APPLICATIONS OF LOW ENERGY LINACS IN CHINA*

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Abstract

Low Energy Linacs have been widely put into use in China. The first field of application was radiotherapy. There are about 680 medical electron linacs, of which about 340 sets are domestically manufactured machines, including standing-wave and travelling-wave medical linacs. A new application is inspection of large containers at ports for customs. About 30 systems for inspecting large containers using linacs as their radiation sources have been installed at 30 ports in China. In addition, 9 systems have been installed or will be installed in ports abroad, such as Australia, Iran, United Arab Emirates, Turkey and Korea. Other main application fields include radiography and radiation processing.

1 INTRODUCTION

Throughout its 40-year development, low energy linear accelerator technology has advanced much in China. Various accelerating structures, which can be used to accelerate electrons and ions, have been widely researched. These include disk-loaded, drift tube linac (DTL), side-coupled, on-axis-coupled, annular-coupled, disk-and-washer (DAW), radiofrequency quadrupole (RFQ), and helix waveguide acceleration structures. Of these, the standing-wave (SW) structure for accelerating electrons has developed especially rapidly. Electron medical linacs are the most common type of accelerators in China. About 310 SW medical linacs for treating cancer were mass-produced by four Chinese manufacturers.[1]

Recently, a new application for accelerators has been introduced with three types of domestic container inspection systems using electron linacs as radiation sources. 30 of these systems have been installed at ports in China, and 5 sets were installed in ports in Australia, Iran and United Arab Emirates. Four additional sets will be installed in ports in Korea and Turkey.

Electron linacs for radiography have played an important role in heavy industry, with 12 sets being domestically manufactured.

Electron linacs for radiation processing were mainly used to irradiate the power thyristor device, which significantly improved its high frequency performance.

2 LINACS FOR RADIOTHERAPY

In recent years, about 2 million patients per year are diagnosed as suffering from cancer in China. 60%~70% of these patients require radiotherapy with accelerators. This huge need has been fuelling the development of medical accelerators in China since the 1960s. Now there are four manufactures which mass-produce medical electron linacs. Of these, the 6MeV SW electron linac is the most numerous. The WEIDA Company and the SMNIF Company have used 6MeV SW accelerating tubes with on-axis couplers as radiation sources. The accelerating tubes used in these machines were produced by Tsinghua University in cooperation with BVERI. The WEIDA Company produced 95 machines, and the SMNIF Company produced 25 sets. The acceleration tube consists of a buncher cavity and five accelerating cavities, excited with a 2.6 MW magnetron. Fig.1 shows a view of the 6MeV SW accelerating tube, with a length of about 28cm. About 200 of these accelerating tubes had been manufactured by the middle of 2002, and they have been used for both radiotherapy and radiography. Fig.2 shows a 6MeV SW medical linac produced by SMNIF.

Figure 1: A 6MeV accelerating tube produced by Tsinghua University in cooperation with BVERI.

Figure 2: A 6MeV electron medical linac produced by SMNIF.

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Another manufacturer, BMEI, produced 115 6MeV SW linacs with side-coupled accelerating tubes. The tubes for these machines were produced by BMEI itself.

14MeV SW medical electron linacs have also been mass-produced by BVERI and WEIDA companies, using 14MeV SW accelerating tubes with a 270^o deflection chamber manufactured by Tsinghua University in cooperation with BVERI. Fig.3 shows a 14MeV SW medical linac produced by BMEI. The linac also uses a 2.6MW magnetron as a microwave power source. The SW accelerating tube consists of a 4-cell buncher and a 25-cell accelerating section with a total length of about 1.4m, which can provide 6 or 12MV X-rays and 6, 8, 10, 12 or 14 MeV electron beams.

Figure 3: A 14MeV SW linac produced by BMEI.

Last year, a 20MeV standing-wave accelerating tube with an energy switch which fits the on-axis coupled accelerating structure was developed by Tsinghua University in cooperation with BVERI. It can provide 6 or 15 MV X-rays and 5, 7, 9, 12, 15 or 20MeV electron rays. A patent has been issued for the energy switch (CN1237079A, 1999). The total length of the 20MeV SW tube is about 1.5m. This year, BMEI in cooperation with Tsinghua University and BVERI began developing a 20MeV SW linac with the 20MeV SW accelerating tube for treating cancer. A view of the 20MeV acceleration tube is shown in Figure 4. The medical linac will be excited by a 5MW magnetron.

There are about 680 electron medical linacs in use. Of these, about 340 sets are domestically manufactured. Every year, the amount of both domestic and imported medical electron linacs increases at a rate of 10~15%.

