THE ITALIAN "IORT PROJECT"

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Abstract

The "Intra Operative Radiation Therapy" (IORT) represents the latest technological frontier in radiotherapy.

The technique utilizes accelerated electrons, as from a tailored designed EB-machine, to destroy rapidly spreading malignant cancer cells and it is appraised to allow a 15% general increase of cancer patients survival.

The Italian "IORT Project", funded by the Italian Ministry of Research (MURST), was started in 1998 from ENEA (Italian National Agency for New Technologies, Energy and the Environment) and is aimed to design and construct two innovative IORT systems as direct enlarged improvement of present IORT-NOVAC7 system, jointly developed in the latest years from ENEA and the Italian Hitesys Company. The paper, after a short review of the NOVAC7 features, will describe the "IORT Project" progress status, focusing attention on both innovative technical aspects of future IORT accelerators, and first prototype early experimental results.

1 INTRA-OPERATIVE RADIOTHERAPY

Radiotherapy of cancer patients to destroy rapidly spreading malignant cancer cells is well known and the IORT technique [1] represents the most recent and advanced technique of radiotherapy application, allowing the delivering of a single high dose (as from accelerated electrons beams) on a tumour bed soon after surgery excision and inside the surgery theatre, avoiding the patient treatment several days after the tumour resection or (traditional and previous IORT) the patient transfer to the hospital radiotherapy shielded department just after the resection.

According to such previous IORT technique, the patient, after surgical excision, was submitted to a radiotherapy treatment carried out in a different hospital area, suffering an additional anaesthesia to cover transfer time to therapy division and back to operating room, and, moreover, being exposed to risks connected to difficulties to preserve a sterile path during conveyance.

The new IORT technique overcomes the above problems: ENEA and HITESYS, since early 90s, started to develop a system, exclusively conceived for intra-operative treatments, allowing to perform IORT application without moving patients and with no structural modification of the operating room. The new system, named NOVAC7 [2], commercialised by Hitesys Co. since 1997, is at present fully operative by seven different hospital in Italy and abroad, and over 200 patients were already submitted to NOVAC7 treatment confirming the process effectiveness and foreseen survival figures.

The main advantage of IORT technique is to be referred to the improved tumour local control [3]: in fact the technique allows the hitting with an high single dose only of tumoral tissue, avoiding to submit to radiation normal tissues and avoiding tumour recurrence in that area. In such a way, IORT represents a gain of surgical excision (the smaller is the residual disease after surgery, the smaller is the cancer recurrence and the greater is the effectiveness of complementary therapies) and a gain of radiotherapy treatment (as it exploits the radiobiological effect of a single high dosage which usually is more effective on tumoral tissues).

Final result, as from a large scientific medical literature, is an improved patients survival, calculated, with reference to a large oncologic spectrum, as more of 15 % in the five years after surgical resection.

The "IORT Project", was started in 1998 from ENEA, the main governmental Italian agency for technological research, on a budgetary program funded by the Italian Ministry of Research (MURST). The Project aim is to design and construct two innovative IORT systems as direct enlarged improvement of present Italian IORT-NOVAC7 system, to be considered at present as the most advanced system at worldwide level.

1.1 The ENEA-Hitesys NOVAC7 system

The NOVAC7 system is a robotic mobile intraoperative electron beam unit (see Fig 1 and table 1).

Table 1: NOVAC7 technical data

Nominal Energy	3, 5, 7, 9 MeV
Beam current	1.5 mA
Repetition frequency	5 Hz
Surface dose	≥80/85 %
Dose rate	≥4 and ≤31 Gy/min
Field size	4, 6, 8, 10 cm
X-ray contamination	≤0.3%
Dimensions	Length 2.3 m, Width 1 m, Height 1.9 m

It is based on an electron beam linear accelerator utilizing a patented autofocusing structure. It is characterized by small size, light weight and negligible diffused X radiation.

Figure 1: The ENEA-Hitesys NOVAC7 IORT-system.

