

# **Manufacturing of Electron Accelerators**

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## **1. INTRODUCTION**

Ion Beam Applications (IBA) is a small Belgian company producing particle accelerators. The company was founded in March 1986 as a spin-off of the Centre de Recherches du Cyclotron of the Catholic University of Louvain in Louvain-la-Neuve (Belgium). The company was initially started to develop and sell an innovative concept of 30 MeV negative ion cyclotron, specially designed for the production of medical radioisotopes: the CYCLONE 30. This first product was a success, and IBA eventually sold 16 of these cyclotrons. As a result, the company grew to more than 100 employees. But it is extremely dangerous for an industrial company to rely on a single product and on a single, relatively restricted, market. IBA decided therefore relatively rapidly to diversify its product range. The first additional products were smaller cyclotrons, for the production of positron emitting radioisotopes, to be used in Positron Emission Tomography (PET), a growing new technology in medical imaging. But this was still, like the CYCLONE 30 in the field of medical imaging. The next step of diversification was to develop a complete system for the therapy of cancer tumours by high energy proton beams. This is still in the medical field, but switching to therapy rather than diagnostic.

## **2. SELECTION CRITERIA FOR NEW PRODUCTS**

For a company in a field like particles accelerators, developing continuously new products is a key to survival. In order to select among the possible new products candidate for development, IBA has progressively defined a set of criteria:

1. The new product should have an existing, or reasonably expectable market large enough to support the expected production. The sales of previous years in this field, as well as the evolution of sales is an indicator in this respect.
2. The new product should have a clear and unquestionable competitive advantage compared to the other products existing or under development in this market. In other words, it is not IBA policy to make "me too" products.
3. The product should, at least in part, make use of the experience and technology developed by the

company experts. We do not like to jump into completely new technological territories, unknown to us. We prefer rather to extend progressively our technological base at each development.

The industrial applications of electron beams had been early on identified as a potential expansion market for IBA. We had ordered, from external companies, market surveys that convinced us that at least the first criterion was met. But the two other criteria were not: we did not have a bright idea to make an electron accelerator that would be much better than what existed on the market. And we felt that we were not knowledgeable enough in the technology of electron linacs to be better than the competition.

## **3. THE INVENTION OF THE RHODOTRON**

While IBA was building cyclotrons, and dreaming about a possible expansion into electron accelerator, a small team at the Commissariat à l'Energie Atomique (CEA) in France led by J. Pottier, was inventing a completely new concept in electron acceleration. It is interesting to note that Pottier was in the LETI, a laboratory whose mission was to develop instrumentation and electronics, and not particle accelerators. Pottier was looking to develop an efficient accelerator for applications, based on the concept of recirculation the beam several time in a single cavity. When the concept was invented, many experts doubted that it would eventually work. Pottier and his team succeeded to convince their management to fund the construction of a "proof of principle" Rhodotron, accelerating beam at 3 MeV in six passes in a meter-size cavity. Despite limited budgets and manpower, and despite limited engineering developments, the Rhodotron prototype proved the validity of the concept and of the underlying calculations. Although the first prototype never accelerated high power electron beams in CW operation (this was mainly due to some engineering shortcomings), it indicated that it was indeed possible to do so.

## 4. OPERATING PRINCIPLES OF THE RHODOTRON

The Rhodotron repetitively accelerates electrons across a coaxial cavity.

The electrons undergo a first acceleration when fired from an external electron gun through opening in the outer cavity towards the inner conductor.

As they merge on the other side of the inner conductor, the radial electric field is reversed, giving them a second acceleration.

The beam exits the cavity, then is bent through 198° by a small external magnet, sending the electrons back towards the inner conductor. Each trip across a diameter of the Rhodotron results in two accelerations of 500 Kv, producing 20 accelerations in all. The rose-shaped pattern described by the acceleration path gives rise to the name of RHODOTRON ; "rhodos " in Greek means rose.

## 5. THE CEA-IBA COLLABORATION

The mission of the LETI was not to develop, and even less to industrialise particle accelerators. The CEA initiated therefore industrial contacts to find an industry (preferably French), interested to industrialise the new accelerator concept. A natural choice would have been the company CGR-MeV, a leader in the market of high energy (10 MeV) accelerators for industrial applications and located close to the CEA. But CGR-MeV, initially a subsidiary of the French Compagnie Generale de Radiologie (CGR), became owned at 50% by General Electric Medical and 50% Sumitomo Heavy Industries after CGR was sold to GE. Furthermore, CGR-MeV was very oriented toward the linac technology, and reluctant to embark in the very different Rhodotron technology.

IBA became aware of the development of the Rhodotron by a serendipitous contact (although the Rhodotron principle had been presented at the first EPAC to which IBA members participated). The first reaction of the author was to reject the idea "we don't know how to make linacs". Having learned that the new accelerator was not a linac, and was presenting very intriguing and exciting features, we decided to learn more and, eventually, to drive to Saclay to see the prototype.

