THE DEVELOPMENT OF ACCELERATOR APPLICATIONS IN CHINA*

Chuanxiang Tang†, Tsinghua University, Beijing, 100084, P. R. China

Abstract

Some latest developments of accelerator applications i China are given in this paper. The application areas mentioned here are including radiotherapy, radioactive isotope medicines, irradiation, non-destructive-test and cargo inspections. There are more than 700 linacs used for radiotherapy in china, and among them about 400 sets are made domestically. Specially emphasized are the cargo inspections applications of linacs in china. Until now, more than 50 large container inspection systems domestically produced using linacs as x-ray sources have been installed in China and other countries. Cyclotrons are also developed for medicine producing and high voltage accelerators with high beam power for removing SO_2 and NO_x from coal-fired flue gas in electricity plant. This paper is mainly on the accelerator technology and application activities in China carried out these years.

INTRODUCTION

In the area of radiotherapy, isotope producing, radiation processing and non-destructive testing (NDT), low energy accelerators have been playing more and more important roles in China [1,2]. The low energy accelerators for medical and industrial applications mainly are low energy linacs, also some cyclotrons for isotope producing and proton radiotherapy, high voltage accelerators for radiation processing.

These years the demands for low energy accelerators in the area of safety inspection and medical applications are increasing. Some new requirements are put forward on accelerator application researches by newly developed applications. For example, the requirement of electron energy of accelerators as x-ray sources range from lower than 1MeV and higher to tens of MeV, and the dose rate from unusual low to extraordinary high, also the accelerator machine needs to be smaller, cheaper and more stable. Large container inspection systems, with electron linacs as x-ray sources, have been fast developed these years. Until now, more than 50 large container inspection systems produced by NUCTECH and Tsinghua University have been installed in China and other countries, including Australia, Korea, Iran, United Arab Emirates, Turkey, Norway and so on, and more than 30 sets to be installed abroad in the following years. A brief introduction of inspection systems designed for train stations and airports is also given in this paper. 2MeV and 9MeV standing wave linacs for NDT have been finished and ready for industrial applications.

More and more accelerators are needed for oncology treatment and medical imaging in China. The number of radiotherapy linacs produced domestically in China is increasing at a rate of more than 30 sets per year, and now the number is totally about 400 in use. Most of the domestically produced medical linacs are 6MeV and 14MeV standing wave linacs. The 20MeV linac with an energy switch is being designed for radiotherapy.

A 10MeV high current cyclotron (CYCIAE-10) is designed and now under manufacturing to accelerate H^- ions with energy of 10MeV in CIAE (Chinese Institute of Atomic Energy). Also in CIAE a 100MeV high current cyclotron CYCIAE-100 is under design. An ion therapy system has been design for HIRFL in LanZhou Institute of Modern Physics (LIMP).

Travelling wave and standing wave Linacs, with beam power from 1kW to 25 kW and electron energy from 2MeV to 10MeV, have been used or under design for mail processing to kill anthrax and other irradiation processing. A high voltage accelerator used for removing SO_2 and NO_x has been finished in Shanghai Institute of Applied Physics.

MEDICAL APPLICATIONS

Most accelerators for radiotherapy are linacs. But racetrack microtrons and proton cyclotrons also are used or about to be installed in China for oncology treatment. As to the radioisotopes, cyclotrons are playing the most important role.

Radiation Therapy with Linacs

According to the data given by the investigation done in 2001, there were more than 30 thousands patients treated by radiotherapy everyday in China. The number of accelerators for radiotherapy is increasing very fast. Until now, the medical linacs made domestically in China are more than 50% in set. But the accelerators for per million residents were still less than 0.5 averagely, much less than the amount recommended by WHO. There are several medical linac manufactures in China, which mainly supplies 6MeV machines. BMEI is still the biggest medical linac manufacture, which has made about 240 sets, including 6 sets of 14MeV. WDVE produced about 96 sets of 6MeV linacs and 1 sets of 14MeV. SMNIF produced about 25 travelling wave linacs of 10MeV up to now. XHMED began to manufacture medical linacs about 5 years ago. Now they have produced about 45 linacs of 6MeV. More and more investment is interested in the medical accelerator industry.