A 35MeV proton linac at the Institute of High Energy Physics (IHEP) has been operating part-time as a fast neutron source for neutron therapy since 1991. At this facility the neutron beam is produced by proton beams bombarding a beryllium target. The proton beam is horizontal and fixed. This facility has conducted many experiments researching neutron radiophysics, neutron preclinical radiobiology, and the effects of neutron radiation. It has provided valuable data for clinical cancer treatment. Based on the results of these experiments, more than 682 patients have been treated with this linac. The clinical results show that neutron radiotherapy is effective for some cancers such as salivary gland sarcoma, prostatic adenocarcinomas, soft tissue sarcoma, bone sarcoma, metastatic cancer of the head and neck, malignant melanoma, and pancreatic cancer.

Figure 4: 20MeV SW medical acceleration tube with an energy switch.

This year, the Yangzhou Marine Electronic Instruments Institute in cooperation with Nanjing University developed a 16MeV medical feedback travelling-wave electron linac, which can provide 8 or 16 MV X-rays and 6, 8, 10, 12, 14 or 16MeV electron beams for radiotherapy. Fig.5 shows the 16MeV medical linac.

Figure 5: 16MeV medical travelling-wave electron linac.

3 ELECTRON LINACS FOR CUSTOMS CONTAINER INSPECTION

A new application for electron linacs is for container inspection at ports for customs. Usually, at customs, container inspections rely on manual inspections, which require opening the container to check goods individually. This manual inspection usually takes a long time, and is no longer acceptable with the increasing numbers of containers being transported. An automated inspection system is necessary, such as ones found in airports for inspecting personal luggage. But in the case of inspecting containers, the radiation rays must be high energy X-rays, which come from accelerators instead of X-ray tubes. To meet these requirements, three types of large container inspection systems for customs have been developed by

Tsinghua University in cooperation with Tsinghua Tongfang NUCTECH Co. LTD. [2]

The systems use high-energy X-rays from linacs to scan the container with detectors and record the radiation intensity passing through the container. There are two ways to scan the container. One is to use a fixed linac while the container passes through the X-rays; the other is to fix the container while the linac moves and generates X-rays that pass over the container. Both types of systems have been developed in China in recent years. The former is called a “fixed” system. The latter is separated into two kinds; one kind is a “relocatable” system, which is installed in a relocatable cement-block shielded shed, the other is a “mobile” system, which is mounted in a truck.

The fixed system uses a 9MeV travelling wave linac as a radiation source which is situated in a shielded room with cement walls two meters thick. The 9MeV linac is driven by a 3.5MeV klystron, which has a 0.4m long bunching section and a 1.8m long main accelerating waveguide. The bunching capture efficiency is more than 75%. The beam pulse current is about 120mA which hits the tungsten target causing it to radiate 40 Gy/min.m X-rays. A triple-quadruple magnetic lens is employed in front of the target to further focus the accelerated beam to 1.5mm diameter. By the middle of 2001, 9 fixed systems had been installed at seaport customs in Tianjin, Dalian, Qingtao, Shenzhen and Shanghai. Fig.6 gives a view of the building and working field of Shenzhen’s system.

Fig 7 gives a picture of a container concealing three smuggled cars which were detected by a fixed system inspection linac.

The fixed system has a very powerful inspecting capability, and can inspect a large container in less than 2 minutes. In order to ensure this inspection speed, three platform wagons, which carry the inspected containers through the X-ray inspecting channel, rotate on rails. But these systems require a vast amount of space---the same area as up to one or two football fields. Most ports have insufficient space to install the fixed inspection system and they also have fewer containers to inspect. Therefore a mobile, flexible, compact system needed to be developed which was mounted in a truck. Two kinds of accelerators have been employed as their radiation sources. One of them is an X-band 9.3GHz 2.5MeV on-axis coupled standing-wave (SW) linac [3]; another is an S-band 2.998GHz 2.5MeV on-axis coupled SW linac. Since it uses a self-shielded acceleration tube, the system possesses a quite low radiation leakage, so the operator can run the system from nearby. The system is called a mobile system. (Fig.8)

5 sets of mobile systems were installed at Chinese ports, such as Guangzhou, Shantou and Kunming.

