SCANNING IMAGING WITH HIGH ENERGY PHOTONS

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ABSTRACT

SCANNING IMAGING WITH HIGH ENERGY PHOTONS

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An inspection system was required in order to eliminate the difficulties which appear during the inspection of the vehicles according to specific criteria at Turkish Custom Border in a short time and effectively. In this thesis, we performed experiments on such a system to obtain the overall performance of its inspection quality.

We firstly give with reasons, why the source of beam is selected as X-ray source. The subsystems of the main system are the accelerator subsystem and detector subsystem.

Their structures and working principles are studied in detail by comparing them with their alternatives.

Series of experiments are carried out to verify the general performance of system in terms of radiation security and quality of images produced by the system. These experiments were classified as general scan experiment, inspection performance experiment, image quality indicator experiment, radiation safety experiment and general performance experiment.

The container inspection system studied and experimented in this thesis is now used effectively in Turkish Customs Boarder, Edirne Kapıkule and Edirne İpsala.

Keywords: X-ray scanning system, X-ray imaging, X-ray detectors, transmission imaging, custom scanning.

ÖZ

YÜKSEK ENERJİLİ FOTONLARLA GÖRÜNTÜ ELDE EDİLMESİ

EMRE, Eylem

Yükes Lisans, Fizik Bölümü

Tez Yöneticisi: Doç. Dr. Akif ESENDEMİR

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Bu tez çalışması Türkiye gümrük kapılarından geçen araçların muayenesi sırasında araçların açılmadan iç ve dış görüntülenmesinin gerçekleştirilmesi amacıyla kullanılacak olan çok amaçlı ve bilgisayar destekli bir tarama sisteminin tasarım, performans, güvenirlilik açısından incelenmesi ve gerekli uygunluk değerlendirme testlerinin yapılışını amaçlar.

Bu tez çalışmasında, öncelikle görüntüleme sistemlerinde neden X-ray teknolojisinden faydalanıldığı sebepleri ile birlikte verilmiştir.

Sistemin alt birimleri, hızlandırıcı alt sistemi, detektör alt sistemi ile beraber incelenmiş, ve alternatifleri ile karşılaştırılarak değerlendirilmiştir.

Sistemin genel olarak yeterliliğini, radyasyon güvenliliğini ve elde edilen görüntü kalitelerini değerlendirebilmek amacıyla bir dizi fiziksel testler yapılmıştır. Bu testler tez çalışması kapsamında, genel tarama testi, görüntüleme performans testi, imaj kalitesi testi, radyason güvenliği testi ve genel performans testi başlıkları altında toplanmıştır.

Bu tez çalışmasında incelemesi yapılan tarama sistemi şu anda Türkiye’ nin Avrupa’ya açılış kapısı olan Edirne Kapıkule ve Edirne İpsala sınır kapılarında kurulmuş olup etkin bir biçimde kullanılmaktadır.

Anahtar sözcükler: X-ray tarama sistemi, X-ray görüntüleme, X-ray dedektörleri, görüntü iletimi, gümrükte tarama.

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CHAPTER 1

INTRODUCTION

Due to a strong growth in the transportation of the various goods through the borders of the neighboring countries, custom officers need more efficient and effective inspection methods in order to answer the following questions:

- Are the goods those of forbidden to enter to the country?
- Are there smuggled loads ?
- Are the amount and the sort of loads the same with the amount and sort of the loads informed before?

Most of the goods are transported in containers. Therefore, to answer the above questions those containers must be inspected. This inspection may be accomplished with the traditional ways but the goods which are transported in a container cannot be seen or touched from their surface without opening the containers. The goods in the containers can be very pressed so that they cannot be moved and inspected in traditional ways. Some gases are used in the containers, to keep the load in good condition. Such a container should be inspected without opening in order not to damage the load. Traditional inspection leads to waste of time and economic loss.

Furthermore an important question is who must pay the costs in the event that the vehicle or the container must be unloaded for further inspection and reloaded again (stripping and stuffing). The load transported in the container can be very dangerous to the human health, for examples gaseous materials. Opening such a container will pose a health hazard. In such conditions inspection requires without opening the container.

Since scanning systems found to be suitable for container inspection, they are widely used around the world. Simply, a scanning system is formed with a radiating source where the radiation crosses the container, and a detector which records the beam intensities and construct an image for eye inspection. The details of such a system is presented in Chapter 3.

The radiation source of such a systems must be so selective that it should not give any damage to the goods which are inspected. Various radiation sources are discussed in the following Chapter. Sources other than X-ray and radioactive elements are not so suitable for such an inspection system. But in that case some materials can not be examined using those radiations such as photographic material. By checking the manifest (custom declaration) one must decide about the inspection in order to reduce the risk.

The inspection duration of each container is the most important parameter at a custom. The allowed inspection duration is inversely proportional to the number of containers per hour. Furthermore, resolution of the obtained images are directly proportional to allowed duration. Therefore, the optimum scanning speed and the resolution at that speed must be known before usage.

In this work, the optimum scanning speed which depends on the inspection duration and the resolution of the scanned images determined at Kapıkule custom border through various experiments. The obtained results are compared with the statistical data and discussed in the conclusion.

Any inspection system which uses high energy photon beam, can cause some contamination which may be dangerous for the human health. Measurement of contamination around the system was necessary. The measured contamination values at several locations around the system are also done an compared with allowed values of World Health Organization (WHO).

CHAPTER 2

THE IMAGE CONSTRUCTION AND THE ELECTROMAGNETIC SPECTRA

Transmission image construction involves three basic concept. First, there must be a beam of radiation source where the photons will cross the objects and will be detected at the other side. Second, there must be some material on the optical path of the generated photons to modify the detected beam intensity. Last, some detectors must be used in order to record these modulated radiation. Therefore, we need to select some interval on the electromagnetic spectra such that the photons will cross the container and then will be detected at the other side.

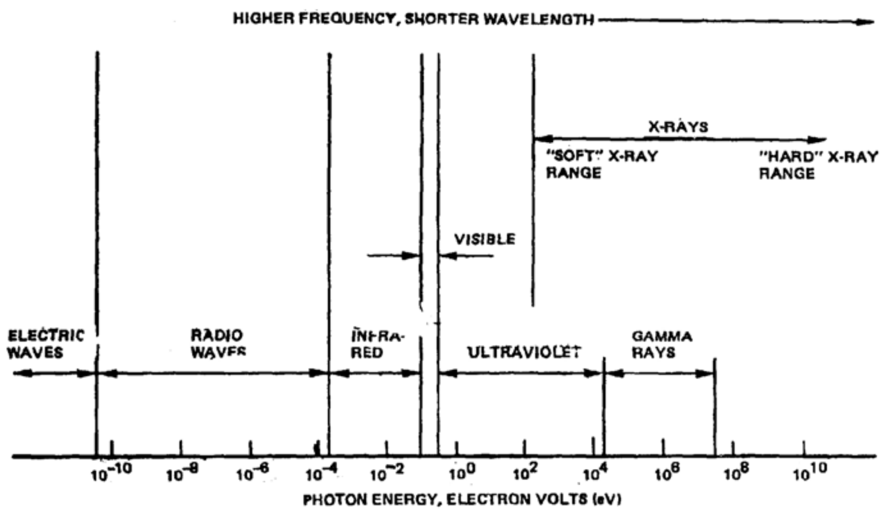


Figure 2.1. The electromagnetic spectrum [1]

Different regions of the electromagnetic spectra are named differently as shown in Figure 2.1. There are no sharp, natural boundaries or exact, fixed, limits in between the regions. The photons which may cross a container through must have an energy of 6 MeV at least . At this energy it is possible to use γ or X-ray sources. X-ray photons are produced by accelerated electrons, while γ-rays are produced by a radioactive materials. Since γ-rays are not easy to handle for imaging, X-rays are preferred.

The modern device for generating X-rays is called an X-ray tube. X-rays are produced when high speed electrons are suddenly stopped by a solid object. Thus to generate X-rays we need a source of electrons, a means of accelerating them, a target to stop them. Electron gun is the electron source of the accelerator that emits electrons of a certain magnitude of energy and current into the standing-wave accelerating cavity which is used to accelerate and energize electrons nearly up to near light speed with the axial standing wave electric field. It is made up of a cathode, a focusing electrode and the anode. When electron gun is heated by the filaments, the cathode of the electron gun can emit electrons and when high voltage is added to the cathode, electrons can be drawn out from the anode and shot into the standing-wave accelerating cavity. At the end of the accelerating process, electrons are shot on the target to produce continuous spectrum X-rays.[2] Accelerating process is explained in the following chapter in details.

2.1 ATTENUATION AND MATERIAL ABSORPTION CHARACTERISTICS

All matter is made up of atoms. Each atom is in turn made up of a nucleus surrounded by electrons in discrete energy levels. The number of electrons is equal to the atomic number of the atom, when the atom is in the ground state. When a beam of X-ray photons is incident upon matter, the photons may interact with the individual atomic electrons. Figure 2.1 shows these mechanisms. Here a beam of X-ray photons intensity $I_0(\lambda_0)$ falls onto a specimen at some incident angle. A portion of the beam pass through the matter and the transmitted portion is given by the expression[3].

$$I_x = I_0 e^{-\mu x} \qquad (2.1)$$

where

I_x :beam intensity after penetrating a distance x

I_0 :original beam intensity (at x =0)

μ : attenuation coefficient (cm^{-1})

x : distance of penetration (cm)

This law is not always exactly applicable. It is correct only when the beam is narrow and parallel beam, with only one wavelength or photon energy present, with no selective absorption or scattering, and the material is of uniform density. It basically is the law, however, upon which X-ray images are established. It shows the changes in the energy or the intensity of the beam that accounts for the contrast seen in recorded images.

In place of the attenuation coefficient, the absorption coefficient is often used. The absorption coefficient relates to actual photons lost and does not include those photons which leave the beam due to scattering. Therefore, the attenuation coefficient is always larger more than the absorption coefficient.

The attenuation or absorption varies greatly with the energy of the photons or wavelength spectrum and with the type of material, and they are defined for only idealized conditions.

These coefficients are often expressed as a mass absorption or mass attenuation coefficient, μ_m, derived by dividing linear absorption coefficient (μ) by the density of the material (ρ). This allows these equations to be used where variances in material densities are expected. Also, separate elements combined either chemically or physically into material compounds can be considered.[4]

These relationships are:

$$I_x = I_0 e^{-\mu_m \rho x} \tag{2.2}$$

or

$$I_x = I_0 e^{-(\mu_{m1}\rho_1 + \mu_{m2}\rho_2 + ...)x} \tag{2.3}$$

where

μ_{m1} : mass attenuation coefficient for element 1

ρ_1 : mass density of 1, as part of the total density of the compound.

In almost all practical situations, the amount of radiation that pass through a material is greater than the amount represented by Eq.2.1, Eq.2.2 or Eq.2.3, and this increase in penetration over that theoretically estimated value is called “buildup”. It is due to the gain obtained from photons being scattered into (or back into) the beam path, re-radiation from ionized atoms, energy from combining electrons-positrons, or new radiations from the energetic electrons that were ejected in the original absorption process. It must be noted that, because the absorption or attenuation is an exponential function, practically shielding can not stop all the radiation even from a weak source. Therefore, a safe level of radiation can usually be achieved and maintained.