There are two kinds of accelerating structures used in the standing wave linacs (see Fig.1). One is magnetic on-axis coupled bi-period standing wave structure. Except BMEI, almost all the other standing wave medical linacs use accelerating tubes (including electron guns and beam windows or targets) using on-axis coupled structures developed by Tsinghua and BVERI. Side-coupled structures are used in the accelerating tubes of BMEI.

*Supported by National Natural Science Foundation, China(10135040).
†Tang.xuh@tsinghua.edu.cn

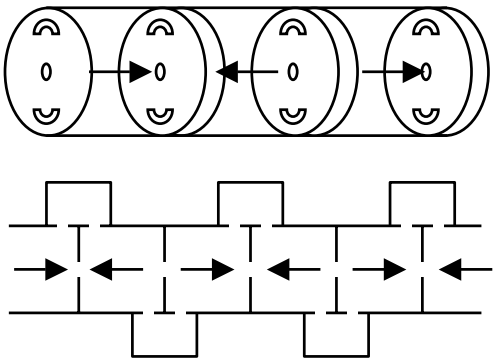

Figure 1: Accelerating structures used in medical SW linacs, magnetic on-axis coupled (up) and side-coupled (down).

The R&D of a 9MeV medical linac (XHA900) was begun in Nov. 2002 by XHMED using a high accelerating gradient standing wave accelerating tube with a triode electron gun (see Fig.2), which was developed by Tsinghua University in cooperation with BVERI. The length of the standing wave accelerating structure is 0.37m, its impedance about 118MV/m. The linac can generate 6MV or 8MV x-ray beam and 4-9MeV electron beams. A 2.6MW magnetron is used as its microwave power source. Because the length of the 9MeV accelerating tube is similar to that of the 6MeV one, it can be installed in the machine vertically. The structure of the machine will be as compact as the 6MeV one and the function of it will be expanded [5].

Figure 2: Photo of a 9MeV high gradient accelerating tube (down-left) compared with a 6MeV one (up-right).

A 16MeV travelling-wave linac (HM-J-16) with a microwave power feedback system for medical applications was passed the product examination in April 2003 (see Fig.3) [6]. This project was begun in 1998 and finished in 2002 by Yangzhou Marine Electric and Medical Instrument Company. Its main parameters are given in Table 1. The microwave power source is a 6MW magnetron. Several stability control systems are designed for this machine, such as automatic frequency control (AFC), automatic current control (AIC), dose monitoring and automatic dose flatness control (ADC).

Figure 3: Photo of the 16MeV travelling-wave electron linac HM-J-16.

Table 1: Parameters of HM-J-16

X-ray energy	8MV, 16MV
X-ray dose rate	250cGy/min
Electron beam energy	4MeV(opt.), 6MeV(opt.), 8MeV, 10MeV, 12MeV, 14MeV, 16MeV(opt.)
Electron beam dose rate	300cGy/min
Field size	40cm × 40cm
Rotation range of gantry	±180°
Constant height	1250 mm
Constant precision	±2 mm

A 20MeV standing wave linac with an energy switch is under developing by BMEI in cooperation with Tsinghua University and BVERI (see Fig.4). The linac can deliver 6 or 15MV x-ray beams and 5,7,9,12,15 or 20MeV electron beams with a 5MW magnetron. The design of the linac has been finished and most of the components are been manufacturing now. High power testing of this linac will begin at the end of this year in BMEI.

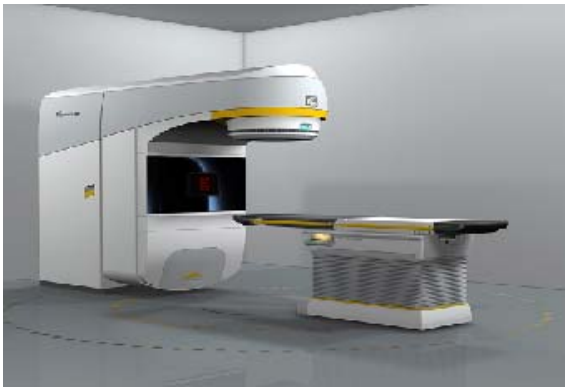

Figure 4: The 3D designed picture of the 20MeV linac in BMEI.

