Development of an automation system for iodine-125 brachytherapy seed encapsulated by Nd:YAG laser welding*

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Abstract. The aim of this work is to develop an automation system for iodine-125 radioactive seed production by Nd:YAG laser welding, which has been used successfully in low dose rate (LDR) brachytherapy treatment. This small seed consists of a welded titanium capsule, with 0.8 mm in diameter and 4.5 mm in length, containing iodine-125 adsorbed onto a silver rod. The iodine-125 seeds are implanted into the human prostate to irradiate the tumor for cancer treatment. Nowadays, the Radiation Technology Center, at Institute for Nuclear and Energy Research, São Paulo, Brazil (IPEN-CNEN/SP) imports and distributes 36,000 iodine-125 seeds per year, for the clinics and hospitals in the country. However, the Brazilian market potential is now over 8,000 iodine-125 seeds per month. The local production of these iodine-125 radioactive sources became a priority for the Institute, in order to reduce the price and the problems of prostate cancer management. It will permit to spread their use to a larger number of patients in Brazil. On the other hand, the industrial automation plays an important role for iodine-125 seeds in order to increase the productivity, with high quality and assurance, avoiding human factors, implementing and operating with good manufacturing practices (GMP). The technology consists of appliance electronic and electro-mechanical parts and components to control machines and processes. The automation system technology for iodine-125 seed production developed in this work was mainly assembled employing a programmable logic controller (PLC), a stepper motor, an Nd:YAG laser welding machine and a supervisory. The statistical repeatability of correctly encapsulated sealed sources with this automation system is greater than 95%.

Key words: iodine-125 seeds • prostate cancer • brachytherapy • automation system • Nd:YAG laser welding

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Introduction

With low dose rate (LDR) brachytherapy treatment, tiny little metal pellets containing radioactive iodine-125 or palladium-103 are inserted into the prostate via needles that enter through the skin behind the testicles. As with three-dimensional (3-D) conformal radiation therapy, careful and precise maps are used to ensure that the seeds are placed in proper locations. Over the course of several months, the seeds release radiation to the immediate surrounding area, killing the prostate cancer cells. By the end of the year, the radioactive material degrades, and the seeds that remain are harmless. Compared with external radiation therapy, brachytherapy is less commonly used, but it is rapidly gaining ground, primarily because it does not require daily visits to the treatment center.

Cancer was responsible for 7.6 millions of deaths in 2005. It represents 13% of all the deaths in the world. The main cancer kinds with bigger mortality were lung

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(1.3 million), stomach (1 million), liver (662 – 1,000), colon (655 – 1,000) and mamma (502 – 1,000). Above 70% of the cases happened in countries of medium or lower income. About 60% of new cases will occur in developing countries in 2020. It also is known that one third of the new cases of cancer that annually occurred in the world could be forewarned. Parkin and collaborators [8] had estimated that the number of new cases of cancer would be greater than 10.1 millions over the world in 2000. The tumors of lung (902 – 1,000 new cases) and prostate (543 – 1,000) would be more frequent in the male, whereas in the female the bigger occurrences would be the tumors of mamma (1 million of new cases) and colon (471 – 1,000). In Brazil, the estimation in 2008 and valid also in 2009, point that 466,730 new cases of cancer will occur. The more incident kinds, excepted of skin cancer type no melanoma, will be the cancers of prostate and lung in the male and the cancers of mamma and colon in the female, accompanying oneself profile of the bulk observed in the world. In 2008 – 231,860 new cases are expected for male and 234,870 for female. Estimation that the skin cancer type no melanoma (115 – 1,000 new cases) will be most incident in the Brazilian population, followed by the tumors of prostate (49 – 1,000), breast feminine (49 – 1,000), lung (27 – 1,000), stomach (22 – 1,000) and colon (19 – 1,000) [4].