Any beam that radiates from a localized source will exhibit an intensity loss because of the geometric increase in the area of the distribution as radiation proceeds from the source. Theoretically, for a point source, this geometric factor will be proportional to $\frac{1}{d^2}$ where d is the distance from the source. For electromagnetic beams, there are other losses in intensity due to interaction with matter that may be located in the path of the beam. There are several kinds of interactions between photons and matter: simple scattering, photoelectric absorption, Compton scattering, These interactions are described below.

a) Scattering (includes Rayleigh scattering).

When photons approach close to charged particles (normally the "orbital" electrons around a nucleus) the directions of some of the photons can be changed with no measurable loss in their energies. The amount and degree of direction changes depends on the number of particles present within the medium and their relative size[2].

b) Photoelectric Absorption.

When a photon passes through matter, its entire energy can be transferred to a bound electron. The photon thus ceases to exist giving part of its energy to eject the electron from its orbit and the remainder impart to the velocity of the ejected electron. This phenomena is known as photoelectric effect or photoelectric absorption (see Figure 2. 2). Radiography is most often dependent upon this absorption process which is usually the most predominant mechanism for photons with energies of 0.5 MeV or less. Photoelectric absorption is an ionization effect that can result in the release of negligibly small-energy photons when the atom returns to its normal state[2].

c) Compton Scattering.

A photon can interact with an orbital electron and transfer only a portion of its energy to the electron. This effect is called Compton scattering (see Figure 2. 2) and often occurs when the photon energy ranges from about 0.1 to 3.0 MeV. Part of the photon energy is expended in dislodging the orbital electron and imparting velocity to it. The remainder of the photon energy continues on as a lower energy photon at an angle with respect to the original photon path[2]. This process can be repeated, progressively weakening the photon until a photoelectric effect completely absorbs the final photon.

Most of these interactions result in losses in the x-ray intensity. This mechanism is normally a minor part of the whole, and because there is a large amount of randomness in its directions, it is usually of no value and can actually cause a blurring of the X-ray image along with the rest of the scattering that occurs.

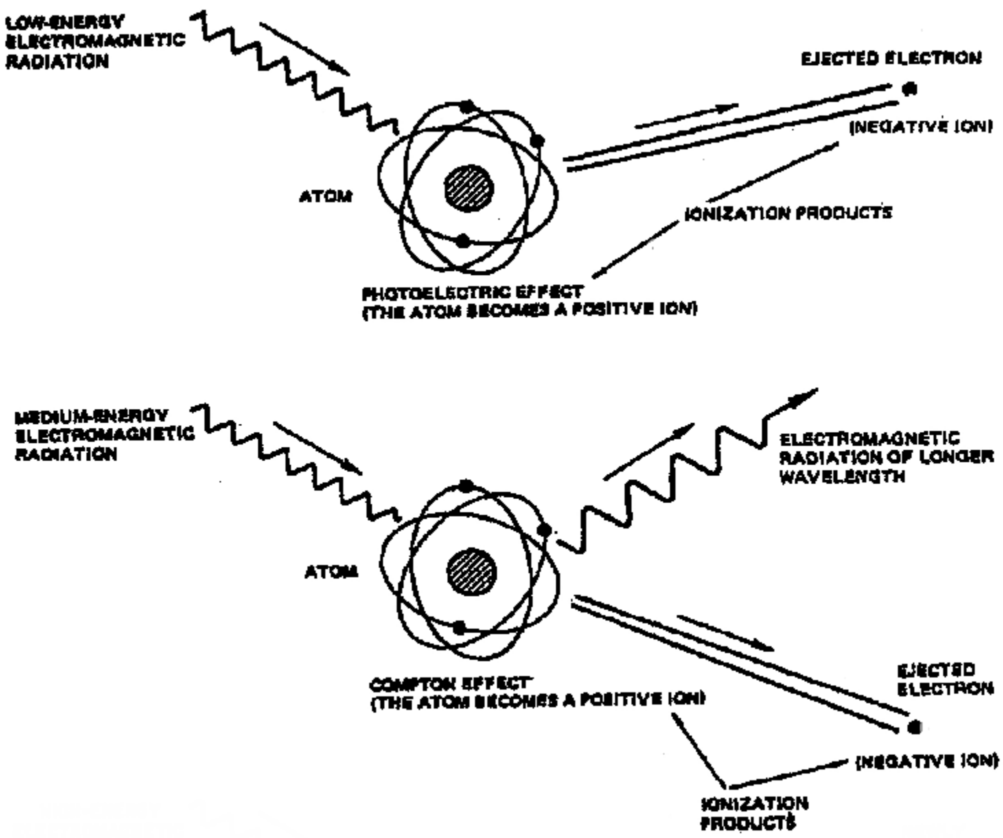


Figure 2.2 Ionization interactions of photons with matter [1]

As a result of these discussions, attenuation depends on the material properties and wavelength of the photons or the intensity of the beam. It is also worth noting that mass absorption coefficient (μ/ρ) of materials is proportional to the atomic number (Z) of the materials. At this point, it is easy to say absorbency of *Pb* with atomic number Z=82 is higher than *Cu* with atomic number Z=29. Sheet lead is thus one of the most commonly used shielding material because of its high atomic number. On the other hand, it should not be neglected that accurate calculations can be made with equation (2.2) only when the quantities μ and ρ are known for the specific wavelength concerned.

2.2 PRINCIPLE OF TRANSMISSION IMAGE FORMATION

Radiation imaging system is a kind of up to date development and sophisticated application of the nuclear technology research. With the penetrating power of X-rays, the radiation-imaging system can be used to observe and analyze the structure and composition of interior objects with the help of their images.

Radiation image-formation is to produce or turn out pictures or images of objects by means of rays generated by any radiation source. The radiation images we usually deal with are X-ray for medical purposes in radiographic inspection. Comparing it with ordinary photograph in our daily life, the basic difference is that the former produces images of the interior of objects, while the latter produces images of the outside of objects.

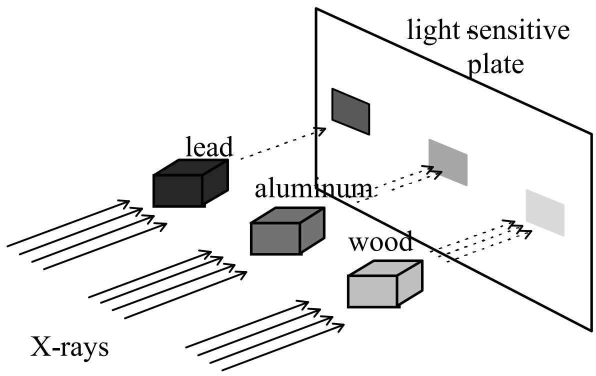


Figure 2.3 The Difference in X-ray Absorbency of Matters With Different Densities [2]

The most commonly used ray in radiation image-formation is X-ray. Compared with ordinary light, it has shorter wavelengths, higher energy and stronger penetrating power, but it is dangerous to human eyes. If X-rays could completely penetrate objects, it would be impossible for us to take advantage of the pictures of the inside of objects taken by X-rays. They are partly absorbed when traveling through an object, and the amount of absorption depends on the object density. This is in fact the reason why we can get the image of the interior of the objects concerned. Thus we know that the pictures directly taken with X-rays are actually the distribution map of matters with different densities, as shown in Figure 2.3 [2]

Traditional X-ray image-formation device is similar to ordinary photograph, both including optical source, imaging device and media for transferring and displaying images, as illustrated in Figure 2.4a and 2.4b. The main difference between the two is that the former takes visible light, such as sunlight and lamplight as its optical source, while the latter uses X-ray source.

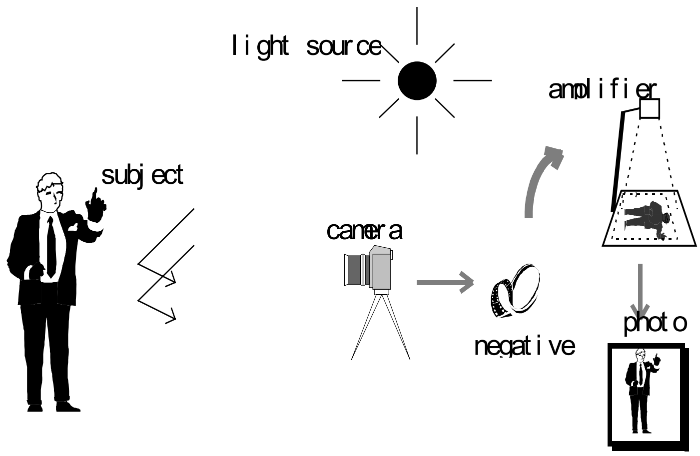


Figure 2.4a Traditional Photography [2]

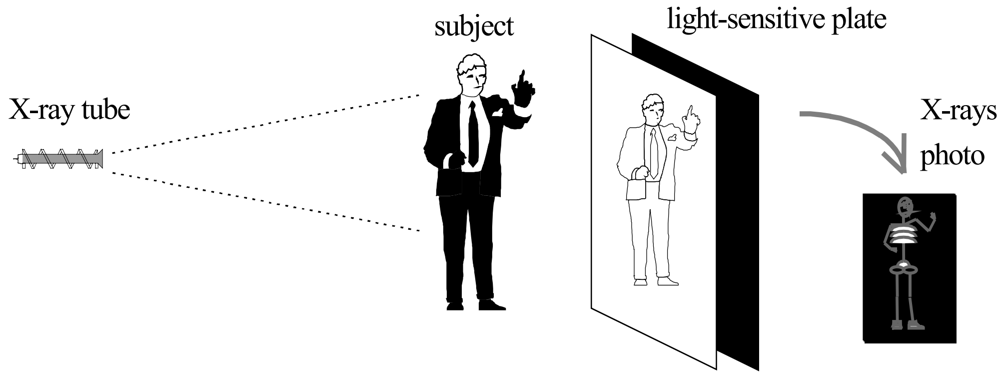


Figure 2.4b Traditional X-ray Imaging Technique [2]

Following the advancement in computer technologies, more and more image-producing systems begin to adopt digitalization systems. The difference between traditional system and digitalization system lies in that the former takes film to record image information while the latter takes digitized data. In addition, these data can be transferred and copied with media such as disk, CD-ROM and modern information network. The data can also be conducted to process various information items on a computer.

To get a X-ray digitized image, there must be an electronic image acquisition device to formulate and then give off the image from the original image details. Unlike the regular camera generally producing images in a CCD (Charge Coupled Device) planar array to convert images into electronic signals; the X-ray digitized image-formation systems uses a special X-ray sensing device to get the necessary image messages. So an X-ray sensing device is often called detector.

On the other hand, it is only when processed by a special image sampling and converting circuit that the electronic signals can be transformed into data for further processing and display. While the circuit in digital cameras is often made of special image sampling chips, the circuit in X-ray digital image-formation system is made of specialized image acquisition units.

