project Development International.

It was also during this time, that Filner became interested in Dr Martin Luther King's Southern Christian Leadership Conference (SCLC) and he assembled other colleagues with investments that helped to put the SCLC on sound financial footings. [12]

Dr. Martin Luther King. Photo: US archives

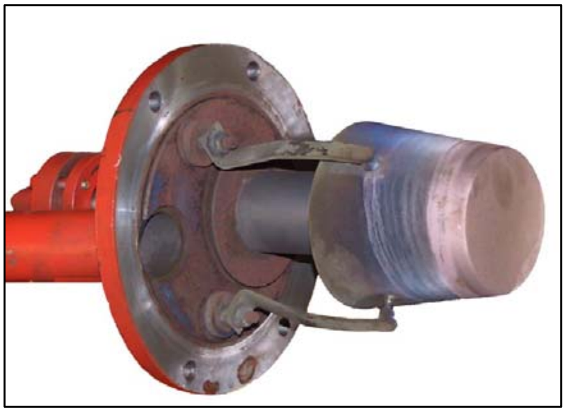
Peter Flood was the chief engineer at INCO (Wiggin Alloys in the UK), a company specializing in high-alloy nickel. Flood was selected to perform the analysis and write a strategic plan for new business development. One of Flood's recommendations was to add welded tube to the company's seamless tube line and this is where he met Filner with the Greenville Tube Company. While Filner was intrigued that an engineer could analyze and redirect a company, he did not contact Flood again until the middle of the night in fall of 1980, when he invited him to St. Paul to see and run Multi Arc.

Flood took 16 trips to the Soviet Union for updates on new developments which were usually full of propaganda, and short on developments. Filner traveled with Flood on several occasions and they usually stayed in the National Hotel overlooking the Red Square in Moscow. It was common for Filner to be visited around 1 or 2 am for unannounced meetings with a GOSPLAN official to discuss world demand of metals for which the USSR could supply. With all the trips to the USSR, the publicity that would come, the royalties that were paid to the USSR, and the summoning of Flood to the Pentagon, it would become clear that the CIA was watching.

Commercialization Launch – The Wild West

The controls in Multi Arc's Bulat machine used vacuum tubes and had no solid-state electrical controls. The vacuum chamber was mild steel and was prone to over-heating. The water-cooled electro-magnets for arc directional control burned out and required rewinding. The vacuum chamber had no o-rings grooves and used flat gaskets for the seals. Proper vacuum levels were difficult to maintain, water hoses often burst and electron tubes went bad. Tool temperatures were difficult to monitor with the rotation and high-voltage biasing. Visual "red checks" were made by the inspectors, not always protecting the hardness of the coated tools.

Multi Arc took what was learned from the Bulat machine, and set out to improve the technology and the coating system operation. Larger chambers were made and the unreliable arc sources underwent two major redesigns: first by Brandolf, then by Clark Bergman and author Vergason, which were patented and are still used today. Brandolf was also responsible for the design of a bias power supply utilizing a 3-phase varister, SCRs and a quartz tube assembly for absorbing the energy of substrate micro-arcs during coating and for implementing infrared temperature sensing mounted on a swivel view-port. Bergman was responsible for replacing the electro-magnetic arc control with reliable permanent magnets and for understanding the physics of the process and the key role that bias power played on substrate heating, film growth and structure.



Bulat cathodic arc source Photo: Anders

Multi Arc source. Photo: Multi Arc

MAV-1 Photo: Multi Arc

Turf War 1: Multi Arc vs American Hoist and Derek

In early 1980, Multi Arc sought capital investment for expansion. Officers from American Hoist and Derek (AmHoist): Robert Fox, president and CEO; Joseph Zook, vice president; and William Mularie, R&D director toured the Multi Arc facility and met with key management and technical staff to understand the cathodic arc process and to perform their due diligence. Months of meetings went by and two days before the signing of an investment agreement, AmHoist called off the meeting. Two months later, they sent a letter to Multi Arc stating that they had purchased rights to a 1971 Snaper patent [13] and that they would be bringing suit against Multi Arc for patent infringement. Flood called Al Snaper and found out that there were two cathodic arc patents that he owned, and AmHoist only bought one of them. That night, Cecil Schmidt, lawyer for Multi Arc, was on a plane with one hundred thousand dollars to purchase the other Snaper patent [14]. The day author Vergason started to work for Multi Arc as an engineering technician, the front page of the 15 December 1981 St. Paul Pioneer Press reported “AmHoist sued for $100 million”.