The iodine-125 seeds are implanted into the human prostate to irradiate the tumor for cancer treatment. These types of sealed sources may be used to treat superficial, intra-abdominal and intrathoracic tumors. Tumors of the head, neck, lung, pancreas, eyes and prostate (early stages) are commonly treated [7]. Nowadays, the Radiation Technology Center, at IPEN-CNEN/SP imports and distributes 36,000 iodine-125 seeds per year, for clinics and hospitals in the country. However, the Brazilian market potential is now over 8,000 iodine-125 seeds per month. The local production of these iodine-125 radioactive sources became a priority for the Institute, in order to reduce the price and the problems of prostate cancer management. It will permit to spread their use to a larger number of patients in Brazil [9]. On the other hand, the industrial automation plays an important role for iodine-125 seeds in order to increase the productivity, with high quality and assurance, avoiding human factors, implementing and operating with GMP.

Automation

Automation is the use of control systems (numerical control, programmable logic control and other industrial control systems), in concert with other applications of information technology such as computer-aided technologies (CAD, CAM, CAx), to control industrial machinery and processes, reducing the need of human intervention. In the scope of industrialization, automation is a step beyond mechanization. Whereas mechanization provided human operators with machinery to assist them with the physical requirements of work, automation greatly reduces the need for human sensory and mental requirements as well. Processes and systems can also be automated. Automation plays an increasingly important role in the global economy and in daily experience. Engineers strive to combine automated devices with mathematical and organizational tools to create complex systems for a rapidly expanding range of applications and human activities. Many roles for humans in industrial processes presently lie beyond the scope of automation. Human-level pattern recognition, language recognition, and language production ability are well beyond the capabilities of modern mechanical and computer systems. Tasks requiring subjective assessment or synthesis of complex sensory data, such as scents and sounds, as well as high-level tasks such as strategic planning, currently require human expertise. In many cases, the use of humans is more cost-effective than mechanical approaches even where automation of industrial tasks is possible. Specialized hardened computers, referred to as programmable logic controllers (PLCs), are frequently used to synchronize the flow of inputs from (physical) sensors and events with the flow of outputs to actuators and events. This leads to precisely controlled actions that permit a tight control of almost any industrial process. Human-machine interfaces (HMI) or computer human interfaces (CHI), formerly known as man-machine interfaces, are usually employed to communicate with PLCs and other computers, such as entering and monitoring temperatures or pressures for further automated control or emergency response. Service personnel who monitor and control these interfaces are often referred to as stationary engineers [5].

An automation system is a precisely planned change in a physical or administrative task utilizing a new process, method, or machine that increases productivity, quality, and profit while providing methodological control and analysis. The value of system automation is in its ability to improve efficiency; reduce wasted resources associated with rejects or errors, increase consistency, quality and customer satisfaction; and maximize profit [5].

Programmable logic controllers

Control engineering has evolved over time. In the past humans were the main methods for controlling a system. More recently electricity has been used for control and early electrical control was based on relays. These relays allow power to be switched on and off without a mechanical switch. It is common to use relays to make simple logical control decisions. The development of low cost computer has brought the most recent revolution, the programmable logic controller (PLC). The advent of the PLC began in the 1970s, and has become the most common choice for manufacturing controls. Programmable logic controllers (PLCs) have been gaining popularity on the factory floor and will probably remain predominant for some time. Most of this is because of the advantages they offer, such as:
– Cost effective for controlling complex systems;
– Flexibility enabling reapplication to control other systems quickly and easily;
– Computational abilities allowing more sophisticated control, and
– Trouble shooting aids making programming easier and reducing downtime.

Ladder logic

Ladder logic is the main programming method used for PLCs. As mentioned before, ladder logic has been developed to mimic relay logic. The decision to use the relay logic diagrams was a strategic one. By selecting ladder logic as the main programming method, the amount of retraining needed for engineers and trade people were greatly reduced.

Stepper motor and driver

A stepper motor is a brushless, synchronous electric motor that can divide a full rotation into a large number of steps. The position of motor can be controlled precisely without any feedback mechanism. Stepper motors are similar to switched reluctance motors, which are very large stepping motors with a reduced pole count, and generally are closed-loop commutated [12].