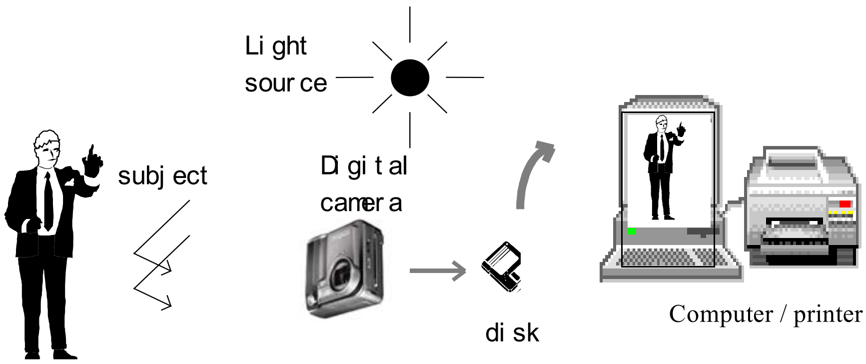


Figure 2.5a Digitized Photography [2]

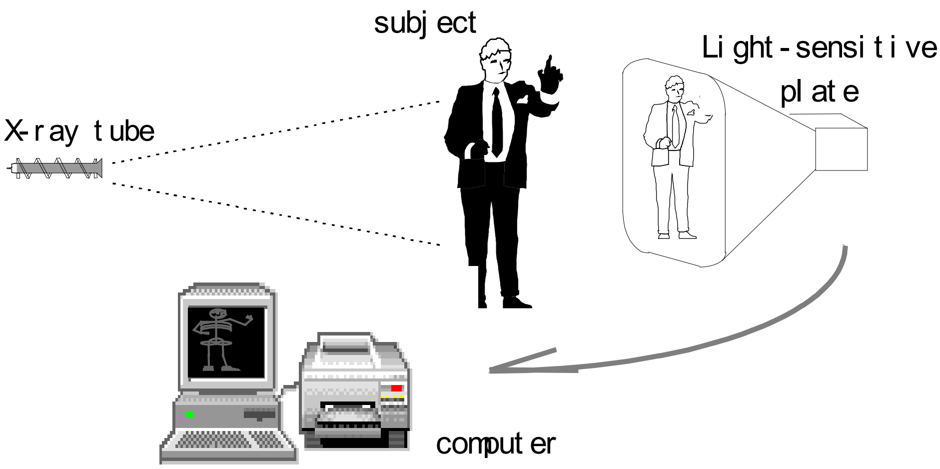


Figure 2-5b Digitized X-ray Imaging Technique [2]

Difference between traditional camera and a digitized image-formation system is that the former records its image messages directly on the film visible to human eyes, while the latter displays its imaging messages on a computer or particular device for the observer to see and analyze directly. Figure 2.5a and 2.5b summarize the digitized photography and x-ray imaging.

For digital imaging it is only necessary to use a special computer image processing system to present and analyze the image data or messages.

As it has been mentioned above, a basic X-ray digital image-formation system should be made of, at least, the following four parts:

- Radiation source
- Radiation detector
- Data acquisition and transmission device
- Image processing system

which is shown in Fig.2.6 as a block diagram.

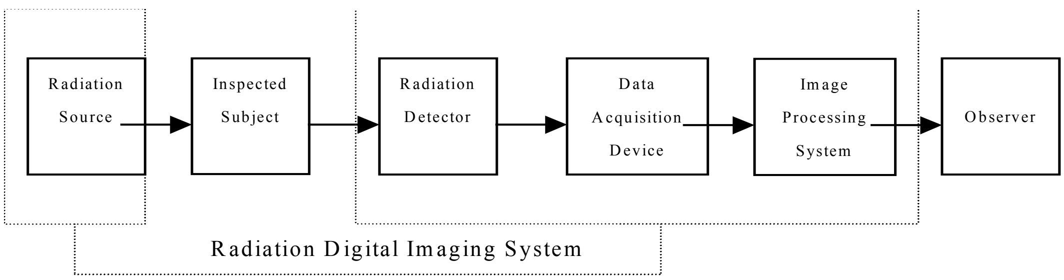


Figure 2-6 The Composition of a Radiation Digital Imaging System[2]

The image-formation mechanism in a container-cargo inspection system is also different from a general purpose X-ray image-formation device for the sizes of objects to be detected is quite different. An ordinary X-ray image-formation system (for example, a medical X-ray image-producing system or a small baggage inspection machine) can be named as a camera, while the container inspection system is more likely to be named as a scanner. Since the objects for the latter to be inspected is usually very large in size, but still high resolution for inspection is needed. Just for this purpose it is essential for a container inspection system to adopt scanning image-formation technology.

Similar to an ordinary scanner, the container inspection system should also be mobile so as to be able to move or turn itself in accordance to its X-ray source and image-formation device during image processing. X-rays, after passing through a narrow slit, penetrate through the container, and then travel across another narrow slit, and will finally be transmitted into the image-formation device. However, what the image-formation device is needed is merely part of container images, just an array of the image in each sampling activity. With the scanning progress going on, these image arrays will eventually form a complete perspective picture of the container as the result of the computer image processing. In most cases, such scanning process is accomplished in a special scanning device. In order to ensure the success of the comprehensive inspection, a control system is needed to coordinate or monitor the whole inspection practice.

Another important point is that X-rays is harmful to some extent to human beings, therefore, it is necessary to attach a set of auxiliary radiation safety devices and radiological safety protection mechanisms. With the help of the safety units, only a part of the radiation image-formation energy is used to the inspection purpose while the rest is prevented or absorbed by the radiation prevention shield and protection attachments.

Digitized radiation images are formed from the image-formation producing system. The purpose of a radiation image-formation unit is to convert the detailed image messages imperceptible for human eye into visible images. In the traditional method, an optical imaging system is made up of light source, visual information sensor, visual signals conversion, transmission device and the image synthesizer. Likewise, a typical radiation digital image-formation system consists of radiation source, radiation detector, data acquisition, transmission device and the image processing device.

Radiation sources for general purposes usually include X-ray tube, radioactive isotope, accelerator, and so on. The rays penetrate the detected subject and then are incepted by the radiation detector. The most common radiation detectors are gas ionization detectors, scintillation detectors and semiconductor solid detectors. After incepting rays, the detector converts them into analog voltage signals or current signals, and then sends them into the data acquisition system with the data transmission device. The data acquisition system is in charge of incepting electric signals from the detector, and converting them into digital signals recognizable to computers after a series of preprocessing and then transmitting them to the image processing system. As a part of a general- or special-purpose computer, the image-processing system is in charge of processing the input data in accordance with the instructions given by the data acquisition and transmission device, and finally produces digital images. The images will then either be displayed on the monitor of the image processing system or be stored in the data memory units for later use [1].

CHAPTER 3

STRUCTURE AND WORKING PRINCIPLE OF THE SYSTEM

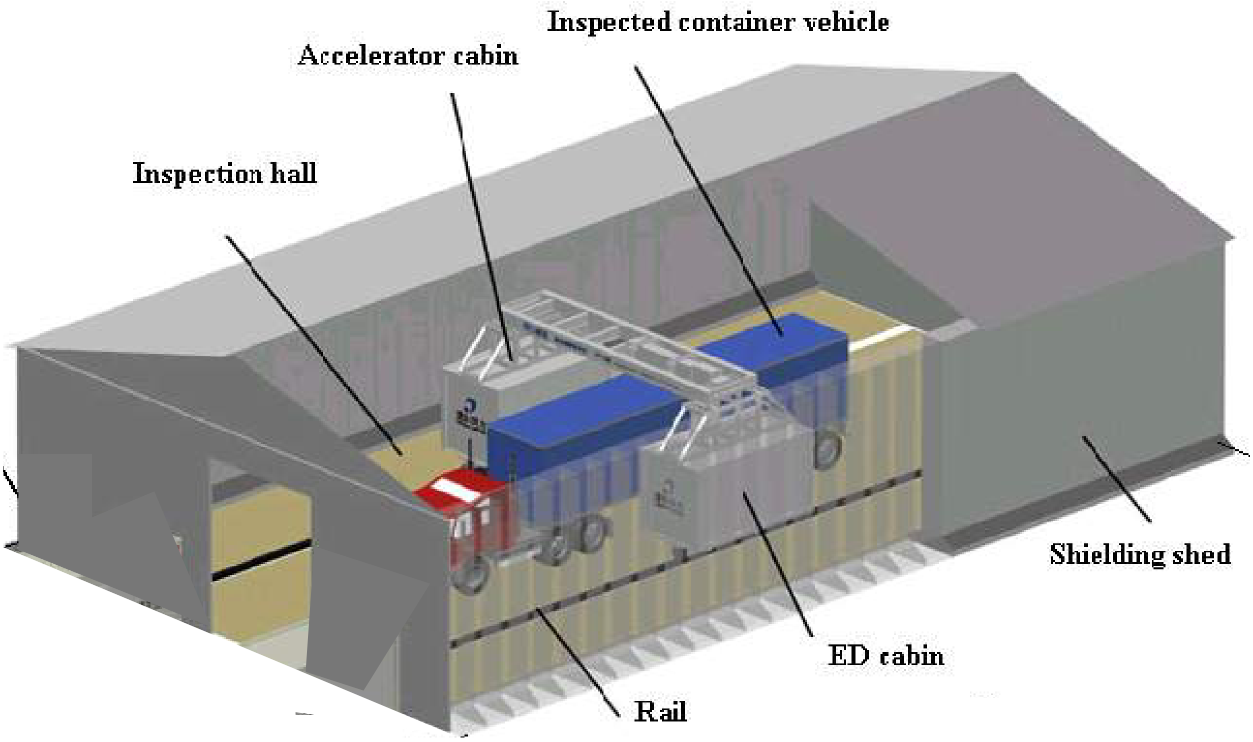
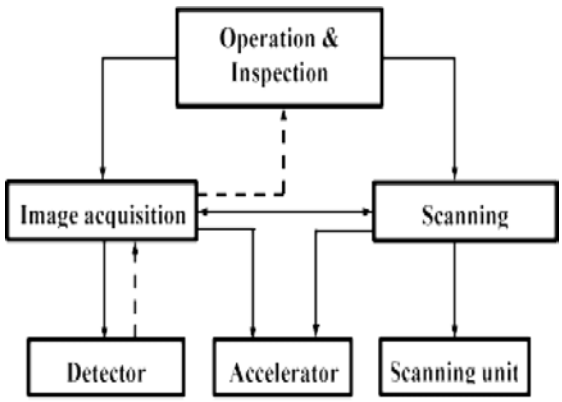


Figure 3-1 The Configuration of the System [2]

Generally, there are three types of container inspection systems working at custom border sites. These are mobile container inspection systems, relocatable container inspection systems and fixed container inspection systems. Although installation of these container inspection systems at custom border sites, energy of X-rays they produced and the aim of special usage or their some structural components can be various, the working principles and the general structure of these systems are basically the same.



Control signal:———▶

Data image   :--------▶

Figure 3.2 Logical diagram of the system [2]

The system which is investigated at this study is a relocatable container inspection system. Basically, such a container inspection system is made up of five subsystems as Accelerator Subsystem, Detector Subsystem, Image Acquisition

Subsystem, Operation Control Subsystem and The Scanning Unit Subsystem. These individual subsystems work dependently on each other. The relation between these subsystems is indicated in the Figure 3.2.

