LOW-ENERGY LINACS AND THEIR APPLICATIONS IN TSINGHUA UNIVERSITY*

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Abstract

Several kinds of low energy linacs were developed for cargo inspection, non-destructive-test and irradiation in Tsinghua University cooperated with NUCTECH. This paper gives some new applications of low energy linacs and discusses the new challenges of the electron linacs. The interlaced pulse dual energy 9/6MeV linac for material distinguishing cargo inspection and a fast-scan system using a 2.5MeV linac as its x-ray source are described.

INTRODUCTION

Low energy accelerators have been widely used in medical, industrial, environmental and security areas. Among them, low energy electron linacs play a key role at medical, non-destructive-test and cargo inspection applications.

Research work on low energy electron linacs and their applications began in 1970's at Tsinghua University. The first radiotherapy linac (BJ-10) was developed mainly by Tsinghua U. cooperating with others, which was a travelling wave linac with electron energy of 10MeV. After more than 30 years research on electron linacs, kinds of low energy linacs have been developed at Tsinghua U. and for different kinds of applications [1].

Now cargo inspection is becoming a very important aspect of the security. And most of the inspection systems are using electron linacs as their x-ray source. Some others use radioactive isotope, such as Co^{60}, and x-ray tubes. Because of the x-ray energy, their penetration ability is lower than those with linacs as their x-ray sources. Tsinghua U. cooperated with NUCTECH developed several kinds of cargo inspection systems, including mobile, re-locatable and fixed systems. And until to 2006, more than 100 sets have been ordered over the world. Now the main need of the inspection systems is for against terrorism. So the detection of explosive materials is the new challenge of the cargo inspection.

LOW ENERGY LINAC TECHNOLOGY

The requirement of market or user is much more important than the technology itself in the area of accelerator applications. There are several main technical itineraries should be considered according to the requirements.

Standing Wave (SW) or Travelling Wave (TW)?

Normally two kinds of standing wave accelerating structures are adopted in low energy electron linacs (see figure 1). The side-coupled structure is more common, for its high efficiency and easy to be tuned. In Tsinghua U., most of the SW accelerating tubes is on-axis magnetic coupled structures, with very thin coupling cavities about 2mm length at S-band.

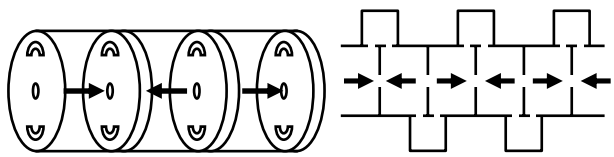

Figure 1: Two kinds of main SW structures, on-axis magnetic coupled (left) and side-coupled (right).

Although SW structures are compact, accelerating gradient higher and transverse motion of electron beam can be easily controlled by the RF field, TW structures are also often used for their high capture factor, wide band width and needn't isolation parts.

S-band, X-band, L-band or C-band?

S-band structures are the most commonly used, for the microwave power source of S-band can be easily bought commercially and is cheaper. As to the accelerating structure itself, the size of the cavities is about 10cm of diameter, not too large and not too small. But S-band power source haven't high average power, so that sometimes L-band is adopted for high average electron power linacs.

For portable linac systems, X-band is the best choice. The X-band linac is more compact than S-band, not only because of the accelerating structure is smaller, but also the microwave sub-system is much smaller than the S-band one. Because the X-band structure is very small and requires very strict manufacture and tuning technology, it's hard to do mass production. C-band is between S-band and X-band, should be a good choice. But because of lack of commercial magnetron or klystron suitable for low energy linacs, C-band is still very rare in low energy linac applications.

Figure 2 gives the 2.5MeV and 6MeV X-band SW accelerating tubes developed at Tsinghua U. The 2.5MeV ones have been used in the mobile cargo inspection system. The reason we used it in the mobile is its

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compact. And the 6MeV one was developed for medical applications.

Reliability and Stability are two very important factors during developing a commercial application linac. The performance meets the requirement, and makes the system simple to improve its reliability and stability.

Figure 2: X-band accelerating tubes, 2.5MeV (upper) and 6MeV (lower).

CARGO INSPECTION SYSTEMS

Nowadays, the illegal transportation of weapons of mass destruction, special nuclear materials, explosives and narcotics by containers is becoming primary focus against terrorism and smuggling. New equipments to fast scan the containers so as to achieve 100% inspection the containers import or export, and to identify materials so as to separate dangerous materials from others.

High Through-Put Systems

The traditional cargo inspection systems need the cargo stop and the driver leaving the cargo waiting outside of the radiation zone. One cargo inspection normally need several minutes, so that only about 20 cargos can be inspected one hour. To achieve high through-put, the cargo should be driven though the inspection area, or the inspection be integrated in the cargo transfer process.

A fast scan cargo inspection system THSCAN® FS3000 (see figure 3) was developed, which can satisfy the demand for fast scan containers. FS3000 can inspect 200-400 containers per hour, with scanning speed of 3.6~15km/h.

A 2.5MeV SW linac was used as the x-ray source. There are two key problems have to be resolved at the linac system. One is the fast beam on. Normal Linacs needs about 5 seconds to have a stable beam, but in FS3000 system, the cargo moving at 1m/s~4m/s means the cargo will be scanned at an unstable beam. And the driver is in the cab when the cargo is inspected. When cab passes the fan-shaped x-ray beam range, the linac will turn the beam on. So fast beam on and beam off are also important for the driver's safety. We designed the linac which needs less than 5 macro-pulses (about 0.1s) to get a stable beam.

The other problem is the repetition rate should be changing according to the cargo's speed. If the repetition rate of the linac is fixed, and when the speed of the cargo is changing, the image will be stretched or compressed (see figure 4).