Driver is an electric circuit or other electronic component used to control another circuit or other component, such as a high-power transistor. This term is used for a specialized computer chip that controls the high-power transistors in DC-to-DC voltage converters. An amplifier can also be considered as the driver for loudspeakers or a constant voltage circuit that keeps an attached component operating within a broad range of input voltages [13].

Supervisory and data controls

SCADA stands for supervisory control and data acquisition. It generally refers to an industrial control system (computer system monitoring and controlling a process). The process can be industrial, infrastructure or facility. Industrial processes include those of manufacturing, production, power generation, fabrication and refining, and may run in continuous, batch, repetitive or discrete modes. Infrastructure processes may be public or private, and include water treatment and distribution, wastewater collection and treatment, oil and gas pipelines, electrical power transmission and distribution, civil defense siren systems, and large communication systems. Facility processes occur both in public facilities and private ones, including buildings, airports, ships, and space stations. They monitor and control HVAC (heating ventilation and air conditioning), access, and energy consumption [14].

Automation process

The automation system technology for iodine-125 seed production developed in this work was mainly assembled employing:
- Electro-electronic and mechanical components;
- Programmable logic controller (PLC);
- Stepper motors and drives;
- Nd:YAG laser welding machine;
- Microcomputer, supervisory and interfaces;
- Photoelectric and optical sensors, and
- Distribution systems for titanium tubes and silver rod with iodine-125 adsorbed.

Integrate hardware and software

On the automation system for iodine-125 seed production developed in this work was necessary to integrate:
- Electro-electronic and mechanical parts and components;