The Accelerator subsystem is the radiation source of the inspection system and emits pulse X-ray under control. It consists of an X-ray head, a modulator, a water cooling system, and other accessories. The detector subsystem receives the pulse X-ray photons after having passed through inspected objects, and converts them into corresponding current signals. The Image Acquisition subsystem converts the current signals into imaging data. The Operation Control subsystem is used for controlling the scanning to the inspected container and providing the safety interlocking logic control for radiation protection. The Scanning Unit subsystem loads all the subsystems above and carries out automatic scanning under the operator's control.

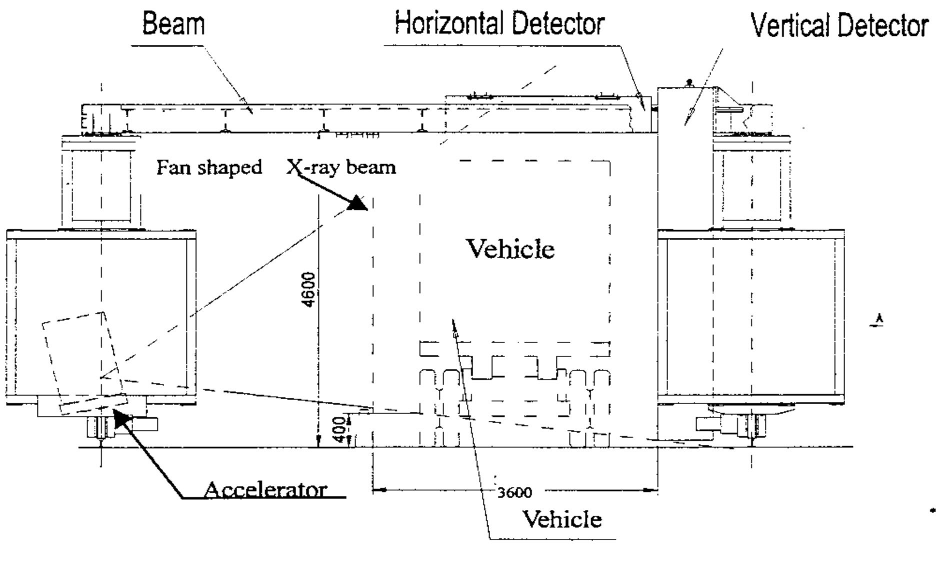


Figure 3.3 Main components of the Container Inspection System [5]

It is seen from Figure 3.1 and Figure 3.3 that how the relocatable container inspection system works in an inspection hall. Accelerator cabin, ED cabin (Electronic Device Cabin) and pen-shaped detectors can move on the rails between scanning starting position and scanning terminating position backward and forward by speed between 50mm/s and 300 mm/s (See Figure 3.4). Container which will be inspected or scanned is fixed during forward and backward movement of inspection system between scanning starting and scanning terminating position.

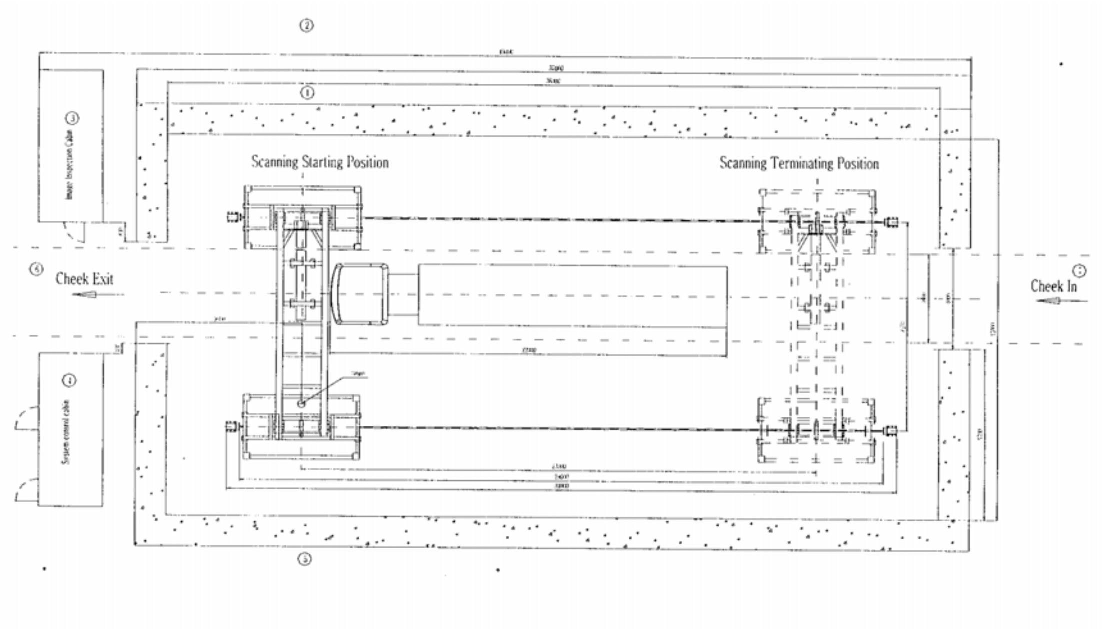


Figure 3.4 Scanning Starting Position and Scanning Terminating Position [5]

Average scanning process time is measured as two or three minutes. “After X-rays with energy of 6 MeV, which is produced by the X-head in the Accelerator Cabin, pass through the collimator with an angle of 45° (+37.7 °~-7.3°)” [5], they are sent in the form of fan-shaped to the container to be inspected during the scanning process. Some part of total energy of X-ray beam is lost by attenuation. Some other part of energy of X-ray is lost during the passing through the container. Since the paths of X-rays beam which arrives to array of detectors have different angles, length of their paths are also different (See Figure 3.3). As a result, some of X-ray beams thus travel much more distance than the others when they arrive to the array of detectors, so the number of photons changes. These different energy losses causes contrast differences at the obtained images during the scanning process. These differences must be eliminated by detector calibration. A calibration device is needed for detector calibration and details about calibration technique and calibration device are summarized in Chapter 4.

3.1 THE ACCELERATOR SUBSYSTEM

3.1.1 MAIN COMPONENTS OF THE ACCELERATOR AND PRODUCTION OF X-RAY

The accelerator subsystem produces relatively strong penetrative X-rays. Figure 3.5 shows the details of accelerator components. The whole system has the parts: X-ray head, modulator, water cabinet and voltage stabilizer. The circuit of the automatic frequency control is installed in the box of the X-ray

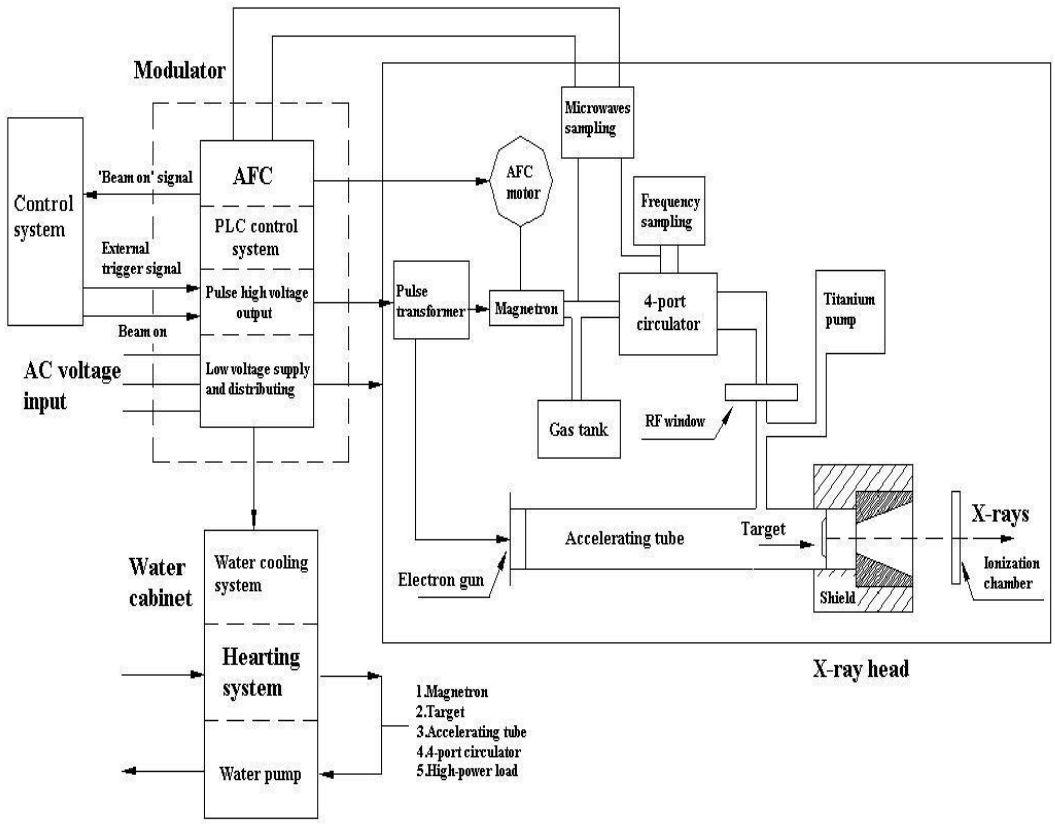


Figure 3.5 Internal Structure of the Accelerator [2]

head. PLC (Programmable Logic Controller) control system is installed in the modulator cabinet. In addition, there is a system interconnected by water pipes and cables.

X-ray head refers to X-ray cabinet or X-ray radiator. The X-ray head is the core part of the accelerator subsystem. It is made up of an accelerating cavity (including electron gun, target and Titanium pump), Tungsten Shield, RF transmission system (including various waveguides, four-port circulator, high power load, low power load), pulse transformer, magnetron, AFC, gas filling system and water cooling tubes.

In the Accelerator subsystem, X-rays are generated in the following steps: High voltage pulse generated by the pulse modulator is delivered to the primary windings of the pulse transformer in the X-head through the high voltage cable. One second winding of the pulse transformer supplies power for the electron gun in the standing-wave accelerating cavity and injects the electrons emitted from the electron gun to standing-wave accelerating cavity. Another second winding of the pulse transformer is added to the magnetron. Radiation frequency microwaves generated by the magnetron are delivered to the accelerating cavity through RF transmission system, and form the standing wave electric field there. Electrons, accelerated in the accelerating cavity, strike the target and produce a spectrum of X-rays.

The electron gun is the electron source of the accelerator that emits electrons of a certain magnitude of energy and current into the standing-wave accelerating cavity.

It is made up of a cathode, a focusing electrode and the anode. The indirect heating oxide cathode used in the electron gun has low working temperature and high emitting current density. The current for heating the filaments is about 2A and the pulse voltage is about 10 kV. When it is heated by the filaments up to 1000C, the cathode of the electron gun can emit electrons and when 10KV high voltage is added to the cathode, electrons can be drawn out from the anode and shot into the standing-wave accelerating cavity [2].

The function of the standing-wave accelerating cavity used in this system is to accelerate and energize electrons nearly up to near light speed with the axial standing wave electric field in the accelerating cavity. At the end of the accelerating process, electrons are shot on the target to produce continuous spectrum X-rays.

As standing wave mode is concerned, the tail of the accelerator structure is connected with short circuit plate, instead of a matching load, thus, the RF is reflected at the tail and follows the opposite direction in which electrons are accelerated. If there is also a short at the head of the accelerating structure, then the above reflecting power is reflected again at the head. If the electronic length of the accelerating structure is adequate, then the reflecting wave and the incident wave achieve identical phases, and therefore the reflecting wave is strengthened and the electric field intensity increased.

