CRITICAL ANALYSIS OF INDUSTRIAL ELECTRON LINACS

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Abstract

The electron Linacs found wide industrial and medical applications. Industrial Linacs include systems for scanning and output electron beam to air with foil window. The critical analysis of electron Linacs for the treatment of materials (degradation of PTFE, curing of composites and others) and food safety is considered in this report. The kind of radiation technologies on the basis of electron beams determines the type of electron Linac. Main physical demands for industrial electron accelerators consist in the variations of beam parameters such as a kinetic energy, power. Questions for regulation of these beam parameters are considered. Scanning electron beam systems with parallel trajectories for electrons are discussed. The level of absorbed doses in the irradiated product and throughput determines the main parameters of electron accelerator. The variant of ideal electron Linac for industrial applications is discussed.

1. INTRODUCTION

The electron Linacs consist of an injector, a linear accelerating structure, a supply system for accelerating structure, a scanning electron beam system, a system for out put electron beam from vacuum chamber to air or chamber for irradiation, vacuum and control systems.

Electron accelerators are classified as Linacs include following accelerators:

- DC accelerators with accelerating structure from disk electrodes;
- RF Linacs with CW and pulsed modes;
- Pulsed Linacs;
- LIA.

The status of electron Linacs in the industrial applications is very complex. The large development of radiation technologies on the basis of electron beam irradiation results in to consideration of task for design of universal (ideal) electron Linac for these goals.

The critical analysis of industrial electron Linacs and attempt for formulation of task directed to manufacturing companies is considered in this paper.

2. APPLICATIONS OF LINACS

Main applications of electron Linacs can be separate into the following main areas:

- treatment of materials;
- synthesis and polymerization of composite materials;
- food irradiation.

The treatment of dielectric materials (cable, PTFE) requires high doses. For PTFE the dose range of dose is 1.0- 2.0 MGy [1]. The total accumulated dose is same level for curing technology [2]. The process of irradiation is stepped with low dose/pass (1-3 kGy) [3]. The food irradiation needs to use low doses on the level 3-5 kGy [4].

Analysis for irradiation of products shows next:

- the kinetic energy determines the thickness of product;
- the electron beam current in combine with time of irradiation and kinetic energy determines the value of absorbed doses in the product.

These main beam parameters in combine of product throughput are very important for determination of the economical efficiency for radiation technologies. So, the every line for irradiation of product must has electron accelerator with variation of electron beam parameters. However, present status of manufacturing industrial electron Linacs presents the separate accelerators with fix scale of kinetic energy and power for electron beam.

3. MAIN DEMANDS TO ELECTRON ACCELERATORS FOR INDUSTRIAL APPLICATIONS

Main demands to accelerators for industrial applications are following:

- the variation of beam power for regulation of absorbed doses in the irradiated product;
- the regulation of kinetic energy for variation of thickness by irradiated product;
- the forming of scanning electron beam with parallel trajectories after foil window;
- be of on-line diagnostic system for measurements of parameters of beam in the irradiated product;
- the long lifetime for cathode by e-gun in the injector and foil window for out put electron beam;
- reliable and low cost of accelerator;
- simple design of electron accelerator for including to the system for irradiation line;
- more universal for different radiation technologies with different materials;

- simple, cheaper and effective radiation shield;

The realistic situation in the accelerator's technology shows that the electron accelerator according of these demands is absent at present and it is task for companies manufacturing the industrial electron accelerators.

The more close to these demands is electron accelerator "Rhodotron" by IBA [5,6]. This type accelerator allows to variation of electron beam current, has parallel trajectories of electron beam, reliable and be can include in the system for irradiation lines.

4. MAIN PROBLEMS OF USING OF ELECTRON LINACS

Main problems of electron Linacs are following:

- the different level of absorbed doses for various radiation technologies;
- problems for regulation of electron beam parameters;
- 30-60% using of electron beam power in the irradiated product.
- The life time of cathode by electron gun;
- the lifetime of foil window;
- the control for electron beam parameters in the irradiated product;
- the high concentration of ozone in the irradiated area.

