Design and Realization of a Radiometric Gauge for Control On-Line of the Galvanization Coatings on Steel Sheet

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Abstract
The steel sheets produced by a Moroccan industrial company, specialized in the field of the metallurgy, are covered with a Zinc layer in order to increase their corrosion resistance. To control Continuously the thickness of the Zinc layer, which is about 30 to 45 µm, this industrial company contacted the CNESTEN in order to develop a device based on the x-ray fluorescence techniques and allow a very precise control .This project, named "Gauge KALFAN", consists of sensors (Source: Am 241 300mCi, Detector: CaF2), data acquisition System and positioning System and Mechanical stand. This gauge, witch has been designed for real time and uninterrupted control of the galvanisation coating on steel sheets, was installed on the line of galvanization of the industrial company and functions since under normal conditions.

Keywords: *Data acquisition, Galvanisation, Gauge, Mechanical stand*

I- Introduction

The CNESTEN plays a very important role in the development of nuclear techniques in industry in response to the specific needs of various local industries. Indeed, a Moroccan industrial company, specialized in the field of the metallurgy, has been interested in this technology and in its uses to improve its production quantity and quality of services. The purpose of this work of research and development is to bring a technological response to the needs expressed by this industrial unit. The steel sheets produced are covered with a Zinc layer in order to increase their corrosion resistance. The chemical method used in the manufacturing process of metal sheets cannot give an exact thickness of the Zinc layer. For this purpose and to control continuously the thickness of the Zinc layer on line production, a layer which is about 30 to 45 µm, we designed a device based on x-ray fluorescence techniques, to allow precision of control. This device, named "KALFAN" (from the Arabic term "*Kalfana*" which mean galvanisation), consists of a monitoring system, an acquisition unit (UA) and a frame on which two synchronised movements of dolly moving three sensors. The sensors are made up of two gamma radiation sources and three CaF2 detectors. The isotope used is Americium (^{241}Am) energy (59.54 keV) which favours a good output of fluorescence. The system controls in real time the amount of the Zinc deposit on the monitoring system. An alarm goes off automatically if the system is out of range fixed by the user. The data measurement can be saved on discs of the type ZIP 100 Mo.

II- Sensors

A. Detectors selection

After having taken measurements on a certain number of detectors, mainly the diode detector [1], the NaI detector and the CaF2 detector [2], [3], it was proved that for the first one we obtain for the low energies (area which interests us: the energy of fluorescence of Zinc is about 8.7 KeV) only noise and this up to 12 KeV. Concerning the detectors NaI and CaF2, we can clearly observe the peak of fluorescence of Zinc with 8.7 KeV, and a second peak of 20 KeV which could disturb our measurements for the NaI detector. So we have chosen the detector CaF2 (good resolution compared to NaI and more robust).

B. Source selection

The measurement of X-ray fluorescence of Zinc is possible using emitter of the X-radiations which has energy higher than the energy of Zinc (8.7 Kev). For that 5 emitters were investigated:

Table1: Tested X-radiations sources

Sources	Period	Energy (KeV)
Américium241	432.2 years	59.54
Plutonium 238	87.7 years	16.40
Curium 244	18 years	16.70
Gadolinium 153	242 Day	41.31
Cadmium 109	463 Days	22.00

The experiments made in the laboratory show that the most interesting radiation sources are: Américium241 and Gadolinium 153. The Source of Gadolinium 153 has only 242 Days as period. So we have chosen the Am241, witch the main characteristics [4] are:

- Isotope: Américium241.
- Activity: 11, 1 GBq, 300 mci.
- Energy: 59.54 keV.
- Half-life: 432.2 years.
- Obturator: disc of 7 mm Dénal

C. The Source-Detector geometry

The fluorescence emitted by an excited material is automatically attenuated by this one. Thus there are two phenomena which are compensated: increase in the output of fluorescence with the thickness of material and reduction in the percentage of photons of fluorescence which manage to exit from material. That's why we quickly reach (a few hundred microns) an "infinite" thickness of material to be measured. Beyond that the fluorescence photons number remains constant irrespective of the thickness of material. For that reason, we varied the intensity of the Zinc with the thickness for several Source-Detector positions, and the most favourable angles obtained are a = 45° (Incident) and b= 90° (emergent). The Source-Detector will be placed so that the detected photons of fluorescence have the shortest way in the Zinc.