At this time, professor Pottier had retired, and the Rhodotron team is now lead by Dr. Annick Nguyen. When we discovered the prototype, and were allowed to play with the controls, we were struck by the simplicity and robustness of the new accelerator. We felt that the Rhodotron had the qualities needed to become a great industrial product. We were also struck by the similarity of the Rhodotron technology and the technology used in present IBA cyclotrons. Actually, many of the

subsystems used to regulate the RF system in our cyclotrons could just be transferred to the Rhodotron, solving some engineering problems observed on the prototype.

We were soon convinced that the Rhodotron was the product IBA was looking for to enter in the market of electron accelerators for industrial applications. We started then to negotiate with the CEA an exclusive, world wide licence to the technology. In compensation, the CEA received a significant down-payment as well as royalties on each sale of Rhodotrons.

The contract further provided that the development of the first "industrial" Rhodotron would be a joint undertaking of the CEA LETI team, and of IBA. The CEA team would concentrate on the physics calculations, while IBA would concentrate on the engineering and industrial design aspects. The construction and tests of the industrial prototype would take place at IBA's factory in Belgium, and the tests would be attended by members of both teams. Regular co-ordination meetings were organised between the two teams.

An element of success was that an excellent collaboration developed immediately between the scientists and engineers of both teams. Each team was bringing to the other some knowledge and technology needed for the success that the other did not have, and each team was pleased and impressed with the other team contribution.

## 6. SELECTING THE PARAMETERS OF THE FIRST INDUSTRIAL RHODOTRON

The first task of the team was to select the parameters of the first model of industrial Rhodotron developed by IBA. Basically, the Rhodotron technology allows a wide choice of energy and currents to be achieved, so the decision had to be based on market considerations. The choice of energy was easy: international regulations limit to 10 MeV the maximum energy of electrons used in industrial applications, in order to stay below the threshold of most gamma-n reactions, preventing therefore a potential neutron activation of the goods treated. On the lower end, accelerators using a DC voltage source, such as Dynamitrons or Insulated Core Transformer (ICT) accelerators are currently produced up to voltages of 4.5...5 MV, offering high beam power and good energy conversion efficiency. The superiority of the Rhodotron over competing technologies would therefore be most obvious in the energy range of 5 to 10 MeV. A maximum energy of 10 MeV was therefore easily selected. In this energy range, the only competing technology is the classical microwave driven electron linear accelerator. For industrial applications, electron linacs suffer from significant inherent disadvantages: the

operation is always pulsed, with a pulse repetition frequency in the hundred of Hertz, and with low duty cycles. This pulsing is a serious disadvantage when scanning the beam over the products to be irradiated is required. This is almost always the case. Furthermore, the energy conversion efficiency of linacs is poor, averaging around 15...20% total system efficiency (total system efficiency is defined here as beam power divided by the total electrical power required by the accelerator system, including all accessories). Finally the energy spectrum of such linacs is generally quite bad, requiring very special precautions to avoid beam losses whenever magnetic deflection is used.

The choice of the beam power level required from the first industrial Rhodotron was a more difficult choice. Most linacs offered commercially for industrial applications have a maximum beam power around 25 kW, one exception being the IMPELA linac developed by AECL which was built with a maximum power of 50 kW. A power of 25 kW is generally found appropriate for the sterilisation of medical devices at a dose of 25 KGy, either in the production line or in a remote contract sterilisation service centre. At higher powers, the material handling becomes a real challenge. However, for other applications such as the crosslinking of polymers or the degradation of wood pulp, higher beam powers are needed to reach the profitability threshold. As the highest accelerator available on the market was the IMPELA with a maximum beam power of 50 kW, we decided, somewhat arbitrarily to set a goal of 100 kW beam power at 10 MeV for the first industrial Rhodotron. We realised that this power was probably more than what many users needed, but on the other hand this would clearly position the Rhodotron as the accelerator able to achieve the highest beam powers at 10 MeV. When this would realised, few people would doubt our capacity to develop a Rhodotron of lower power, while the opposite approach would not have been as credible.

So the first industrial Rhodotron was designed as a 10 MeV, 100 kW CW beam power accelerator. The model was dubbed model TT200 for Ten MeV, Ten passes and an available RF power of 200 kW (when you start designing an new kind of accelerator, the beam power that you will eventually achieve is still somewhat uncertain, while the output power of the RF amplifier is a much safer bet).