Radioisotopes Producing by Cyclotrons

Radioactive isotopes are widely used in both diagnostic and therapeutic applications. Most of the accelerators used to produce radioactive isotopes are cyclotrons. In recent years, the small medical cyclotrons are developing greatly. There are several manufactures of commercial

cyclotrons in the world, such as CTI (Knoxville, TN), IBA (Belgium) and Ebco (Vancouver).

In 1958, the first cyclotron was developed in CIAE in China, which can accelerate proton, deuterium and α particles. The maximum energy of α particles can be 25 MeV. It was updated to energy of 28MeV during 1960s to 1970s. A 30 MeV cyclotron (CYCIAE 30) designed specially for producing radioactive isotopes for medical applications was finished at the end of 1994 by CIAE. It is used to accelerate protons and its current is about 350 μA. It can produce about 60 kinds of isotopes. CYCIAE 30 has produced 8 kinds of isotopes to use domestically or abroad, such as 18F, 57Co, 201Tl, 68Ge, 111In, 109Cd, 67Ga and 103Pd. CYCIAE 30 has very good stability, and its operating hours per year are shown in Fig.5.

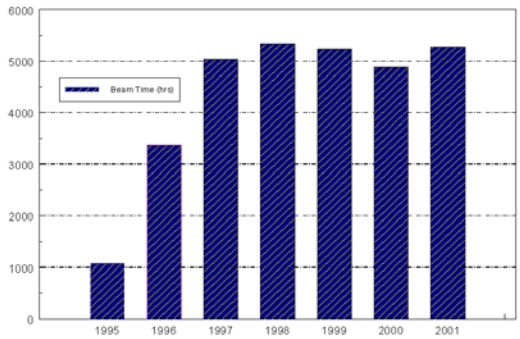

Figure 5: Operating status of CYCIAE 30.

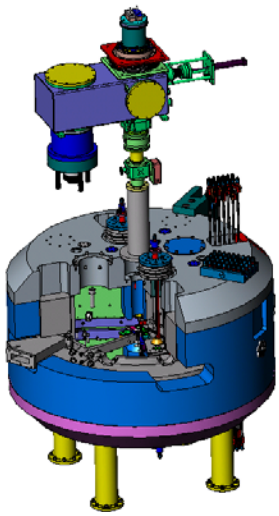

Figure 6: Main structure of CYCIAE-10.

A 10MeV high current small cyclotron (CYCIAE-10) is developing by CIAE (see Fig.6) [3], which can produce the isotopes for PET systems. The beam current will be 200~500μA. The main structure of the cyclotron is manufacturing and some of the sub-systems have been ready. Another 100MeV cyclotron (CYCIAE-100) is under design by CIAE to accelerator H^- ions, with beam current about 200 μA, which can be used for proton therapy.

Lanzhou Institute of Modern Physics (LIMP) also developed a 10MeV cyclotron as the proton injector of SSC. This cyclotron also can be used for PET to produce isotopes medicines. Its rf system works at 35MHz, and its average magnetic field strength is about 1.39T. It is under testing now (see Fig.7).

Figure 7: The 10MeV cyclotron developed in LIMP.

Until now, there are totally more than ten sets of cyclotrons imported from CTI, IBA, Ebco and GE, which are been using in hospitals of Beijing, Shanghai, Guangzhou and Kunming. They are used for producing isotopes for PET.

Proton and Ion-beam Therapy

Because of the Bragg peak in the absorption curves of proton and ion-beams, proton and ion-beam therapy has great advantages to x-ray and electron beam therapy. Proton and ion-beam therapy facilities are designed in HIRFL in LIMP. They are planning to use SFC and SSC to supply heavy ion beams of 100MeV/u, or to use PDC and SSC to supply 100-200MeV proton beams. The clinical experiments will begin this year [4].

Proton therapy facilities are going to be imported from IBA by China-Japan Friendship Hospital in Beijing and Wanjie association.