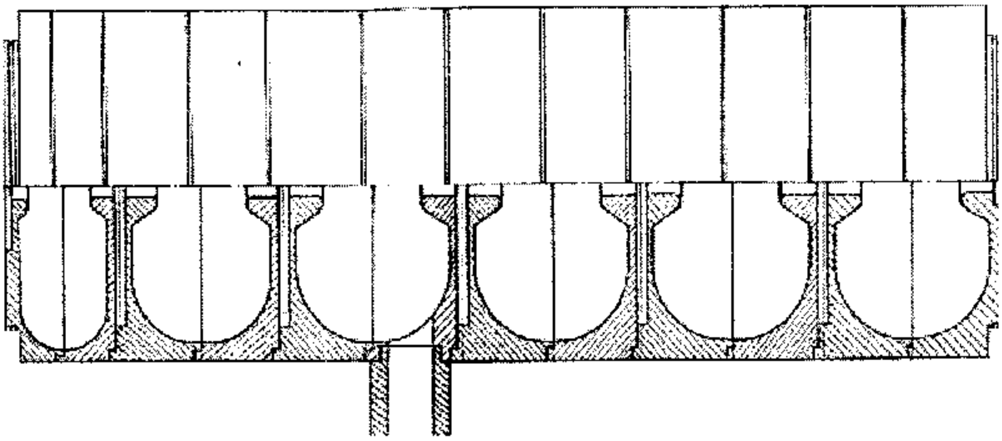


Figure 3.5 Cutaway view of the accelerating cavity [2]

In this way standing wave can be considered as a superposition of forward moving and backward moving traveling waves. It is advantageous to use the standing wave acceleration when the accelerating structure is comparatively short, because of the same RF power, standing wave acceleration can energize electrons to a higher level.

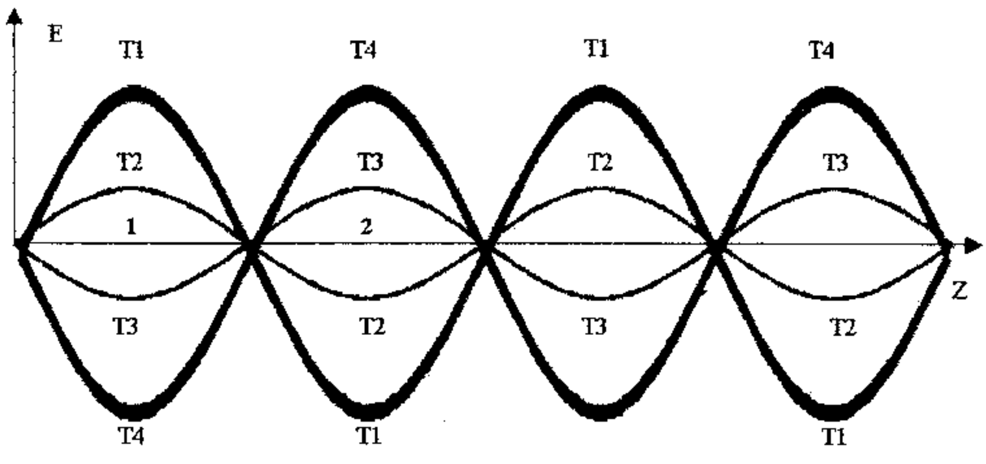


Figure 3.6 Envelope of the Electromagnet Field inside the Accelerating Cavity[2]

No matter which type of standing wave structure, it can be considered as a chain of resonant cavities coupled in certain ways. There is hole in the axis of the resonant cavity to allow electrons pass through. Along the accelerating cavity an axial electric field is produced, whose intensity and direction alter with time. However, the envelope does not move, and hence is called the standing wave. The field intensity of the electromagnetic field in cavity 1 gradually decreases with time. When its direction is suitable for accelerating electrons, the field in cavity 2 is decelerating. After a while when the field in cavity 1 decreases with time to a negative value, the direction of the field in cavity 2 becomes suitable for accelerating electrons. Therefore, to emit electrons into cavity 1 at the moment its electric field direction changes from negative to positive, the further the electrons advance, the stronger the field intensity and the higher energy level of the electrons. When the field intensity mounts up to its peak value, the electrons arrive at the very center of the cavity. Then the field intensity begins to decrease while the electrons travel in the second half of cavity 1. When the field intensity turns from positive to negative, the electrons leave cavity 1 and enter cavity 2 whose field intensity turns from negative to positive; therefore cavity 2 can continue to accelerate and energize the electrons. If the above arrangement can be realized, then the electrons can be continuously energized. This is the process of the standing wave acceleration. Its necessary to design the structure of the accelerating cavity in a way that will enable the RF entering the accelerating cavity to set up and electromagnetic field that can satisfy the above accelerating and focusing requirements mentioned and also improve the accelerating efficiency. This is the key issue of the theoretical research in the accelerator [2].

Since the speed of the electrons is relatively low at the beginning of the accelerating process, the first several resonant cavities are of relatively shorter length. After having been accelerated by several cavities, the speed of the electrons approaches to light speed and maintains this magnitude while their energy keeps increasing. Therefore the latter several resonant cavities are of similar length.

The characteristics of X-rays are determined by the thickness and density of the target and the energy spectrum of the electron beams. X-rays, generated by striking the electron beams against the target, are distributed in 4π space according to certain rules. The Tungsten shield and collimating cone shield the X-rays from other directions and only leave the desired fan-shaped forward moving X-rays. The beam of X-rays can penetrate containers and can reach the detector.

Standing wave accelerating cavity is the core component of the accelerator and should be kept high vacuum state for the following reasons:

- Reduce the probability of the collision between electrons and air molecules.
- Increase the field intensity of the high frequency electromagnetic field in the accelerating cavity.
- Prevent the cathode of the electron gun from being oxidized thus extend the life of cathode.

The vacuum in the accelerating cavity is sustained by a titanium pump.

High voltage pulses coupled through the pulse transformer energize the magnetron to provide microwave power or RF power. The RF is delivered to the accelerating cavity through the RF transmission system to produce a standing-wave electromagnetic field. RF system consists of magnetron (RF power source) and S-band RF transmission system. The type of magnetron used in this system MG5115. The operating pulse has a maximum power 1.3 MW; output frequency range of 2293~3002 MHz. RF transmission system consists of S-band 4-port circulator, high power load, low power load, wave guide adapter, flexible & twistable wave guide, pressurizing wave guide, sampling wave guide and various curving and straight wave-guides. Microwaves diffuse in space toward different directions. The wave-guide is a device to transmit microwaves along a defined path to defined destination. The aim of usage of 4 port circulator in RF transmission system to ensure that RF power is absorbed by the loads instead of being reflected into the power source and thus damaging the magnetron [2].

Tungsten shield stops the X-rays of other directions, leaving a set of fan-shape forward moving X-rays.

Voltage changes of commercial power can affect the stable running of the pulse modulator and cause an irregular beaming dose rate in the accelerator. Thus the voltage-stabilizer is used in the accelerator subsystem to overcome commercial voltage changes.

3.1.2 CENTRAL CONTROL SYSTEM OF THE ACCELERATOR

The central control commands the operation of the entire accelerator and processes various problems that may occur in operation (Fig 3.7). It is a type of PLC (Programmable Logic Controller), and is mainly composed of a CPU module, an input module, an output module, a memorizer, a power supply, and a relay.

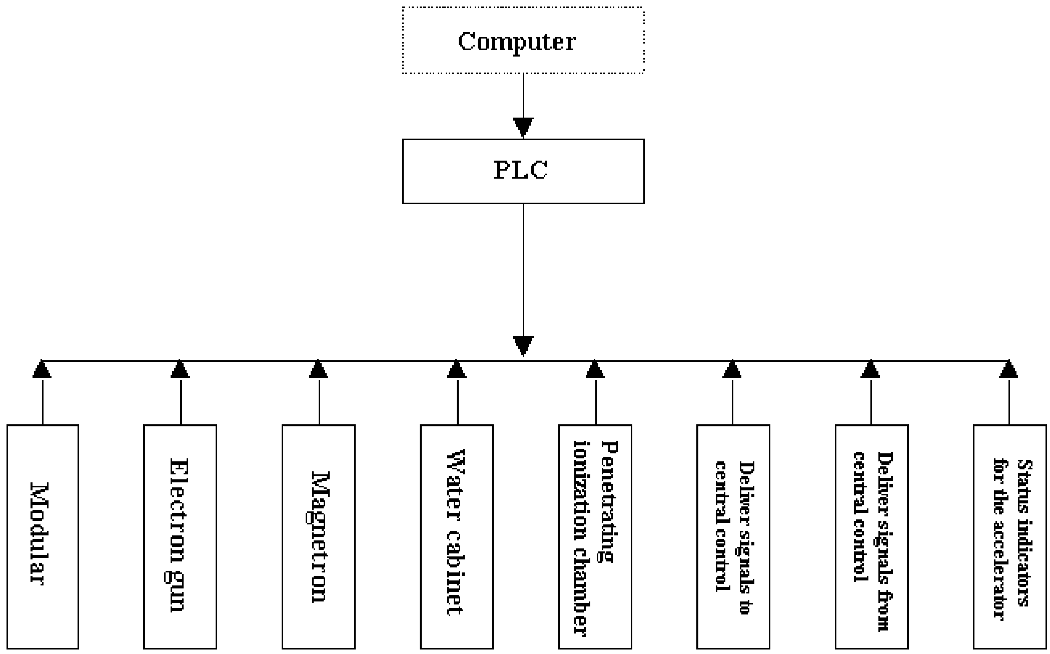


Figure 3.7 The Structure of Central Control of the Accelerator [2]

The Central control provides an operation panel for the Inspection System. The central control reports and processes various faults of the Inspection System, and performs logical control on the safety interlocks, emergency-off, power startup, and HV switch on and off, etc.

Major components controlled by the system are: modulator, electron gun, magnetron, water cabinet, and penetrating ionization chamber. It also indicates the accelerator's status, receives from and transmits signals to the central control system.

3.1.3 SUPPORT SYSTEMS (COOLING AND INFLATING)

Fans provide forced ventilation convection cooling to the X-ray head and the inside of the modulator. Two fans are separately mounted on the left and right panels of the X-ray head. There are also extraction fans on top of the modulator.

Changes in the temperature of the magnetron and the accelerating tube significantly affect the working status of these two devices; therefore, a water cabinet (or called a thermostatic water-cooling system) is an indispensable component of the accelerator. It mainly supplies thermostatic cooling water to the accelerator. The water cabinet is composed of three parts: cooling-water circulating system, refrigeration circulating system, and electric control system. The circulation of the cooling water inside the water cabinet takes out heat from those radiating components inside the accelerator (such as accelerating tube, target, magnetron, 4-port circulator, and high power load). The heater can quickly raise water temperature up to the working value. The refrigeration and heating work together to ensure constant working temperature of the magnetron and the accelerating tube, and thus ensure the smooth operation of the accelerator (Figure 3-8).