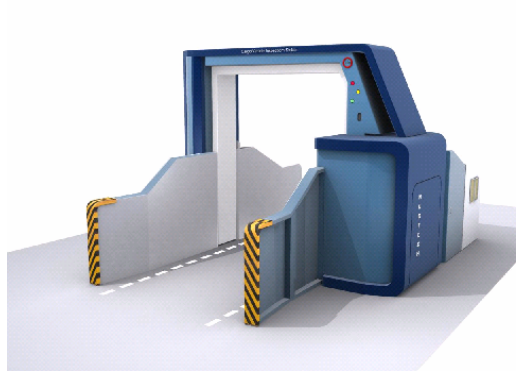

Figure 3: FS3000 fast scan system developed by Tsinghua U. and NUCTECH.

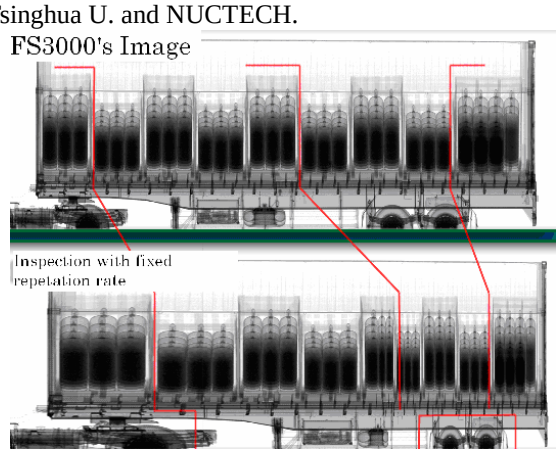

Figure 4: FS3000's inspection image (upper) and the image with fixed repetition rate (lower).

Dual Energy System

When an x-ray beam passes though the object, due to the attenuation effect, the passing X-ray will lose part of energy. There are three effects which can cause the attenuation: scattering, photoelectric and electron positron pair effects. The attenuation has relationship with the effective atomic number (Z), so that different material will cause different degrees of attenuation. So by comparing the X-ray images of various energy levels, identification of the effective atomic number (Z) can be achieved accurately [2,3].

A linac has been developed to emit an x-ray beam with one high energy pulse alternately, followed by one low energy pulse. The separation between two pulses is less than 4 ms, so that we can approximately consider the two x-ray beam transparent same part of the cargo. A magnetron is used as the RF power source in the linac, so

it's relatively compact than those using a klystron. The electron energy of this linac is 9MeV and 6MeV for the high and low x-ray beams (see figure 5).

Figure 5: Photo of the dual energy linac.

Two X-ray attenuation images are created after the scanning process is over. Then raw data will be processed by a sophisticated image registration algorithm, which means the process of image fusion, superimposition, weighting, matching or merge. Thereafter, high penetration, high contrast, and high resolution gray images can be obtained. After colorization, different types of materials will be painted with different colors. Figure 6 gives an image of a truck containing four types of items including organics, inorganics, light metals and heavy metals.

SUMMARY

Kinds of low energy electron linacs have been developed by Tsinghua U. and NUCTECH for cargo inspection systems and NDT applications. And high average electron power linacs for sterilization are also under developing.

The low energy linac is playing a more and more important role in industrial, medical areas and especially for against terrorism now.

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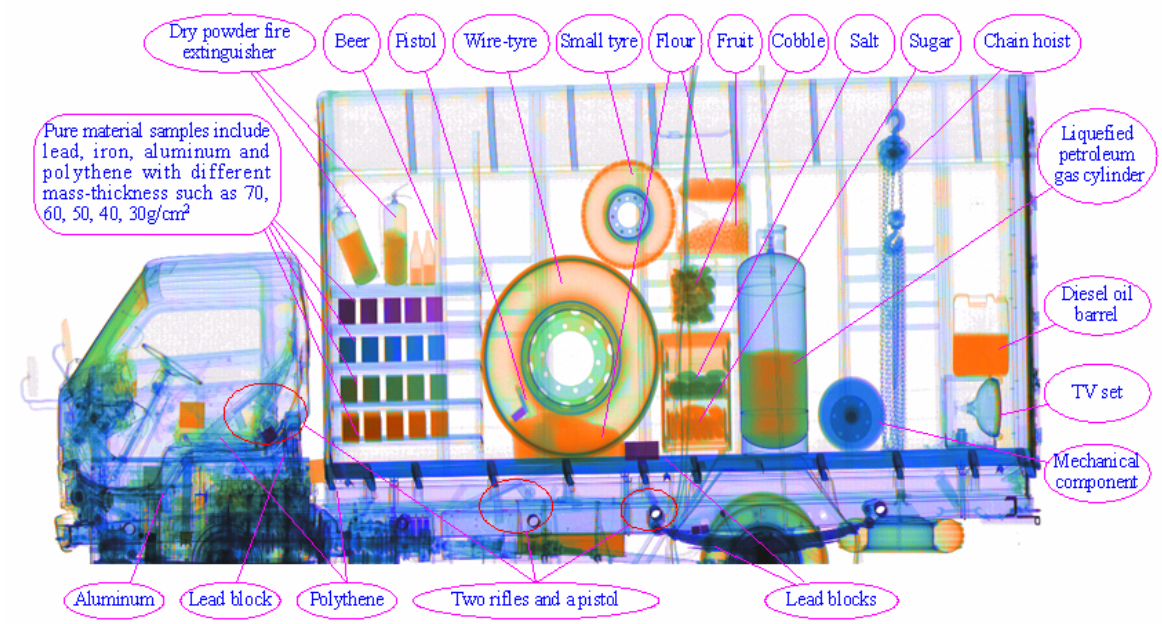

Figure 6: Image of the dual energy cargo inspection system.