RADIATION PROCESSING

Radiation processing with accelerators is yielding tremendous industrial and societal benefits in the fields of polymer, healthcare, food and environment. As the economy situation in China is becoming better and better, the demands of accelerators for radiation processing are increasing. There are mainly two kinds of accelerators being developed for radiation processing in China, high voltage accelerators and high power electron linacs.

Cleaning Flue Gases by Electron Beams

The electron-beam (EB) technology to remove SO_2 and NO_x, has been developing for years in China. Two power plants in Chengdu and Hangzhou, have been installed EB flue gas cleaning systems, by Ebara Co. Some other power plants also want to use the EB systems. R&D of the EB technology for cleaning flue gases are done at LIMP in Lanzhou, Jiuyuan Co. in Mianyang, SIAP in Shanghai and Tsinghua University in Beijing. A high

voltage accelerator with electron energy of 650keV and beam current of 300 mA was developed in SINAP (see Fig.8).

Figure 8: The high voltage accelerator developed in SINAP for EB cleaning flue gases.

High Power Electron Linear Accelerators for Irradiation

These years, linacs were developed for mail processing against anthrax. A 2MeV linacs with beam power of 1kW and a 4.5MeV one with 2kW were installed in Beijing by CIAE and NUCTECH separately.

A 10MeV linac with beam power about 20kW for radiation processing is being developing by Beijing Atom Hightech Co. LTD. A 45kW klystron is used to supply microwave power to the travelling wave accelerating waveguide (see Fig.9).

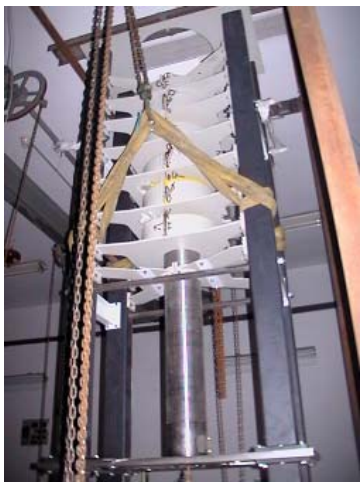

Figure 9: The 10MeV radiation processing travelling wave accelerating waveguide.

NONDESTRUCTIVE TESTINGS AND CARGO INSPESTINGS

These years, many linacs were developed by Tsinghua University cooperated with NUCTECH, BVERI and CIAE, used for NDT or in cargo inspection systems as the x-ray sources. The energy of the linacs was range from 1MeV to 9MeV, and the dose rate from 3cGy/min to more than 3000cGy/min. An x-band mini linac, HPBL (High Precision Baby Linac) ,has been developed in Nanjing University (see Fig.10). It works at 9370MHz, and uses a 300kW magnetron to supply the microwave power to a travelling wave accelerating waveguide. Its energy is about 1.6~1.8MeV, with x-ray dose rate about 6~8cGy/min.

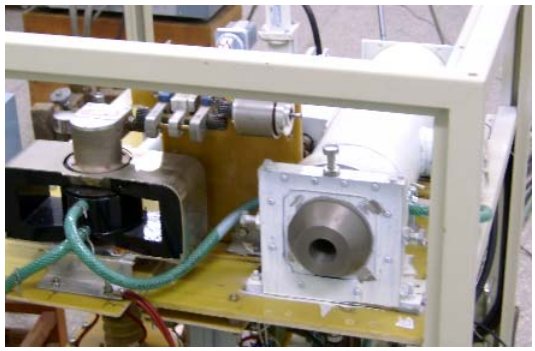

Figure 10: The X-band travelling wave mini linac by Nanjing University.

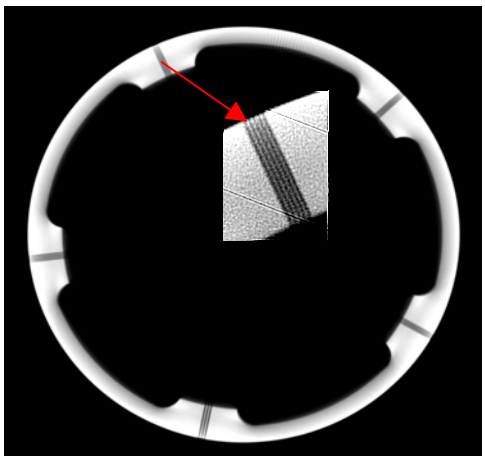

Figure 11: The CT space resolution testing picture by a ICT system with a 9MeV SW linac by CAEP.