Tuesday

St. Paul Pioneer Press

Minnesota's First Newspaper

Metro Final

Military tightens grip on Poland

U.S. responds to crisis with temporary halt of food aid

Israel moves to annex Syria's Golan

A kidney from Dad

Top o' the morning

NSP proposes special rate for low incomes

NSP gets first nuclear fine

Panel restores benefits

Standard & Poor's places Minnesota on bond 'watch' list

AmHoist sued for $100 million

St. Paul Pioneer Press 15 Dec 1981

Historical note: Poland, fearing reprisals from the Soviet Union, clamped down on the Solidarity movement by declaring martial-law. The East German Government took this as a reason to recall all East German students from Poland, including author Anders, terminating their foreign studies.

Now Multi Arc and AmHoist each owned a Snaper patent and neither had the clear right to use. Cross-licensing brought the litigation to a close and both parties went about their own business: Multi Arc using the Sablev (Bulat technology) patent with its gap arc confinement method along with the Snaper patent; and AmHoist's newly formed company, Vac-Tec Systems Inc. (1981) using Snaper and soon to be Mularie patent for boron nitride (BN) arc confinement methods [15].

Multi Arc saw many potential customers with interest to purchase its systems. Niagara Cutter visited around 1982 and ultimately bought Balzers equipment. Hauzer visited around 1983 and started work on making its own equipment. The biggest deal breaker for some of the potential customers was the royalty payment stream that would be associated to the products coated using the equipment. These revenues had to be calculated to make royalty payments back to KIPT. Early on, tool manufacturers were not interested in prolonging the life of their tools; they wanted to sell more of them (tools). This all changed when Multi Arc's sales strategy targeted large end users, such as Ford Motor Company. Ford ultimately told their suppliers that if they did not sell them coated tools next year, they would buy tools from someone else; the race was clearly on. Multi Arc achieved significant growth in 1984 and 1985 of its technical and commercial resources through its joint ventures with Siemens in Germany, Sumitomo in Japan and HIT in France.

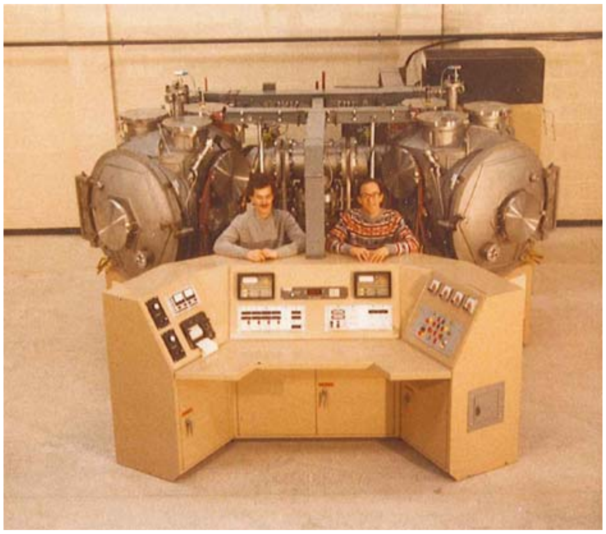
MAV-4 Multi Arc's first sold machine and engineering staff, 1983. Photo: Multi Arc

Multi Arc England's (Consett) first technician Alan Holmes & secretary Marian Green. Photo: Multi Arc