For medium sized ports, the “fixed” system is too expensive and the “mobile” system is too limited. So a “relocatable” system was developed which can be placed in a simply-shielded cement-block shed but possesses more penetration power and more quick inspection velocity than the mobile one. An S-band 6.0MeV self-shielded SW linac was chosen for its radiation source. A double-housing gantry structure is employed in this system (Figure 9) with the radiation head mounted on one

Figure 6: Building and working field of the fixed inspection system at Shenzhen seaport customs

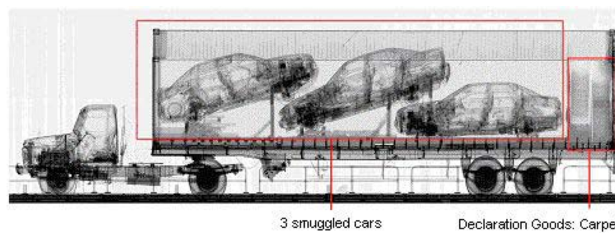

Figure 7: Three smuggled cars detected by high energy X-ray

Figure 8: Mobile container inspection system.

side of the gantry and a detector array mounted on another side of the gantry. About 16 of these systems were installed at Tianjin, Dalian, Qingtao, Shanghai and Xiamen. [4]

Figure 9: Relocatable type container inspection system

In addition, in order to improve security an airline cargo inspection system was developed by Tsinghua Tongfang NUCTECH Co. LTD for airports, which employed an S-band 4MeV or 2.5MeV SW linac as its radiation source. All the components of the system can be mounted in an airport as a part of the cargo transport line. One system has been installed at Shanghai International Airport (fig.10).

Figure 10: Airline cargo inspection system

4 ELECTRON LINACS FOR RADIOGRAPHY

Linac radiography as one of the methods of non-destructive testing (NDT) has been widely employed in industry to check the flaws and welded joints of high-pressure vessels, main axles, and large casting. About 20 electron linacs have been used for radiography at heavy industry companies in China. Among them, 12 sets are domestically produced, with electric beam energies of 3, 4 and 9MeV.

Fig. 11 shows a picture of a 9MeV electron linac for radiography, which was developed by BRIAMI in cooperation with Tsinghua University and BVERI.

Figure 11: 9MeV electron linac for radiography

This year, a 16MeV backward travelling wave acceleration tube was developed by Tsinghua University, with a magnetic coupled acceleration structure. The shape of the acceleration cavity was optimized to get high shunt impedance. The length of the acceleration tube is about 1.6m, which consists of a 4-cell buncher and a main acceleration section. This accelerator achieved a dose rate of about 120 cGy/min.m. The results of research on this accelerating tube are presented in a paper at this conference. [5]

5 ELECTRON LINACS FOR RADIATION PROCESSING

Electron linacs have a unique advantage in the field of radiation processing, since they can easily let the accelerated electron beam reach a higher energy. In the field of radiation processing, most accelerators are high-voltage type accelerators, with electron beam energies generally lower than 4~5MeV. In contrast, the electron linac can easily reach or even exceed this level. Additionally, electron linacs also can be used to accelerate electrons to lower energies necessary for some radiation processing applications.

China has long-term experience with radiation processing. The first Chinese electron linac for radiation processing (BF-5) was developed by Tsinghua University, BMEI and Beijing Normal University in 1979. Since then, the 5MeV electron linac has been used to research radiation processing techniques, for small-scale production of irradiated products and for basic research in radiation chemistry, including the study of pulse radiolysis. Using the electron linac as its radiation source, the products manufactured include high voltage wire used in televisions and computer monitors, polyethylene heat shrinkable tubes and sheets, as well as cables for special uses. A pulse radiolysis system with a time resolution of 2 microseconds has been constructed with the BF-5 linac. The system uses a kinetic spectrophotometer to monitor the transient species produced by a single electron pulse. In the mid-1990's, on the basis of the BF-5's technology, BMEI constructed another 5MeV electron linac for the Tianjin Cable Company to irradiate the cables they produce.

In the early 1980's, the Chinese Institute of Atomic Energy (CIAE) reconstructed its linac for scientific research to meet radiation processing requirements. After reconstruction, the electron beam reached 14MeV and was mainly used to radiate the power thyristor device. Electron radiation can control the lifetime of the minority charge carrier in the silicon power device so that to reduce the thyristor's switching time which significantly improve its high frequency performance.

In 1996, Nanjing University developed a 4~12MeV, 3 KW electron linac (NFZ-12) for the Institute of Electric Locomotion at Zhuzhou, Hunan province, which was also used to irradiate the power thyristor device.

Figure 12: A 4¬12MeV electron linac for radiating the power thyristor device.

At the end of last year, in order to protect against anthrax, TW electron linacs were developed by CIAE and by Tsinghua Tongfang NUCTECH Co. LTD in cooperation with Tsinghua University respectively. The former's electron energy is 2MeV with 1 KW beam power; the latter is 4.5MeV with 2.0 KW beam power. They will be used to sterilize mail. Fig. 13 gives a view of the CIAE machine. Fig.14 shows a picture of the 4.5MeV machine developed by Tsinghua Tongfang NUCTECH Co. LTD in cooperation with Tsinghua University.

Figure 13: 2MeV electron linac for protecting mail against anthrax.

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Figure 14: 4.5 MeV electron linac for protecting mail against anthrax.

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