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Zeszyty Naukowe WCO, Letters in Oncology Science 2020;17(1):11-15

Letters in Oncology Science
ISSN 2543-6724
ZESZYTY NAUKOWE WIELKOPOLSKIEGO CENTRUM ONKOLOGII

Praca poglądowa/Review paper

Radiation shielding swing door drive control system for linear accelerator bunkers

Jaroslaw Kurkiewicz[1], Michal Salwa[1], Anna Majewska[1], Leszek Zylka[1], Andrzej Kuciak[1]

[1] *Nuclear Equipment Division HITEC, National Centre for Nuclear Research*

Abstract

The paper aims to describe an upgrade to the radiation shielding door control system as designed and manufactured by the National Centre for Nuclear Research in Otwock, Poland. Basic principles and normative references as well as a short historical overview of control approaches are described.

Keywords: radiation shielding, radiotherapy bunker, shielding door, radiation safety, linear accelerator

Introduction

Since the discovery of X-rays in 1895, by Wilhelm Roentgen, and radioactive decay in 1896, by Henri Becquerel, many beneficial applications of the phenomenon of radiation have been discovered, including medical, industrial and energy applications. However, most of the hazards associated with ionizing radiation were not quickly recognized. One of the first advice on radiation protection was formulated in a note published in 1901 by William H. Rollins, who studied the effects of X-rays as early as 1896. Nevertheless, his suggestions for limiting exposure by wearing radiopaque glasses or encasing x-ray tubes in lead were considered excessive at the time [1]. The first International Congress of Radiology was held in 1925 and only then were the protection standards considered internationally. Fortunately, the importance of radiation protection is now recognized globally, and international cooperation ensures continuous improvement of protection methods. As experience has shown over the years, both industrial radiography and medical radiotherapy are most safely carried out in a shielded enclosure. In higher energy applications in fixed installations, such enclosures usually take the form of custom built bunkers. Naturally, the bunker design must provide safe entry. Although it is possible to design doorless entrances by using long enough mazes, shielded doors are the most common solution [2,3]. The selection of shielding materials and radiation protection standards used in the

Adres do korespondencji
Jaroslaw Kurkiewicz
Zakład Aparatury Jądrowej HITEC, Narodowe Centrum Badań Jądrowych,
ul. A. Sołtana 7, 05-400 Otwock
e-mail: jaroslaw.kurkiewicz@ncbj.gov.pl

construction of such accelerator bunkers has been described in numerous publications, such as [4], and thus will not be presented in this paper. In the case of radiation shielding door system described in this paper, the relevant legally binding document is the Polish ordinance [5]. One important, but often downplayed, aspect of radiation protection deals with access control and interlock systems. The aforementioned legal document [5] requires installation of doors that can be manually operated, both from inside and outside, in the event of power failure. At the same time, the door has to be interlocked with the accelerator system so as to prevent its operation while the door is opened. Practice shows that such systems should be as tamper-proof and fail-safe as possible since adherence to operational procedures is harder to enforce. Ideally, interlock systems should be designed in a way that disables accelerator systems in case of disconnection. Otherwise, accidents such as case 6 as described in [6] are likely to happen. There are also other, not radiation related, hazards that need to be taken into account during the use of motorized shielding swing doors. This paper describes a new design of control system for radiation shielding swing doors as employed in the National Centre for Nuclear Research in Otwock, Poland.

Basic data and requirements

- **Motorized radiation shielding swing door safety**

The door assembly belongs to the broad category of machinery within the meaning of the EU Machinery Directive [7]. This means that the manufacturer must implement various safety measures to comply with the 'Essential Health and Safety Requirements' (EHSRs). The EHSRs are a comprehensive set of safety principles, related to ergonomics and control systems as well as mechanical, electrical and other hazards, compiled both for general reference and specific machine classes.. Machinery should meet all relevant EHSRs, as far as state of the art permits, and machine users should be informed of all residual risks [7]. In pursuit of compliance, engineers can apply harmonized standards. One of these standards is ISO 12100, which sets out the general principles and methodology for achieving safety in machine design. The control system of swing door assembly falls within the scope of IEC 60204-1, which deals with the general requirements for electrical, electronic and programmable electronic equipment and systems [8]. ISO 13850, which defines the functional requirements and principles of designing the emergency stop function, is among the particularly interesting standards in the field of swing door safety [9].