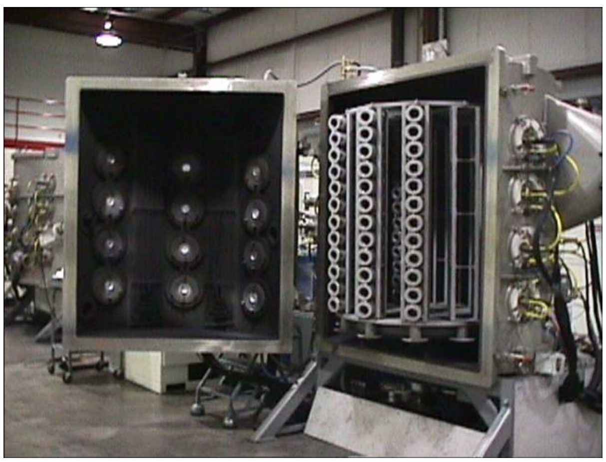
A.Snaper, H.Gabriel , P.Hatto, H.BlairIII-Administrator

C.Bergman, D.Teer , H.Brandolf, R.Bunshah

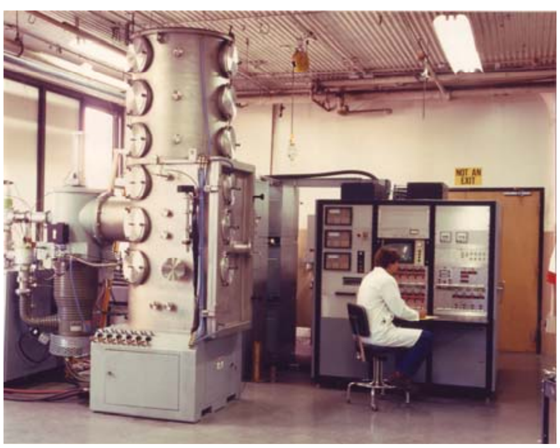
Multi Arc's technical advisory team



Multi Arc Consett installers Ed Anderson and author Vergason. Photo: Multi Arc



32 cathodic arc source system.   Photo: Multi Arc



2.5 meter cathodic arc system.   Photo: Multi Arc

Vac-Tec Systems Inc.

Vac-Tec Systems Inc. moved from St. Paul, Minnesota to Boulder, Colorado shortly after settlement of the lawsuit with Multi Arc. Their ATC-400 cathodic arc systems typically used four large area 8-inch by 24-inch cathodes. The arc motion was magnetically driven using three, oval, electro-magnets that were controlled to drive the arc more evenly across the cathode surface and to accelerate the speed of the arc spot travel. Rotary vacuum motors were used to rotate the trigger wires to contact the cathode face to start the plasma. Internally water-cooled liners kept the chamber walls clean and cool. As with the Multi Arc machines, the vacuum chamber was the anode for the electron return path. Detailed information is still being sought for Vac-Tec's technology development, but it is known that William Mularie, Richard Welty and Harbhajan (Randi) Rhandhawa were early contributors.

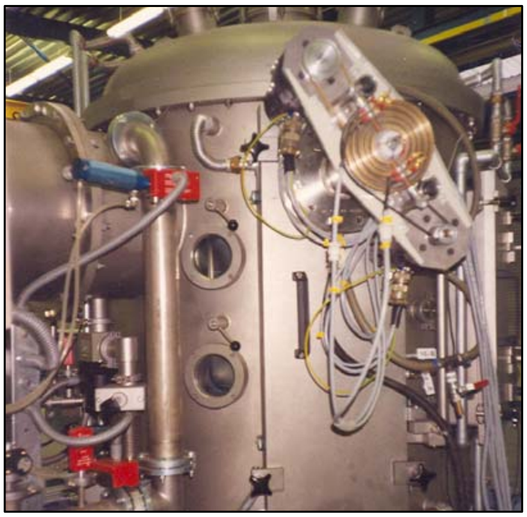
Vac-Tec large area BN arc source, 8 X 24-inches. Photo: Vergason Technology

Modified Vac-Tec ATC-400.
Photo: Vergason Technology

Hauzer Techno Coating

In 1983, Hauzer Techno Coating converted an existing vacuum soldering furnace into a cathodic arc coater named HC-1. A second machine, HC-2, was better designed and technology support was received from Art Anderson and Olive Johansen from Vac-Tec utilizing boron nitride arc spot confinement methods with the 8-inch by 24-inch planar cathodes. BN technology had no intellectual protection in Europe.