The primary function of the cooling water is to take out the heat sent off by the accelerator in order to ensure its smooth operation. When the accelerator is in operation, some components consume large quantities of power. The accelerating tube and its target chamber can be an example; furthermore, while the electron beam hits the target to produce X-rays, heat also burst out. If the target can not be cooled down in time, it will be damaged by overheat. The high power load, 4-port circulator, and the magnetron also need to be cooled down.

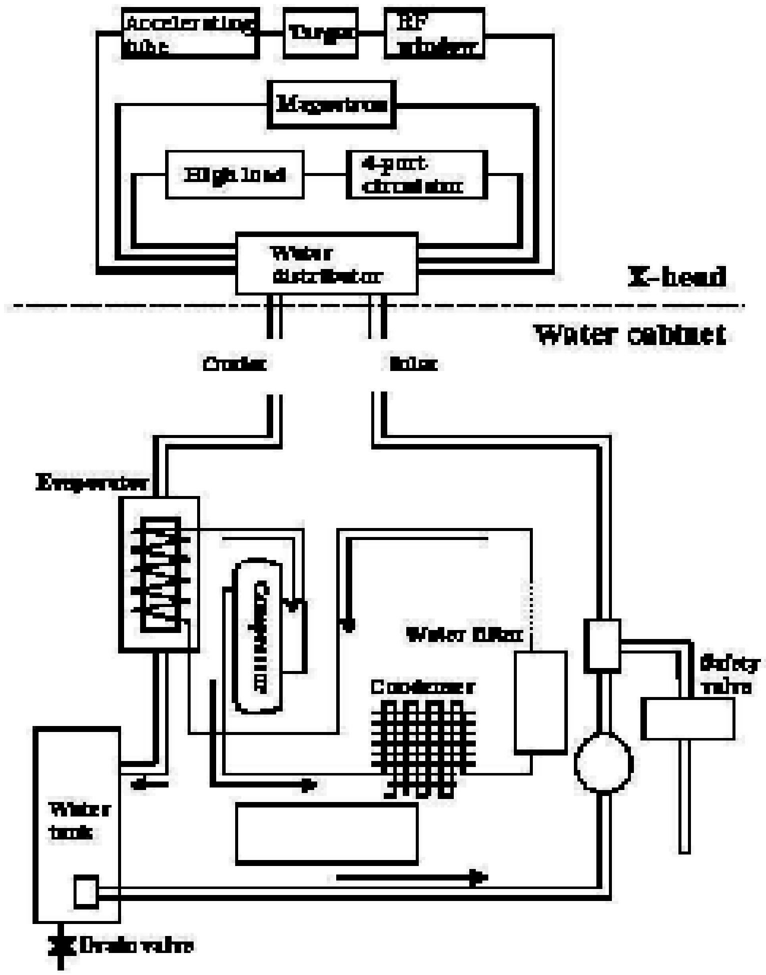


Figure 3.8 Structure of Water cabinet [2]

The RF transmission system is used to deliver RF generated by the RF power source to the accelerating cavity. An intense electric field is built up in the wave-guides when they transmit sizeable RF power; therefore to avoid penetrating firing, it needs to fill high pressure insulated gas into the wave-guide system and the insulation of the high power transmission system is improved. The maximum RF pulse power of the RF transmission system is 2.6 MW. Wave-guide system is filled with SF_6, with pressure of 0.16~0.2 Mpa. [2]

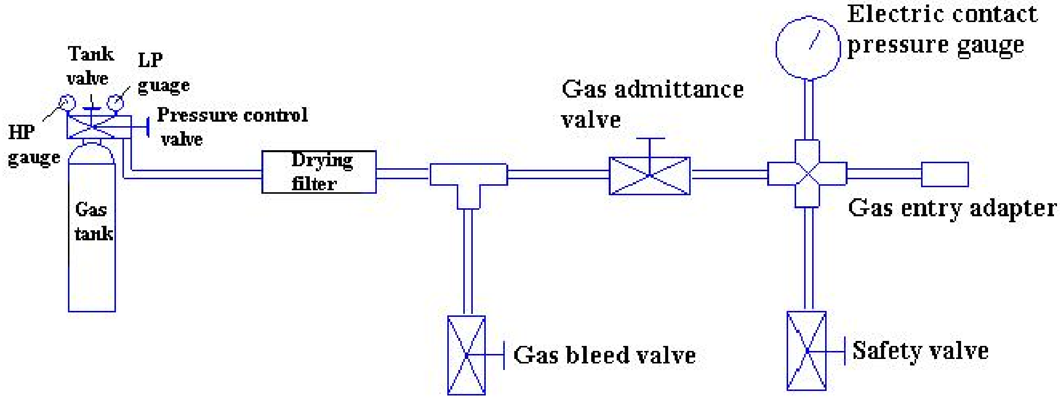


Figure 3-9 Gas-feed Unit [2]

The Gas-feed unit (Fig.3.9) is mainly composed of a gas tank, desiccators and pressure gauge. The Gas-feed unit uses manual operation to fill the gas. To ensure gas purity and thus to ensure insulation intensity, at the first time of inflation, deflate air out of the waveguides, then open the valve of the gas tank to inflate the system to defined gas pressure.

There is an under-pressure interlock in the gas-feed unit. When gas pressure is lower than the defined value, it automatically cuts off the modulator's HV and signals an under-pressure fault. It needs to inflate the system to raise it to the defined pressure, then the fault indicator light goes out and it gets ready for operating modulator's HV.

3.2 DETECTOR SUBSYSTEM

3.2.1 STRUCTURE OF THE DETECTOR SUBSYSTEM

The structure of the detector subsystem is shown in Figure 3.10. The front collimators are located in the side of the checking passage near to the accelerator. The collimator is made from lead pieces, including the collimator's bracket and the collimating block. The bracket is the supporting part of the collimator, bearing the load of the collimator. Collimating block collimates X-ray beams and forms a fan-shaped X-ray beam convenient for detecting objects. The detector arms are made up of the horizontal and vertical detector arms in the box-type structure. They are the carrier of the pen-shaped array detector, including the horizontal and vertical detector arms. The pen-shaped array detector has 560 channels, every 16 channels make up a module, and so there are 35 modules together. A detector module is made up of pen-shaped array detectors converting X-rays into electric signals and front-end circuits which amplify, filter, sample and hold the electrical output signals of pen-shaped detector.

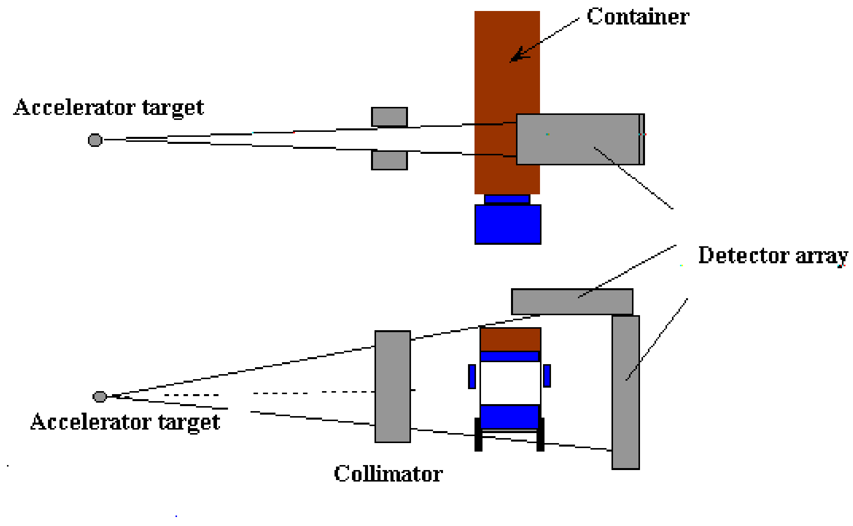


Figure 3.10 Detector arms [2]

3.2.2 WORKING PRINCIPLE OF DETECTOR SUBSYTEM

The X-rays emitted by the accelerator do not satisfy the requirement for the scanning container completely. The basic function of the detector subsystem is to absorb the energy of X-rays emitted by the detected objects and convert them into electronic signals, which are used for A/D conversion by the image acquisition subsystem in the next stage. In the detector subsystem, the rays beam radiated by the accelerator subsystem goes through the beam-limiting collimator, forming a fan-shaped rays beam convenient for inspecting objects (see Figure 3.11). Array of detector converts the received X-rays to pulse current signals; the front-end circuits converts these pulse current signals to pulse voltage signals which can be analyzed by Analog Digital Converter. Analog Digital Converter is the main component of the Image Acquisition Subsystem and there is no need to give the details about conversion process within the context of this thesis.

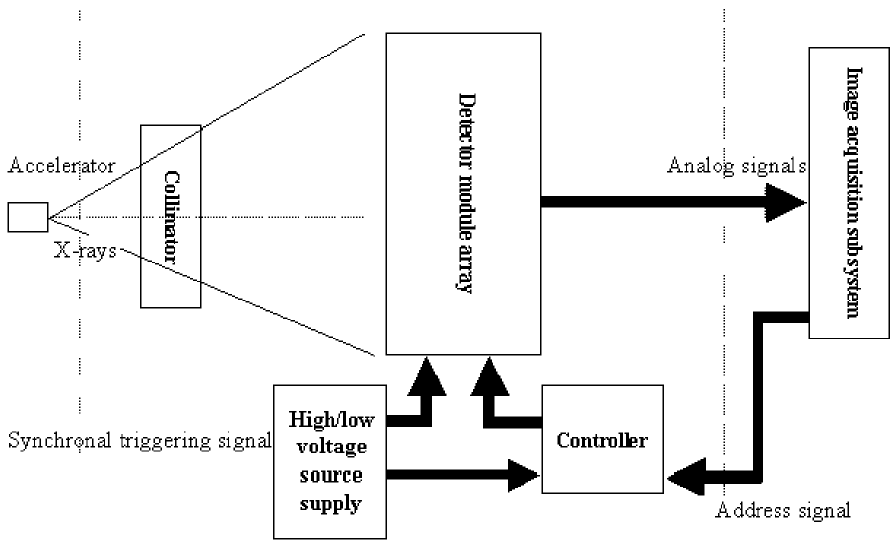


Figure 3-11 The logic structure of detector subsystem [5]

3.2.3 DETECTOR TYPES

Among radioactive detectors only gas detectors and solid scintillation detectors are powerful enough for container inspection. Gas detector is selected in our relocatable container inspection system. Following is the comparison of these two detectors and it is explained that why usage of gas detectors are more suitable in container inspection systems.

No matter what kind of detectors is involved, their working principles are the same. What they have to do is to admit part of the energy of the input X-rays, and then convert it into electrical signals, whose magnitude is correspondingly in proportion to the intensity of the X-rays input. The working principle of the detectors mentioned above is illustrated in Figure 3.12.

The difference of the above two detectors lies in what material they use to produce of X-rays and how they convert the energy into electric signals. The operation procedure of gas detector is quite simple and the X-rays input can directly be converted into electric signals. However, the operation procedure for the solid detector is rather complicated because the X-rays input has to be first converted into visible light, and then re-converted into electric signals with a photographic sensor (Fig. 3.12b).