D. Principle of detection

The radiation detectors used are scintiblocs. A scintibloc is a unit made up of a scintillator (CaF2 in our case), of a photomultiplier (PM) and an input window. The PM is supplied by high negative voltage, referenced by SAPRA CHRIST 97 [5]. Each gamma photon, crossing the window of the detector, interacts with the scintillator is converted into luminous pulses which are proportional to the energy of this photon. The photomultiplier converted these luminous pulses into electrons with high gain, and then we obtain an output current, which allows us to measure a voltage across the load. The physical signal obtained is processed by a card called PRETHOT, in order to eliminate the drifts from the PM. This card discriminates the counting in two different windows of energy. The output TTL Signal is then processed by the acquisition unit.

E. Principle of measurement

i. Zinc Measurement

The Zinc thickness measurement is taken by x-ray fluorescence [6], [7], [8], [9], [10]. The gamma rays emitted by the source of 241Am (59.54 KeV) excite the Zinc atoms which re-emit an X ray-radiation of energy 8.7 KeV. The integral of this ray (in count per second) is directly related to the thickness of the Zinc coating. Using different samples of zinc we obtained the curve shown in the

Fig.1. This curve shows that we can determine the thickness of Zinc layer from the intensity of Fluorescence Zn for values < 80 um. The area of interest is between 30 and 45 µm.
The Iron is also excited and its fluorescence is taken into account (energy: 6.4 KeV).
Our experiments show that for the zinc thickness less than 20µm, the influence of Iron is considerable and is approximately 13.6%. This percentage falls down to 2% as soon as the Zinc thickness reaches 30 µm. In our case the Zinc thickness is higher than 30µm. Thus only the fluorescence of Zinc is taken into account in our measurements.
The equation modelling the system is as follows:

$$R = R_{inf}\,(1 - e^{-\mu_{Z8} \cdot \varepsilon_z} + \frac{R_0}{R_{inf}} \cdot e^{-\mu_{Z6} \cdot \varepsilon_z}) \quad (1)$$

With:

- R: the counting rate measured (coups/s)
- R0: the counting rate when there is only Iron (null Zinc thickness) (c/s)
- Rinf: the counting rate when the thickness of Zinc is infinite (c/s)
- µZ8: the absorption coefficient in Zinc for an energy of 8.64 keV (µm-1)
- µZ6: the absorption coefficient in Zinc for an energy of 6.4 keV (µm-1)
- εz: the Zinc thickness (to be found) (µm)

The Zinc thickness is not direct calculated, because we can not isolate the unknown factor εz in the equation. We find the value by resolving the equation numerically (Newton method).

ii. Steel Measurement

The thickness measurement of the steel sheet is done by gamma radiation absorption of the Americium 241 (59.54 keV) source. First of all, the beam crosses the top layer of Zinc, then the steel sheet and finally the bottom layer of Zinc. By determining the thickness of each layer of Zinc and the absorption coefficients of each material (Iron and Zinc), we can find the thickness of steel.
The equation modelling the system is as follows:

$$R = R_0\,(e^{-\mu_{Z60} \cdot (\varepsilon_{Z1} + \varepsilon_{Z2})} + \cdot e^{-\mu_{F60} \cdot \varepsilon_F}) \quad (2)$$

Where:

- R: counting rate measured (coups/s)
- R0: counting rate with any materiel (neither Iron nor Zinc) (c/s)
- εZ1 , εZ2: thicknesses of the two layers of zinc (µm) (known)
- εF : thickness of Iron (µm) (to be found)
- µZ60: Zinc absorption coefficient with 59.54 keV (µm-1)
- µF60: Iron absorption coefficient with 59.54 keV (µm-1)