- **Door control approaches**

For decades engineers utilized time-proven electromechanical relays in all kinds of control systems. Even today electromechanical relays are often favored over programmable electronics, especially in safety applications, mainly due to the fact that relays' failure modes are well understood. Relays' predominant failure mode is open circuit [10]. Short-circuit failure is not as common and usually is a result of contact weld, which is easily remedied by redundancy. Failure modes of electronic devices, on the other hand, are harder to predict as they can be a result of hardware or software shortcomings. Nevertheless, cost and space savings achieved through the use of electronic devices is significant and diligent design and implementation can guarantee safe operation. The door drive system can be implemented using a hydraulic system or an AC or DC motor. Initially, the motors were line powered and over time AC inverters and electronic DC motor controllers were introduced, which allowed for gentle acceleration and deceleration of the door leaf. Traditional systems using fixed braking times and fixed limit switches are still common. Encoder based systems have been introduced in the Centre that allow remote monitoring of door positions and custom drive configuration depending on the end user's requirements.

Regardless of the type of underlying control and drive systems, there are multiple approaches to operational procedures regarding door operation. In the past, it was common to require the operator to keep the close button pressed for the whole duration. This was needed to ensure that no hazards occurred during operation. This approach was sometimes used in conjunction with a confirmation button inside the bunker which had to be pressed after visual confirmation that the bunker is empty.

A new solution for the motorized radiation shielding swing door system

In this chapter, in order to illustrate the challenges facing the constructor in the process of designing motorized radiation shielding swing door systems, a system currently in use at the National Centre for Nuclear Research is analyzed. This modern solution was developed in-house for use in bunkers, where R&D of linear accelerators takes place. At the same time, it forms a prototyping backbone for commercial systems offered by the Centre.

In general terms, the system consists of the following parts:

- Interlocking limit switches
- Door control boxes
- Safety sensors and switches
- Motor assembly
- Drive and control system cabinet

• Interlocks

Interlock failure can lead to potentially serious consequences. Therefore, special care must be taken to ensure proper operation. In the case of the investigated control system, interlock consists of 2 redundant limit switches with a total of 5, normally open contacts. Two pairs of contacts are utilized for the connection with the accelerator control system which energizes the circuit and one contact is used for signaling internal to the drive system itself. Additionally, provisions were made for closure confirmation through fieldbus communication with the drive, which compares the signal from limit switches to its internal position keeping. Discrepancies can be communicated via fieldbus to the accelerator system.

The circuit is closed only after the door closes, which means that broken wiring or switch failure in open position prohibits activation of the accelerator system. Doubling of limit switches and their contacts reduces the risk associated with contact welding. As an alternative, a system utilizing a single safety limit switch with positive opening normally-closed contacts according to IEC 60947 could be used. The opening of the door instantly disables the accelerator system.

• Door control boxes

Operating panels with control buttons are located just outside and inside the bunker in a place guaranteeing full view of the passage. From the outside, it is possible to open the door fully or partially for quick passage as well as close them. In order to close the door, it is, however, necessary to first press confirmation or "search" button. The confirmation button is located in a place allowing full view of the bunker. This way an operator can check for any remaining personnel before closing the door. Consequently, it is impossible to close the door from the inside. Both control boxes are equipped with emergency stop buttons as specified by ISO 13850.

• Safety sensors and switches

Even relatively light doors pose a significant crushing hazard and described heavy door system, would be extremely dangerous without appropriate precautions. There are two main hazards occurring during door operation:

1. Entrapment and crushing between the door and the wall during opening.
2. Entanglement and crushing during door closing.