2 THE ENEA IORT PROJECT

2.1 New frontiers for IORT

The ENEA "IORT Project" is divided in three phases:

- Development of electron accelerators
- Development of robotic systems
- Development of hardware and software systems for the process control

It foresees the realization of two systems named IORT-1 and IORT-2: the main features of these systems compared with the NOVAC7 system are summarized in table 2. In both new systems the features of easy handling, compactness and low weight of the machine will be preserved.

Table 2: IORT systems evolution

	NOVAC7	IORT-1	IORT-2
Maximum Energy	9 MeV	12 MeV	15 MeV
Energy variability	Four steps from 3 MeV	Five steps From 4 MeV	Continuously from 3 MeV
Beam current	1.5 mA	0.1-1.5 mA	0.1-1.5 mA
Dosimetry	Gafchromic setting	Gafchromic setting	Real time Dosimetry
Treatment planning	traditional	Advanced (clinical representation based on a mathematical model)	Advanced + virtual reality simulation

2.2 IORT-1 system

The NOVAC7 does not employ scattering filters that in the conventional machines are the main source of stray radiation, but for this reason it is complicate to modulate accelerator dose rate, which is high comparing to conventional accelerators. This prevents the use of ionisation chambers that show a too high saturation factor due to the high dose rate. In the NOVAC7 the use of a diode gun prevents to change the injected current without changing the injection voltage. In the IORT-1, in order to modulate the beam current preserving the beam characteristics at the linac input, a triode gun followed by an univoltage lens was designed. The electrodes geometry was optimised by using the EGUN code (fig.2).

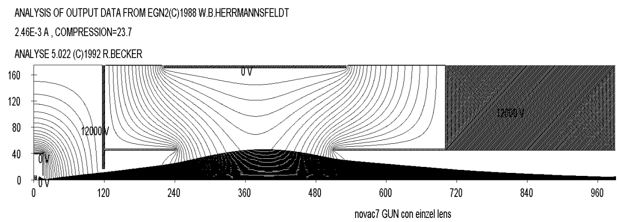

Figure 2: Computed equipotential lines and electron trajectories in the IORT-1 gun.

The gun was built and tested in an apposite test chamber furnished of two screw drives moving along two orthogonal directions (x,z) a target collecting the electron current. The variation of the beam current with grid voltage (fig.3) and the beam dimension were measured

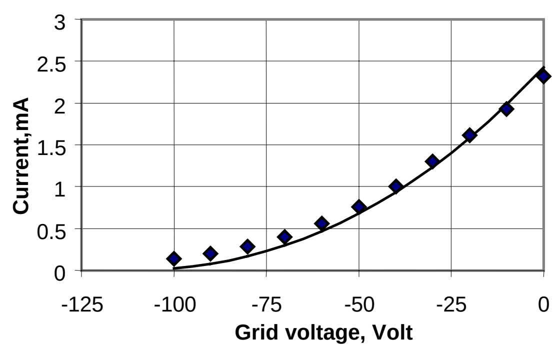

Figure 3: Beam current vs grid voltage

The second improvement of the IORT-1 system concerns the accelerating structure. The NOVAC7 accelerating structure consists of a β graded SW 2998 MHz on-axis coupled linac operating in π/2 mode with 11 accelerating cavities and is 50 cm long powered by a 2.6 MW magnetron: it is a compact accelerating structure in which the beam focusing is automatically achieved without using external magnetic lenses and the losses are kept at low energy so getting a negligible diffused X radiation. For the IORT-1 system the single cavities shapes were optimised (fig.4) in order to maximise the efficiency and to reduce the dark currents, which could be a serious problem for the operation of the system at very low currents. In particular the beam hole diameter was reduced from 8 to 6 mm and the cavity nose shape was modified. The shunt impedance was increased of 15%: in this way adding only four cavities to the NOVAC7 structure it is possible to increase the maximum energy from 9 to 12 MeV with the same power availability. The maximum Kilpatrick factor in the whole structure was lowered from 1.8 to 1.5 and in particular in the first cavity it has been reduced to 1.2.