## **7. DEVELOPMENT AND CONSTRUCTION OF THE TT200 PROTOTYPE**

For the development of the first industrial Rhodotron prototype, IBA was able to obtain an interest-free loan from the high technologies ministry of the government of the Walloon region. When this loan was

obtained, in April 1992, the development effectively started. The development was truly a team efforts between the CEA team, led by Dr. Annick Nguyen, and the IBA team led by Michel Abs. The CEA group, based in Saclay (France) did the beam dynamics computer modelling of the new accelerator, and joined the design reviews. The IBA team in Belgium did the magnetic design of the magnets, the mechanical and electrical design of the whole accelerator, all the engineering and the actual construction and assembly of the prototype. The beam tests involved members of both teams. The two teams met monthly during the development period for co-ordination and design review meetings.

After the design period, the Rhodotron cavity was ordered in September 1992. The cavity of the TT200 Rhodotron, designed to resonate at 107 Mhz (the upper limit of the FM broadcasting range) is made of formed and welded steel plates, then machined to the required tolerances and electro-chemically copper plated. The cavity was delivered to IBA in June 1993, and the prototype assembly started. The full accelerating RF field was obtained without any difficulty in October 1993, and the first beam tests started immediately after that. The beam test ran very smoothly. The only difference with the computer predictions was found in the beam spot size after a couple of cavity crossing. The problem was rapidly identified: a correction term, representing the finite gap effect on the axial focusing forces of the magnets had been neglected in the calculation, and was found to have a significant effect. The magnets were recalculated with the missing term, and the pole face angles were slightly modified. With this correction, the beam behaved completely in accordance with the computer calculations.

An interesting problem, when you want to test an accelerator producing 100 kW of beam power is what to do with this beam? We designed a beam dump, consisting essentially of a water target, in which the beam power was stopped in water circulating rapidly to remove the beam energy. The water was separated from the beam line vacuum by a thin metal window. Stopping the beam in water minimises the production of X-rays. This target was shielded by a thick wall of lead bricks. We were very surprised to discover that, after a few hours of operation, the lead bricks wall was so heated by the X-ray absorption that it started to melt!

In April 1994, the Rhodotron prototype had reached 100 kW at 10 MeV in continuous, reliable operation, and we were ready for the next challenge: to find a customer willing to take the risk to try this new technology.

## **8. SELLING THE RHODOTRON**

Selling the Rhodotron was another formidable challenge: this was a new, untested accelerator

technology, and potential purchaser of such major industrial equipment are generally unwilling to bet millions of dollars on an industrially unproved design. Furthermore, within IBA, no one had any serious knowledge of the users and of the market of industrial electron irradiation. IBA was equally unknown to these prospective customer. This is in contrast with the world of cyclotrons that the author and the other founders of IBA knew relatively well at the time of the creation of IBA.

To be able to sell the first Rhodotrons, two conditions had obviously to be met :

1. To build a prototype meeting the promised specifications, available for demonstration at IBA factory.
2. To start a process allowing IBA marketing and sales people to get to know the main players of the market, and get known by them.

The solution to the first issue was made possible by an interest-free loan of the regional government of the Walloon region of Belgium, covering 60% of the prototype development cost. The second issue was addressed by defining a policy of intensive presence of IBA representative at every significant conference or trade show of the E-Beam processing and sterilisation industry. After a long time of efforts, this succeeded to provide the first order to Studer AG in Switzerland. The fact that Studer can truly be considered an industry leader in this field gave this order an additional value of example.

We found however, that to reach a good enough penetration of the E-Beam market, we needed to do more : hire within IBA sales department people who were long time actors in this field. This was done in 1995, when we hired two gifted individuals, which had previously been working with a major E-Beam contract sterilisation company in USA. We also hired as project manager an engineer which had been in the field for most of its professional life, running an E-Beam facility for the last ten years.

These efforts were successful : with six accelerators sold in 1995 and the first half of 1996, the Rhodotron appears today like an impressive commercial success, claiming a market share of more than 65% for the accelerators of high energy sold during this period. The future only will tell us if this initial success is confirmed on the long run, but we will certainly do our best to reach this goal.

## 9. CONCLUSION

For IBA, switching from the world of proton accelerators to the world of industrial applications of electrons has been a challenging but successful and rewarding experience. The success can be attributed to different causes :

- The inherent qualities of the Rhodotron technology developed by J. Pottier.
- The professional qualities and dedication of the teams developing the industrial prototype : the CEA team, led by Annick Nguyen and Jean-Marc Capdevilla, the IBA team led by Michel Abs and Frédéric Genin.
- The enthusiasm, creativity, dedication and plain hard work of the IBA E-Beam sales team, with Dominique Defrise, Thierry Delvigne, Pauline Pastore and Arnold Herer, and their manager Ahmet Cokragan, who succeeded, against all odds, to impose the Rhodotron and the name of IBA in a new market.
- The foresight and intelligence of experienced customers like Studer AG, which accepted to take the risk of a new, only partly demonstrated accelerator technology on the base of its technical merits and of its value to them.
- Serendipity, and a trace of good judgement of IBA management, allowing the company to get the right technology at the right time.

## 10. REFERENCES

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