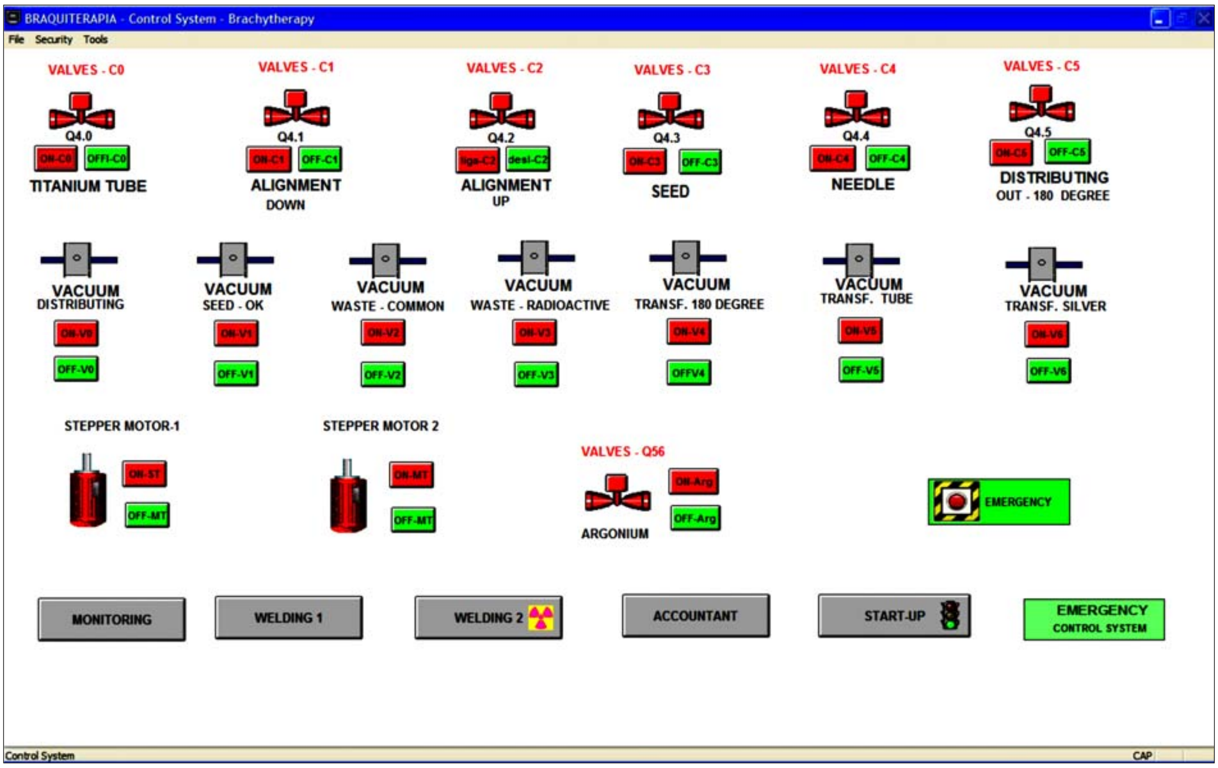

Fig. 1. InduSoft Web Studio 6.1 supervisory [15].

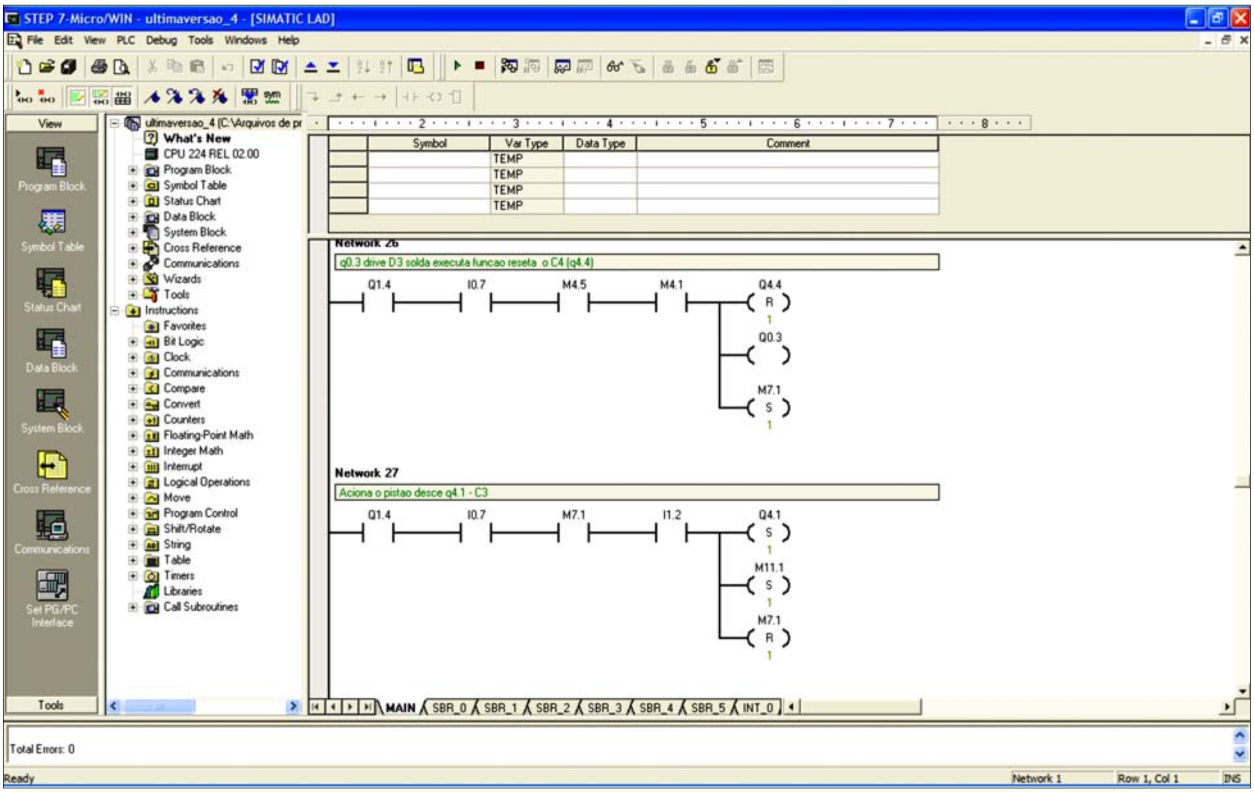

Fig. 2. Siemens Step S7 200 MicroWin 4.0 software [11].