The main problem of electron accelerators for industrial application is variation of electron beam parameters. The pointed above different large scale of absorbed doses from 1 to till 2000 kGy [7] presents the big technical problem for design of electron accelerators. The RF system of supply for accelerating structure and dynamics of electron beams can not allow realizing the conditions of variation of electron beam power in wide range. The variation of beam power using effects for time duration and repetition of pulses in combine with conveyer system can relationship variation of the power on the level of 20-40% for fix kinetic energy. The second important problem is variation of kinetic energy for irradiation of product with different thickness and density of irradiated product.

Analysis of beam power loses shows next 3 main factors:

- the distribution of absorbed doses in the irradiated product on the level of 20% regarding average dose;
- an angle scanning of electron beam;
- the factor of using of conveyer line.

The first factor determines the optimal thickness of irradiated product and for increasing of this factor better use 2-sided irradiation. The second factor leads to using of scanning electron beam with parallel trajectories. The computer simulation of homogeneous absorbed doses shows that angle of scanning for electron beam is about 12-18 degrees. The magnetic system for beam scanning with parallel trajectories can be built on the basis of series of double coils or coil with iron. Few variants of system for this task considered in the [8]. The last factor demands the design of conveyer system and fixing of irradiated product with electronic control systems.

The lifetime for cathode by electron gun of injector can be increase on the basis of last achievements in the emission electronics and design of cathodes with lifetime 15,000 -100,000 hours (oxide, and impregnated and reservoir cathodes) [9]. The main task of cathode's units is the understanding for influence effects of grid with RF modulation on the lifetime of cathode.

The window for out put electron beam from vacuum chamber to air on the basis of thin foil must have high corrosion resistance with ozone and other gases components from irradiated product. The protective coatings on the basis of carbon films [10] are solution of this problem.

The control of parameters of electron beam must be on-line system with optimization of beam parameters at process of irradiation. The films dosimeter system can not work in on-line mode.

The high concentration of ozone in the area of irradiation leads to toxic reactions and additional chemical processes with irradiated product and corrosion processes of metal elements of accelerator.

The consideration of main problems of using electron accelerators in the industry shows the task for search of new concepts and approaches to accelerators for industrial applications.

5. MAIN TYPES OF ELECTRON LINACS

DC Linac. DC Linacs have large power and limitation on the value of kinetic energy for electron determines by accelerating voltage. The classical variant of supply of disk- electrodes system by full voltage lead to problems of high voltage insulation. The transition on the supply of every 2 electrodes of the accelerating structure can decide problem of high voltage insulation and leads to increasing of length of accelerator. But using vacuum high voltage insulation can be decreasing the dimensions of accelerator [11].

RF Linac (CW and pulsed). The RF Linacs have RF system for supply of accelerating structure. The development of new RF devices (magnetron and klystron) can be improving this system for regulation of power to accelerating structure. The very interesting approach we can point in the design of few cavities ILU from Budker Institute for Nuclear Physics [12] for high power to till 50 kW.

PULSED Linac. The pulsed electron Linac with induction storage of energy was considered in the paper [13]. The status of this type of accelerator is research. The development of semiconductor technologies for trigger switches gives optimistic future of this idea.

LIA. Linear Induction Accelerators present pulsed high power system with induction accelerating structure LIA can be used for X-rays sources and for irradiation of product with extremely high doses for pulse. This type of accelerators is research now and in few years these accelerators can be available for industrial applications.

6. X-RAYS SOURCES ON THE BASIS OF ELECTRON ACCELERATORS

The low factor of conversion of electrons to X-rays in the electron beam irradiated target leads to increasing of power electron accelerator. The average power of electron accelerator for X-rays source is about 50 – 100 kW. In this case more reliable the pulsed and CW RF Linacs on the energy 10 MeV and DC and Pulsed RF Linacs on the power 50 kW to till 5 MeV. The pulsed high current accelerators can be considering in the future for generation of X-rays for industrial applications.