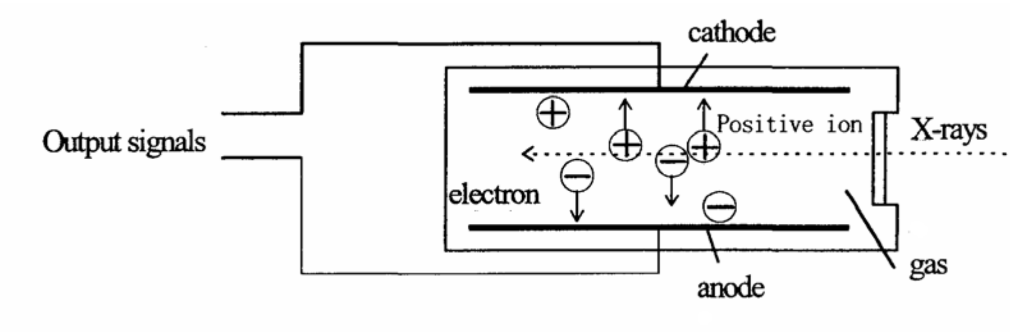


Figure 3.12a Sketch of Gas Detector principle [1]

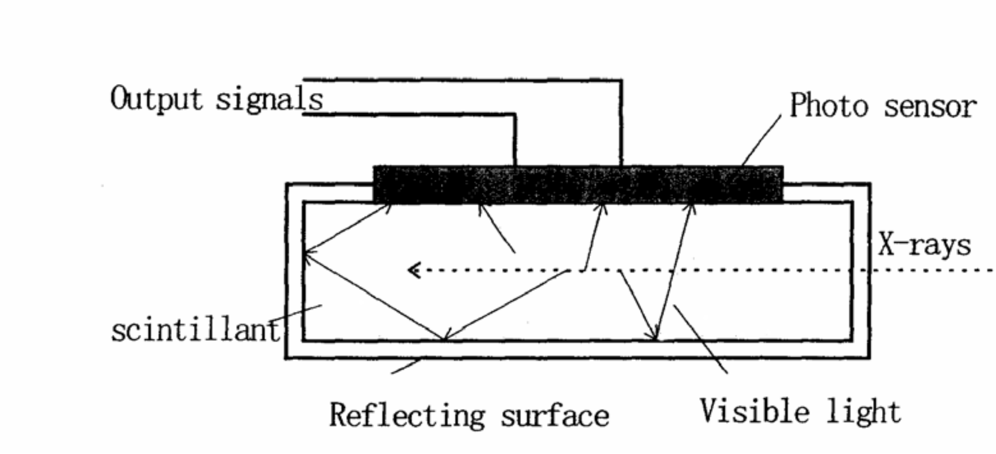


Figure 3.12b Sketch of Solid Detector Principle [1]

There are not many factors affecting the selection of detector. Main properties of the two kinds of detectors are listed in Table 3-1, and the following text explains their effects on the system.

Table 3-1 Comparison of Detectors

	Gas Detector	**Solid Detector**
Sensitive Region Section	5mmX5mm	5mmX5mm
Detection Efficiency	10-40%	20-50%
Dark Current	Weak	Strong
Weight and Volume	Big	Small
Operation Life	Long	Middle
Cost	Middle	Middle

Sensitive Region in Table 3.1 refers to the detector area that receives the rays in the incident region and converts to electrical signals and whose density determines the resolution of images. In application of container inspection systems it should not be too small. Detection efficiency affects the speed of image formation. Though solid detector incepts more X-ray energy than the gas one, it must re-convert the visible light generated into electric signals, thus resulting in some loss of its signals during the conversion. Dark current refers to the current existing in the detector when there are no irradiating rays. It may cause some noise to the output signals and consequently affects the picture quality. Dark current of gas detectors is very small since the gas in the gas detector is insulating in nature. It is necessary to replace solid detector plate regularly since rays may cause the radiation damage to the solid detectors. However, the gas detector is immune to damage, its working life can last infinitely if there is no rust with its metal parts or leak with the gas used. Usage of gas detectors are thus more appropriate for the inspection systems which work in long-term periods.

CHAPTER 4

PHYSICAL EXPERIMENTS OF THE CONTAINER INSPECTION SYSTEM

A series of experiments were carried out to verify whether the chosen relocatable container inspection system was really the most appropriate system as for the performance, security and reliability for Turkish Customs Sites regarding the structural and functional properties of the system in detail.

Kapıkule Custom Site is marked as the most intensified customs of Turkey in terms of the number of vehicles to be physically controlled. Therefore, it has been decided to install the system at this site first. Therefore, all physical experiments of the relocatable container inspection system were carried out at Kapıkule Customs Border at real working conditions. The experiments can be classified into five general groups as follow;

1-General Scan Experiment,

2-Inspection Performance Experiment,

3-Image Quality Experiment,

4-Radiation Safety Experiment,

5-Performance Experiment.

4.1 GENERAL CAPABILITY OF THE SYSTEM

At this part, the general capabilities of the system were tested. These are given as follows:

1. Preparation time of the system for scanning process,
2. The ability of the system for recognizing the difference of the density,
3. Forward and backward scanning ability of the system,
4. Calibration requirements.

These four tests can be summarized as follaws:

1. In case of emergency, the system can be turned on very quickly for scanning process. Therefore, the preparation time of the system is an important parameter for inspection activities. System was turned on and off several times and heat-up time is obtained around 15 minutes. This time interval is an acceptable for the start of inspection activities.

2. Custom officers verify the images of the containers to be inspected during the inspection activities within the limits of eye inspection on the computer screen of the system. For this reason, the ability of the system for recognizing goods with different densities is an important step for normal inspection activities. This is namely the inspection performance of the

system. An experiment was made to observe the inspection performance of the container inspection system by loading container with different densities of materials, for example wood block and oil barrels cargo types. Wood block and oil barrels are partly loaded to a container and are they distinguished on the screen of the computer of the container inspection system? It was clearly observed that materials with different densities were recognized on the screen of the computer of the container inspection system.

3. The time for forward and backward scanning capability of the system is also an importantrequirement. After a forward scan process was completed, the system can scan another container backward without taking the system to initial position, which causes time loss. In addition, the quality of the images produced as a result of these backward and forward scanning processes should be the same. This experiment was made to determine the possible systematic error sources by scanning the same container in both directions. The obtained images are found to be similar within the limits of eye inspection,resolution.

4. It was aimed to observe the effect of the calibration of the detector on the images at this stage of experiment. A raw image (un-calibrated detector output) and a processed image (calibrated detector output) and calibration data output was presented on the computer screen. Images produced by the container inspection system showed some contrast differences due to the angle of reflection of the beam sent from the source. In order to eliminate

these contrast differences between the raw image and processed images, calibration is required.

The calibration device is composed of the frame, electrical motor, lead-screw, guide rail and four calibration pieces and is located in front of the target of the x-ray accelerator. The calibration is driven by a 90W motor through the lead-screw. A pair of flat guides is equipped for supporting the weight of the calibration pieces.

The calibration device is given four correcting positions and a free position. Plies of the correcting pieces are 50 mm, 100 mm, 150 mm and 250 mm, respectively. The process of calibrating the detector is similar to the acquisition of scanning data. It also constitutes a series of data acquisition periods. However, there are two points of difference. First, there is no container passing in the X ray zone when calibrating the detector, but a calibration device will be started. Second, the scanning data are not sent to generate images but serve as parameters for calibrating the detector array and front-end circuits after being analyzed and processed.

4.2 INSPECTION PERFORMANCE OF THE SYSTEM

Main responsibility of the custom officers is to prevent the entrance of the smuggled goods, such as cocaine, hund gun, cigarette etc. from borders to the country. These smuggled goods are frequently hidden among the ordinary commodities transported by the containers. Therefore, high inspection sensitivity is required during the inspection of the containers. At this part of the experiment, a smuggling event is simulated, and smuggled goods like cigarette, cocaine, and hund gun were hidden behind the ordinary commodities like potatoes, wood and diesel oil, respectively. All the smuggled goods hidden behind of ordinary commodities were recognized on the images produced by the system. Table 4.1 shows the thickness of the commodities and contrabands or smuggled goods hidden behind them.

Table 4.1 Thickness of Ordinary Commodities and Contrabands

	Contrabands / Commodities	Cigaratte	Cocaine	Hand Gun
1	**Potatoes**	1750 mm	1250 mm	1250 mm
2	**Wood**	2000 mm	1500 mm	1500 mm
3	**Diesel Oil**	1600 mm	1350 mm	1080 mm

The value at the intersection of the first row and the first column of the Table 4.1 means that cigarette was recognized at the behind of pile of potatoes with thickness of 1750 mm at the images within the limits of eye inspection. Similarly, the intersection of the second row and the second column of the table indicates that bulk cocaine was recognized at the behind of block of wood with thickness of 1500 mm at the images within the limits of eye inspection,and so on.

4.3 IMAGE QUALITY INDICATOR EXPERIMENT

Image quality indicators (IQI), are often considered to be used in radiography. The main usage of Image Quality Indicators in radiography is to measure radiographic quality and to provide a check on radiographic technique. Therefore, they are very important, and do determine to a high degree to potential effectiveness of a particular radiograph [6].

At the specification table of the system, wire detectability is given as 5 mm steel wire behind the steel plate with thickness of 150 mm with the speed of 5 meters per minute. This means that Image Quality Indicator of the system is 3 % at speed of 5 meters per minute. This IQI value indicates the resolution sensitivity of container inspection system. In order to confirm this specified value, wires with thickness of 4, 4.5 and 5 mm were placed behind the steel plates having certain thicknesses as in Figure 4.1. In order to determine the affect of the speed of the system on the resolution sensitivity system speed was also varied during the experiments. We determined whether the images of these wires behind steel plates having certain thicknesses can be recognized at the end of scanning process. The results are given in the Table 4.2.

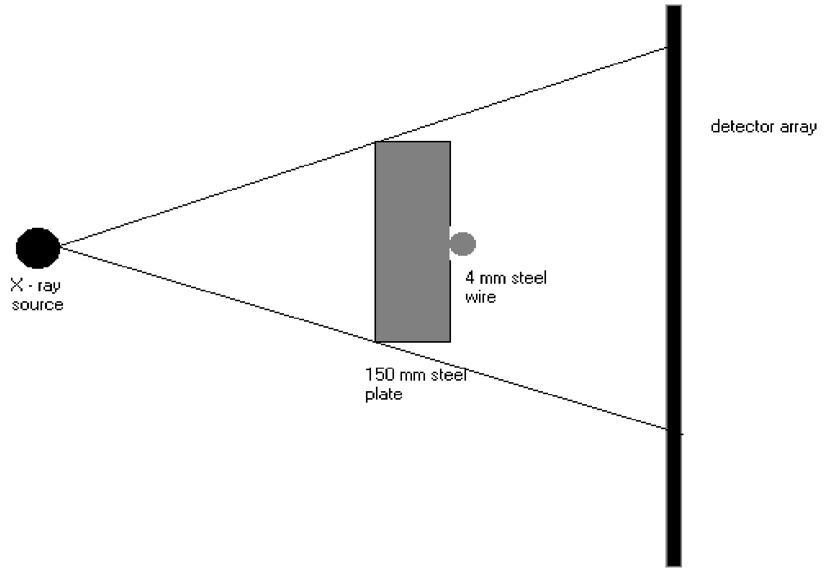


Figure 4.1 Drawing of the IQI measurement

The IQI value of the system was calculated by:

$$IQI = \frac{D}{E} \cdot 100 \qquad (4.1.)\ [6]$$

where; D is the minimum wire diameter detected (mm) and E is the thickness of the steel plate (mm).