To minimize risks and prevent accidents during door operation two different types of sensors were installed. The internal side of the door is lined with pressure sensitive safety edges while the external surface is protected by infrared presence sensor. The safety edges are mounted in a way that ensures proper activation both for standing and lying person. The presence sensor is placed in a way to prevent both simple hit by door leaf and insertion of limbs into moving parts of the door.

- **Motor assembly**

The whole motor assembly is hidden above the door leaf. It consists of a three-phase AC motor, a clutch and encoder subassembly. The encoder is mounted in a way that ensures a positive connection with the door shaft. The presence of the clutch is needed to satisfy requirements regarding door operation under power failure conditions. Moreover, the clutch disconnects the door shaft from the other parts of the drive system, which allows manual operation even in the case of mechanical failure of drive components. Additionally, in contrast to common overhead arm power door operators it is never necessary to use cranks or chains to open doors manually – the forces required allow manual opening by pushing.

- **Drive and control system cabinet**

The cabinet housing the control system is located in the control room. The control system within consists of the following:

- Single-phase programmable inverter
- Safety relay
- DC power supply
- EMC filters
- Auxiliary relays and contactors
- Circuit breaker
- Warning light
- Emergency shutoff pushbutton

System operation

The system is an upgrade of a legacy control system utilizing relays and a simple inverter. The new control system reduced the number of auxiliary components such as relays to a bare minimum. The old system consisted of 10 relays and 3 timing relays while the upgraded version requires only a single safety relay, one relay for clutch operation and one main contactor.

The inverter operates in a sensorless vector control mode which maximizes torque output at low speeds thus enabling faster acceleration times. Its incorporation significantly shortened door opening times without compromising other functions. Most importantly, simple mechanical construction is preserved in contrast to some other common ways to improve opening times, such as utilizing double leaf swing doors [11]. Moreover, the programmable nature of the inverter allows easy modification of the operating conditions based on the on-site requirements. Functions previously executed through complicated chain of relays were taken over by the inverter, the performance of which is similar to early programmable logic controllers. At the same time, it implements a safe stop circuit allowing direct, standards-compliant, stop according to stop category 0 as defined in IEC 60204-1. Commonly, relay logic is replaced by programmable logic controllers (PLC) but through utilization of programmable inverters, as is the case in presented system, significant cost and complexity reduction is possible, all the while making it possible to achieve the same amount of flexibility and personalization as competing PLC-based systems such as [12].

Emergency stopping in the investigated system is performed differently based on the source of emergency actuation:

- **Emergency stop by pushbutton or safety edge**

Whenever an emergency stop pushbutton is activated the drive proceeds to immediately cut power to the motor according to the uncontrolled stop category 0 principle. At the same time, the clutch is not released until a specified delay time passes, to ensure the quickest possible braking of the door leaf and to allow manual operation of the door shortly afterwards. The same operation follows the activation of a safety edge, which is monitored by a specialized safety relay.

- **Emergency stop by presence sensor**

The infrared presence sensor has wide and deep enough area of operation that it is more prudent to execute emergency controlled stop equivalent to IEC 60204-1 stop category 2. The motor decelerates the door leaf and disengages the clutch afterwards.

The control cabinet is also equipped with a keyed, emergency shutoff pushbutton intended to cut all power to the drive and motor in the event of electrical or fire hazards.

Summary

Aspects related to door control systems and safety are well defined by international standards. As such, further improvements in this field are focused on user friendliness, ergonomics and convenience. Many engineers in the industry, as well as end-users, tend to favour well-known, legacy technologies which exhibit known failure-modes, without consideration for modern approach to safety. The presented system can therefore be considered a new reference point in the sense of the most fundamental, but at the same time state-of-the-art, radiation shielding door system for widespread use. Through the use of a programmable inverter operating in tandem with an absolute encoder it is possible to monitor the position, speed and momentum of the door leaf in a continuous manner, which was impossible previously. The system is also ready for incorporation in building automation and monitoring systems, which can potentially lead to site-wide safety improvements. Furthermore, it showcases how innovative subsystem choices can simplify the entire system and reduce costs by up to 50%. Compared to the established solutions currently available on the market, the presented system guarantees the same or better level of safety and better performance.

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