7. THE IDEAL ELECTRON LINAC FOR INDUSTRIAL APPLICATION

The ideal electron Linac must has regulations for kinetic energy and power of electron beam. Linac can include in to system for irradiation of product. Two variants of ideal accelerators for industrial applications can consider:

- the single accelerator with high power with variation of kinetic energy and power for electron beams;
- separated accelerators with few level of kinetic energy with required variable power.

The few levels of kinetic energy can be consider for Linacs:

a) 0.25 – 3.0 MeV; b) 3.0 – 7.0 MeV;

c) 7.0 – 10.0 MeV.

The design of ideal accelerator has very close with ideal X-rays sources for radiation technologies.

8. SYSTEM FOR IRRADIATION OF PRODUCT

The critical analysis of electron Linacs shows that for industrial radiation technologies we must consider the system for irradiation of products on the basis of irradiator. This system must include the next main components:

1. Irradiator on the basis of electron accelerator (X-rays source);
2. System for radiation safety;
3. Irradiation chamber;
4. System for delivery of product to irradiation chamber;
5. Control system for absorbed doses in irradiated product.

The cost of the system must be considered in the combine of these main components in the dependence from throughput of irradiated product. The task is complex. The task must take into consideration all aspects of technologies and equipment.

9. CONCLUSION

As a results of this critical analysis of electron Linacs for industrial applications in the wide aspect for different radiation technologies with required doses from 1 to 2000 kGy in the irradiated product we can make next conclusions:

- at present time the universal industrial electron accelerator is absent in the manufacturing aspect;
- this paper is attempt for formulate of task for design of universal electron accelerator for industrial applications;

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References

1. 1. G.V. Shiriava, Yu.D. Kozlov. Technology of Radiation Curing of Coatings. Atomizdat, Moscow, 1980
2. R.J. Wood, A.K. Pikaev. Applied Radiation Chemistry: Radiation Processing. A Wiley-Interscience Publication, John Willry & Sons, Inc.New York, 1994
3. M. Wilenski, C. Eberle, S. Korenev, V. Lopata, M. Stein. Proc. of 45th International SAMPE Symposium, 2000, CA, USA.
4. S.L. Bogart, N.G. Tostun. Proc. of 1999 Particle Accelerator Conference, BNL, V.1, p. 603. 1999.
5. J. Pottier. Nuclear Instruments and Methods in Physics Research, 1989, B40.41, p.943.
6. Y. Jongen and et. al. Proc. International Conference on the Application of Accelerators in Research and Industry, November, 1992, Denton, Texas.
7. S. Korenev. Proc. of VIth Intern. Conference on Electron Beam Technologies, June. 2000, Bulgaria, Book of abstracts, p.84; Vacuum (in print).
8. M.P. Svin'in. Calculation and design of high voltage electron accelerators for radiation technologies.. Energoatomizdat, Moscow, 1989.
9. Technical Digest of IVESC 2000, Orlando, FL, USA, Editors: E. Wintucky, N, Hills, K. Jensen..
10. S.A. Korenev and et. al. Instruments and Experimental Techniques, Vol. 38, No.3, Part 2, 1995, p. 411.
11. S. Korenev, A. Korenev. "Electron accelerator for destruction of industrial wastes" Patent RU 2115976, Bulletin of Patents, No20, 07/20/98.
12. V.L. Auslender and et. al. "Industrial electron accelerators type ILU for industrial application" in book "Radtech– Euroasia, Novosibirss, BINP, 1999.
13. E. Galstain, L. Kazanskiy. Proc. of 1999 Particle Accelerator Conference, BNL, V.3, p.1477, 1999.