– InduSoft Web Studio 6.1 supervisory (Fig. 1);
– Siemens programmable logic controller (PLC) and Step S7 200 MicroWin 4.0 software (Fig. 2);
– Miyachi Unitek Nd:YAG laser welding machine 15 W, and
– Applied motion drives of the stepper motors (Fig. 3).

Iodine-125 seed production process

The iodine-125 seed produced by IPEN-CNEN/SP consists of a titanium capsule with an external diameter of 0.8 mm, 4.5 mm in length and 0.05 mm in thickness [1–3]. It is a radioactive sealed source, in which the silver rod with iodine-125 adsorbed is positioned inside

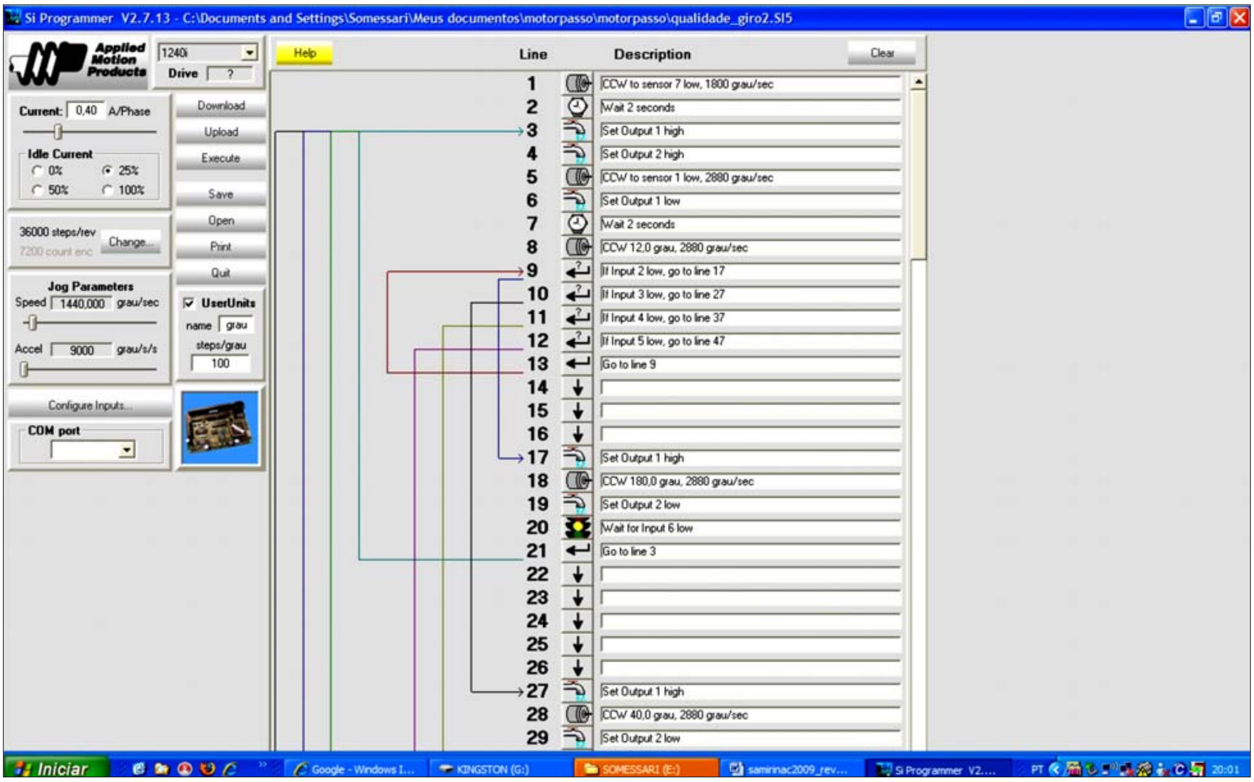

Fig. 3. Applied motion stepper motor controller software [10].

the titanium capsule, welded in both extremities by Nd:YAG laser welding machine [6, 9].