In Table 4.2, for example, the fourth row gives that the wire with diameter 4 mm behind a steel plate with thickness of 120 mm was not recognized at the computer screen, whereas wires with diameters of 4.5 mm and 5 mm behind of steel plate with thickness of 120 mm were clearly recognized at the computer screen. The speed of the scanning device for this specific experiment was measured as 213 mm/s. IQI values were calculated as 3.75 % and 4.17 % for wires with diameters of 4.5 mm, 5 mm, respectively. Similarly, it can be seen from the sixth and seventh rows that wires with diameters of 4 mm, 4.5 mm, 5 mm behind steel plate with thickness of 145 mm were not recognized at the computer screen. The speed of the scanning device for this specific experiment was measured as 213 and 200 mm/s. However, it can be seen from last row of the table that when the speed of scanning device was decreased to 83 mm/s, wire with diameter of 4 mm behind the steel plate with thickness of 150 mm can be recognized at the computer screen. As a result, when the speed of the scanning device is decreased, scanning sensitivity of the system increases, as expected.

Table 4.2 Detectability of wires behind steel plates at specific speeds of scanning

Thickness of The Steel Plate E (mm)		Minimum Wire Diameter Detected (D mm)			IQI= D / E x 100 (%)	Speed of Scanning Device
		4	4.5	5		
1	60	OK	OK	OK	6.7 / 7.5 / 8.3	213 mm/s
2	80	OK	OK	OK	5.0 / 5.6 / 6.25	213 mm/s
3	100	OK	OK	OK	4.0 / 4.5 / 5.0	213 mm/s
4	120	NO	OK	OK	-- / 3.75 / 4.17	213 mm/s
5	140	NO	NO	OK	-- / -- / 3.57	213 mm/s
6	145	NO	NO	NO	---	213 mm/s
7	145	NO	NO	NO	---	200 mm/s
8	150	OK	---	---	2.67	83 mm/s

OK: Wire is recognized   NO: Wire is not recognized   ----: Not measured

4.4 RADIATION SAFETY EXPERIMENT

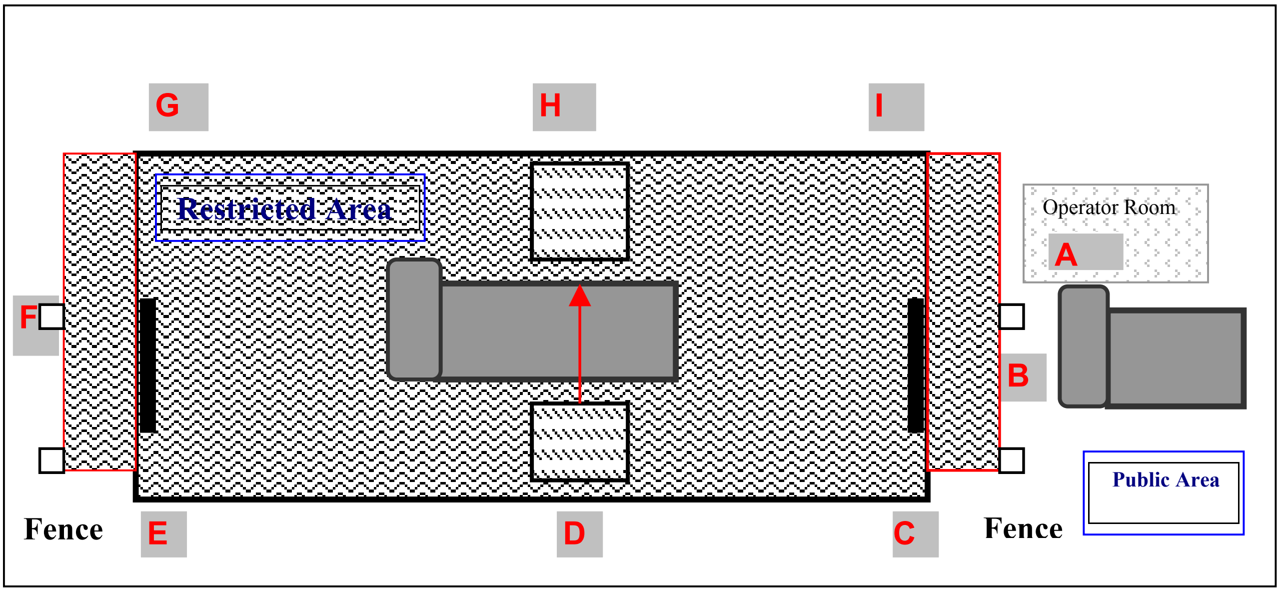


Figure 4.2 Drawing of The Scanning Hall

It was aimed to measure the radiation dose rate at points marked A, B, C, D, E, F, G, H, I in the Figure 4.2 showing the scanning hall. Points C, D, E are two meters above the ground. The other points are one meter above ground. Point B is the entrance of the scanning hall and point F is the exit of the scanning hall. Arrow in the Figure 4.2 indicates the direction of X-ray beam. Maximum radiation dose rate must not be higher than 1 μGy/hour according to the standards determined by WHO (World Health Organization) [7].

The points where the measurements were made and the radiation dose rate at these points are given in the table.

Table 4.3 Radiation dose rates at specific points

Points	Radiation Dose Rates
Point A	0.10 μGy/hour
Point B	0.26 μGy/hour
Point C	0.10 μGy/hour
Point D	0.10 μGy/hour
Point E	0.10 μGy/hour
Point F	0.24 μGy/hour
Point G	0.10 μGy/hour
Point H	0.10 μGy/hour
Point I	0.10 μGy/hour

As it can be seen from table, radiation dose rates do not exceed 1 μGy/hour at the points where the measurements are taken, therefore the system is secure as for radiaton dose rate.

4.5 PERFORMANCE EXPERIMENT

Imaging systems at the custom sites usually works 24 hours continuously and the increase of radiation rates is a problem of long term operations. We carried out experiments to determine the 24 hour performance, and it was observed that after the system powered on at 12:30 on Dec.6,2002 with normal operating conditions the radiation dose did not increase follawing a 24 hours of operation period without any problem.

CHAPTER 5

CONCLUSION AND DISCUSSIONS

In Chapter 1, troubles appearing at Turkish Custom Sites about interior inspection are determined during the routine controls of containers or ordinary vehicles by the custom officers. The main idea of chapter 1 was how to eliminate these troubles. Are there any container inspection systems that facilitate and also accelerate the routine inspection activities at custom sites? General parameter of these systems, such as the inspection speed, reliability, security etc, were tested in the present study.

General properties and the preferences of X-ray usage in detection systems were discussed in Chapter 2. General requirements for radiographic testing are defined. It is determined that X-rays have more advantages than its alternatives. One of the reason is that the individual energy of the photons and the intensity of the X-ray beam required for penetration can be varied by the manipulation of the voltage and the current of the X-ray source. It is not valid for other radioactive sources since the total energy of photons depends on the amount of radioactive source. Radioactive sources can have a fixed frequency so fixed photon energy level. This is not the case for X-rays because of the fact that the spectrum of an X-ray beam is continuous. Principles of radiation image formation are also discussed in Chapter 2. Differences between the ordinary photography and radiography were explained.

Chapter 3 consists of two main parts: General configuration of relocatable container inspection systems and the working principles of their subsystems, accelerator subsystem, and detector subsystem, separately. Unlike from fixed container inspection systems, the working place of the relocatable inspection systems can be changed after some usage in a custom site. Scanning hall is the only requirement for new installation. The container to be inspected is fixed during the inspection process, whereas inspection system moves by the speed around 200 mm/s on the rails. Forward and backward scanning is also possible without any side effects.

Container inspection system uses electron linear accelerator because of having more advantages than X-ray apparatus. Radial energy, which determines the penetration thickness of the ray, is high in linear accelerator. Similarly, radial intensity, which determines rapidity of imaging, is also high in linear accelerator. Thus, today, almost all container inspection systems in the world are equipped with accelerator as X-ray source.

As explained in details in Chapter 3, It is advantageous to use the standing wave acceleration when the accelerating structure is comparatively short, because of the same RF power, standing wave acceleration can energize electrons to a higher level. In comparison with traveling-wave accelerator, standing-wave accelerator has the following characteristics:

1. Smaller size, lighter weight and higher efficiency,
2. Higher accelerating field strength, and lower injection voltage,
3. Hermetic structure, and high degree of vacuum.

In today's container inspection systems, there are two types of detectors: Gas detectors and solid detectors. The difference of the two detectors lies in what material they use to produce X-rays and how they convert to energy into electric signals. The operation procedure for the gas detector is quite simple, the X-ray input directly be converted into electric signals. However, the operation procedure for the solid detector is complicated because the X-ray input has to be first of all converted into visible light, and then re-converted into electric signals with a photographic sensor. Dark current, which refers to the current existing in the detector when there are no irradiating rays may cause noise to output signals affecting the picture quality. This noise is small for gas detectors since the gas in the gas detector is insulating in nature. This is why gas detectors is more suitable for container inspection systems.

All the details about physical experiments of the container inspection systems are given in Chapter 4. The experiments of the system can be classified into five groups:

1. General Scan Experiments,
2. Inspection Performance Experiment,
3. Image Quality Indicator Experiment,
4. Radiation Safety Experiments,
5. Performance Experiment.

The heat up time of the system was found to be around 15 minutes. Container was loaded by goods, such as wood block, oil barrels having different densities, and images produced after scanning process were investigated within the limit of eye inspection. It was clearly observed that goods having different densities were recognized clearly at the images. Forward and backward scanning were also made for the same container in order to determine possible systematic error sources. The same images were however obtained within the limit of eye inspection. Effect of calibration on the images are remarked after comparing the calibrated outputs and un-calibrated outputs. After calibrating the detector by calibration device, the contrast differences between the images were partly eliminated.

Inspection performance experiment was made to observe the sensitivity of the container inspection system by using contrabands and ordinary commodities. The container to be inspected was loaded by ordinary commodities like potatoes, wood and contrabands such as cigarettes, cocaine, were hidden at the behind of these contrabands at specific distances. The images produced by the inspection system after scanning process were examined within the limit of eye inspection and density differences were clearly recognized.

The image quality indicator experiment was also applied to the system within the limit of predefined specifications of the system. It was aimed to recognize the steel wires with diameters of 4, 4.5, 5 mm at the behind of steel plate with varying thickness from 40 mm to 150 mm. Speed of the scanning device was changed during the experiment and the results were reevaluated. Wire detectability of the system had been defined as 4 mm wire behind the 150 mm steel at a speed of 5 meter per minute.

Radiation safety experiment was made for variety of points marked in the scanning hall by measuring the radiation dose rate by dosimeter. There were no points whose radiation dose rate exceeds the maximum level proposed by WHO.

In the performance experiment of the system, it was observed that the system can work 24 hours continuously without any radiation dose fluctuation or any other troubles.

It is also worth noting that as scanners are deployed in more an more countries a network of scanners liaison officers should be developed. Each country should nominate one officer who could arrange for exchanges of officers between systems, act as a focal point for exchange of scanner information, request for information, expertise, etc.

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