A 9MeV electron linac with new standing wave structure was developed in CAEP, which is used for a ICT system (see Fig.11). The spot size of the linacs is about 1.4mm in diameter and the dose rate is about 3400cGy/min.

The industry of cargo inspection systems with electron accelerators as x-ray sources is growing rapidly, for the customs to against smuggles or checking cargos for safety. Until now, there are more than 70 linacs of different energy and dose rate have been manufactured by NUCTECH and Tsinghua University for cargo inspection systems. Among them, there are about 10 travelling wave linacs of 9MeV for fixed large container inspection systems, more than 35 standing wave 6MeV linacs for relocatable inspection systems, and about 25 linacs of 2.5MeV used for mobile systems. Except the 40 systems for China customs, NUCTECH has got more than 60 sets of orders abroad. More than 20 cargo inspection systems have been installed abroad, including Australia, Korea, Iran, United Arab Emirates, Turkey, Norway and so on. Fig.12 gives an example of the relocatble system installed in Sydney. Fig.13 gives another example of the pictures

detected by the relocatble system in Shanghai, in the cargo we can see the smuggling ivory.

Figure 12: The 6MeV relocatable system installed in Sydney.

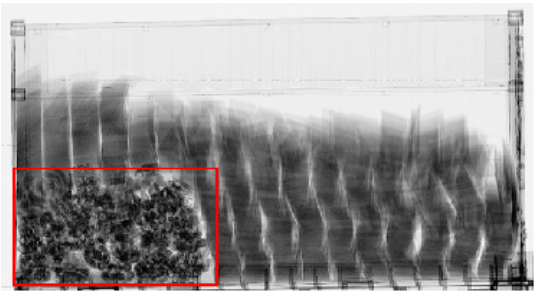

Figure 13: 3000kg of smuggling ivory, detected by relocatble system in Shanghai.

Figure 14: Inspection system with a 4MeV linac installed at Beijing West Railway Station.

New kinds of inspection systems are developed by Tsinghua University cooperated with NUCTECH, including the inspection systems for railway stations to inspect large baggages and railway containers (see Fig.14), which use 4 MeV linacs as x-ray sources. The mobile systems were also updated to mobile low-target systems, whose x-ray generated from targets much close to the ground. And a new s-band 2.5MeV linac was used in these kinds of systems.

A series of NDT linacs–HEXTRONs, with electron energy from 2MeV to 9MeV have been developed in Tsinghua University in cooperate with NUCTECH. Fig.15 gives the photo of the HEXTRON-3000, with electron energy of 9MeV and dose rate of 3000cGy/min.

Figure 15: The 9MeV linac HEXTRON-3000 for NDT developed by Tsinghua and NUCTECH.

ACKNOWLEDGEMENT

The author would like to thank Prof. Lin Yuzheng, Guo Zhiyuan, Zhao Hongbin, Zhou Wenzhen, Li Minxi, Zhao Minghua, Zhang Tianjue, Zhang Xiangyang, Zhao Zhentang, Xu Zhou, Zhang Huayi, Yuan Ping, Wang Zhenzhou for providing information and pictures.

REFERENCES

[1] Yuzheng Lin, “Applications of Low Energy Accelerators in China”, APAC’01, Beijing, China.
[2] Yuzheng Lin, “Applications of Low Energy Linacs in China”, Proceedings of LINAC2002, Gyeongju, Korea.
[3] Tianjue Zhang, Chengjie Chu, Zhengguo Li, et al, Medical Equipment Vol.16, No.9,2003, P28-32. (in Chinese)
[4] Wenlong Zhan, Medical Equipment Vol.16, No.9, 2003, P50-53. (in Chinese)
[5] Xiuqing Li, Medical Equipment Vol.16, No.9, 2003, P59-60. (in Chinese)
[6] Pu Chen, Zhonghui Zou, Chungen Chen, et al., Medical Equipment Vol.16, No.9, 2003, P61-63. (in Chinese)