The automation system technology for iodine-125 seed production developed in this work was controlled by Applied Motion stepper motor controller supervisory and Siemens Step S7 200 MicroWin 4.0 software.

The production process of iodine-125 seeds consists of:

a) A distribution device which uses a titanium tube. It is positioned accurately on the welding device, in which one titanium tube extremity is welded by laser;
b) After welding this first extremity, the mechanism inverts the titanium tube, which goes back for the welding device;
c) When the titanium tube is in right position, another distribution device transports the silver rod with iodine-125 adsorbed. Then, the silver rod is positioned into the titanium tube, and
d) Then, the welding device is positioned with accuracy to weld the second extremity of the titanium tube. The iodine-125 seed becomes a radioactive sealed source.

Figure 4 shows the automation system with electro-mechanical and pneumatic components for iodine-125 seed production. Figure 5 shows the automation system employing a programmable logic controller (PLC) to control machines and processes for iodine-125 seed production. The statistical repeatability of correctly encapsulated sealed sources with the automation system developed in this work is greater than 95%.

Conclusions

The main advantage of brachytherapy application in cancer diseases treatment compared with external radiation therapy (teletherapy) is precise targeting of the radiation with sparing of healthy tissues, what boosts success of therapy.

The industrial automation plays an important role for iodine-125 seeds in order to increase the productivity and flexibility, with high quality and assurance, decreasing costs, avoiding human factors, implementing and operating with GMP.

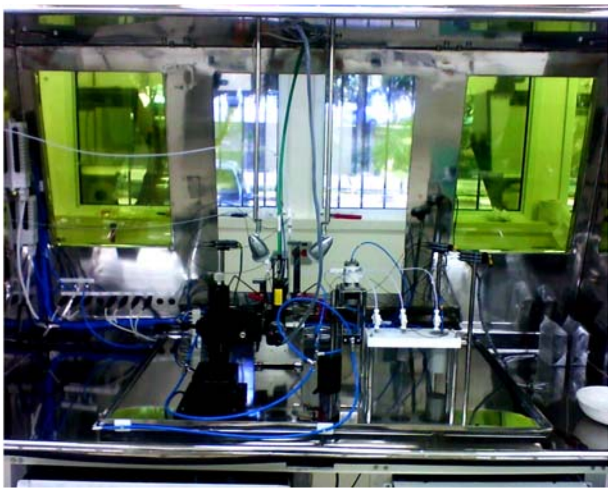

Fig. 4. Automation system with electro-mechanical and pneumatic components for iodine-125 seed production.

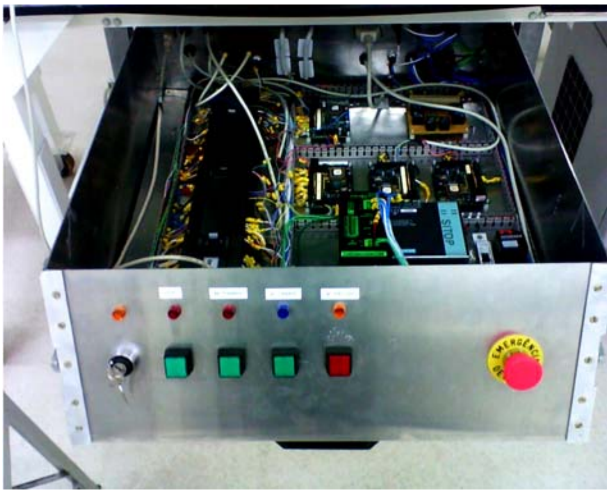

Fig. 5. Automation system employing a programmable logic controller (PLC) to control machines and processes for iodine-125 seed production.

Complex automation systems integrate computer hardware and software, robotic equipment, line equipment, shipping processes, inventory control and employee training to increase manufacturing efficiency and productivity.

Computer software and hardware play an important role in automation systems. Computers control and manage the automation of physical and analytical tasks.

The statistical repeatability of iodine-125 brachytherapy seed correctly encapsulated by Nd:YAG laser welding with the automation system developed in this work is greater than 95%.

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