Further development use of HC-2 in 1985 used the rotating magnet steering patent of Ramalingam et al. from the University of Minnesota [16]. Deep erosion grooves formed in the cathode from the single rotating magnet. A new machine development project, the HC-6, was led by Boudewijn Buil. These new efforts were initiated to solve the previous cathode erosion problem by installing a two-axis servo drive system for the magnet configuration. The magnet drive system was freely programmable and allowed for unlimited arc spot pattern configurations to optimize the cathode surface erosion. Staff from RWTH in Aachen, Germany, assisted with the calculations, mechanical design and manufacture of the new device. The mechanical design improved the robustness of the cathode device, since the servo system had to operate in a noisy electrical environment.



Machine HC-6, equipped with a steered arc (Ramalingam patent) designed by Hauzer Techno Coating. This empirically designed steered arc was driven by a two-spindle servo which improved target life.
Photo: Hauzer Techno Coating

Magnetically Steered Arc Cathode with Gap and BN Confinement. Photo: Hauzer Techno Coating

Unfiltered random and steered cathodic arc processes inherently generate large diameter (up to 10 micrometers) macro-particles. One solution was to operate the arc sources at the lowest possible current which reduced the size and number of macro-particles. The process was unstable at low currents because there was only a single spot and if it got trapped in a groove and lost the conductive electron return path to the anode(s) the process would stop and would require re-ignition, which also caused macro-particle generation. Large inductances were needed to stabilize the current at low settings. Custom power supplies were developed with over-voltage sensing and controls to protect the power supplies. Special circuitry solutions were required for the current rise directly after arc ignition on the cathode. This addition was also necessary with the steered arc. These power supplies were able to operate at currents up to 300 to 400 Amps

Boudewijn Buil with HC-4 machine, Czech Rep., 1986. Photo: Hauzer Techno Coating

Author Tietema working on a HC-4 commissioning, Czech Rep., 1986.Photo: Hauzer Techno Coating

HC-10 with six 5-inch diameter steered arc sources, future equipment design changes added up to 3 more sources. Note: This system had the optimized design, according to the work of the mathematician and the mechanical engineer of RWTH, Aachen. The 9 cathode system was made for a special application. Photo: Hauzer Techno Coating

Turf War II: Multi Arc vs Vac-Tec and Perkin-Elmer

Perkin-Elmer entered the cathodic arc business when it hired William Mularie to head its new Cat-Arc division. Perkin-Elmer had acquired a license from Vac-Tec to use its BN confinement technology, and knowing the litigation minefields that existed, developed discrete anodes and did not use the chamber as anode. Author Vergason was hired as operations manager and Michael Carpenter worked on the new cathode design. Paul Nurkkala, Thomas Howard and author Vergason developed a regenerative ignition device that was filed for a patent in Europe and was later abandoned.

Multi Arc was coming under increasing pressure from its existing customers to either get rid of its royalty program or go after other companies that offered nearly the same technology without costly royalties. In 1985, Multi Arc brought suit against Vac-Tec and Perkin-Elmer for patent infringement. The suit came to an end when Vac-Tec filed for bankruptcy and Perkin-Elmer closed its Cat-Arc division and turned over its designs, which included the controls and software for the world's first computer-controlled cathodic arc system.

Perkin-Elmer Cat-Arc system .
Photo: Perkin-Elmer literature

New Birth of Technology

Starting around 1985, many new companies came into the cathodic arc arena with new developments. Those companies include: PVT, Kobelco, Vergason Technology, Vapor Technologies, Platit, Eifeler, Metaplas (old Interatom/Multi Arc), Surface Solutions, and others. Explanation of the new contributions that these and other companies have made to cathodic arc technology will have to wait for Part II – The Next Generation.

Acknowledgements

Special thanks to Peter Flood for the many days of time spent reviewing information, forwarding pictures and digging in his archives to help bring life into this presentation.

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