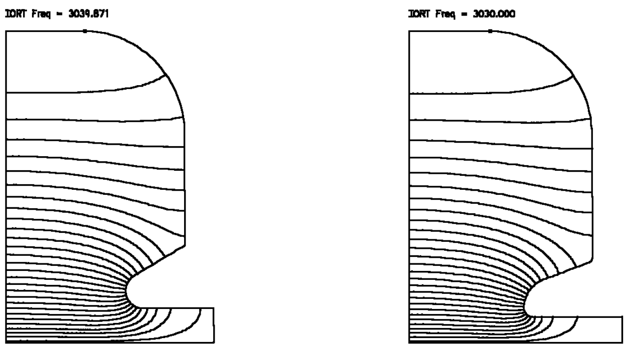

Figure 4: Optimisation of the cavity shape by SUPERFISH: NOVAC7 cavity (left), IORT-1 cavity (right)

PARMELA beam dynamics computations were done in order to check the matching between the new gun and the new structure and showed that the autofocusing feature is preserved in spite of the increase of the emittance of the injected beam due to the output gun lens (fig.5).

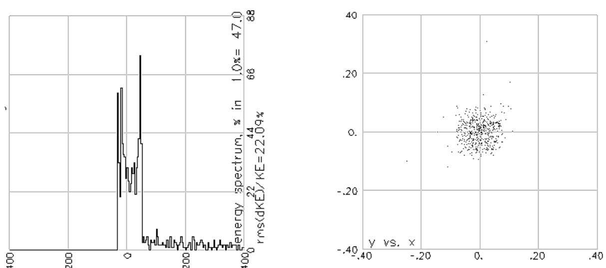

Figure 5: Computed IORT-1 output e-beam energy spectrum (x axis units = keV) and transverse profile (x axis units = cm).

The accelerating structure has been tuned and brazed. The robotic arm is in course of assembling and it is foreseen that in one month the IORT-1 electron beam will be tested with RF. Afterwards the system will be transported and installed in a Southern Italy hospital.

2.3 IORT-2 system

The second IORT system will be an upgrade of the IORT-1 system. In order to reach the maximum energy of 15 MeV the 2.6 MW magnetron will be replaced by a 3.1 MW magnetron and four cavities will be added to the IORT-1 structure for a total length of 90 cm. Differently from the previous systems in which an energy variation by steps is obtained varying the input RF power, the peculiarity of this system is to provide a continuous variation in the wide range 3-15 MeV with an alternative method having the advantage to avoid to degrade the output beam energy spectrum and quality. The technique is based on the use of a special side coupling cavity with movable posts which allows to change the amplitude of the electric field in the adjacent cavities introducing an asymmetry of the posts length. This approach, already proposed for medical linacs [4], has been revised and improved in order to maximize the variation of the electric field amplitude for a given asymmetry: this is obtained adding a central disk in the side cavity with the aim to reduce the frequency difference between the first higher mode (TM_{011}) and the TM_{010} operating mode. This method has been theoretically analysed by an extension of the usual coupled circuits theory to higher TM-like modes and a seven cavities copper model was built in order to test some original technical solutions (fig.7).

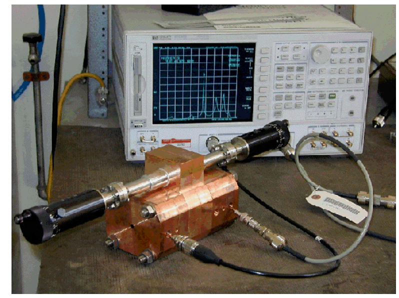

Figure 6: Model for testing the energy variation technique in the IORT-2 system

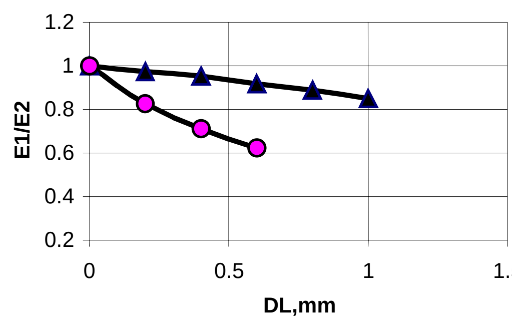

Figure 7: Measured electric field amplitude ratio vs posts asymmetry in the side cavity for energy variation: no disk ▲ with disk ●

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