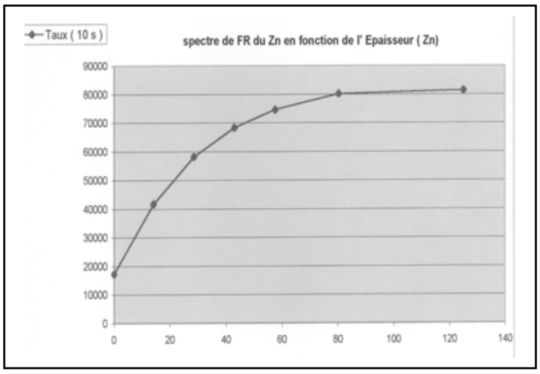

Fig.1: Spectre of Zinc : Curve - several samples of zinc

The Iron thickness is given by:

$$\varepsilon_F = \frac{1}{\mu_{F60}} \cdot \left[\ln \frac{R_0}{R} - \mu_{Z60} \cdot (\varepsilon_{Z1} + \varepsilon_{Z2}) \right] \quad (3)$$

III- Measurement Devices

The electronic system of Gauge KALFAN consists of the principal elements:

A. Monitoring System and Software (WINKALFAN)

The Monitoring System is the interface between the user and the gauge. It is the master PC which communicates with the Acquisition Unit (UA) by RS 485 connection. A software, WINKALFAN (working under Windows), especially developed for gauge KALFAN, makes it possible for the user to choose the sweeping mode for measurements; it calculates the Zinc and steel thicknesses from the counting rates provided by the UA. At the time of retiming it recomputes the parameters of adjustment of the gauge in order to avoid any drift in time. It makes it possible for the operator to monitor in real time the measured thicknesses on graphs (Winkalfan). In the event of exceeding of the work limits, fixed by the user, an alarm is activated. It will be deactivated either by a return to normal values, or by the user.

B. Acquisition Unit

The Acquisition Unit (UA), built around electronic cards of ultra compact technology of high performances, allows for the acquisition and the processing of data delivered by the nuclear detectors and delivers the analogical signals which represent the average amount of Zinc for both layers. The UA manages also the logical inputs/outputs and the communication with the master PC. The UA works with software specifically developed and named "NUDAS 4" (for Nuclear Data Acquisition Software): it is useful for the installation and the maintenance. However, in the event of breakdown of the master PC, NUDAS 4 can be very useful for the recovery of the data measured by the detectors. The principal tasks carried out by the software are:

i. Acquisition:

Every 100 milliseconds, the software records the value delivered by Detectors for the three channels corresponding to the top layer, the bottom and the steel sheet then resets the system to 0. The recorded values are stored in "a buffer" permanently. At the end of the time of integration (T=10s), after compensation and correction the software calculates the average value and retains the counting rate representing information on the measured Zinc amount. The software measure also the steel sheet speed.

ii. The transfer of data to the main PC:

A communications protocol allows the exchange of the data in real time with the main PC. The transfer is carried out through the serial port RS485. If the PC is not connected, the calculator safeguards the data in a file. The safeguard can last up to 48 hours.

iii. Command of the Analogue and Digital Inputs/Outputs:

- Analogical outputs delivering the Zinc amount
- Analogical inputs proportional to the steel sheet speed
- Digital inputs indicating the radioactive sources states (opened or closed).
- Digital outputs for activating /deactivating alarm in the event of going beyond the ranges setting up by the user
- Digital input for alarm deactivating.

iv. Retiming:

The master PC sets within interval of regular time the detectors in front of 3 reference points to make a retiming and requires from the calculator to carry out the acquisition, in this case the software sends measurements of retiming to the main PC and uses them for its local retiming.

v. The automatic restarting in the event of the unit acquisition blocking:

Assembly called "watchdog": restarts the system after 1.2 seconds time of blocking.

vi. The parameters acquisition:

The software gives the possibility to introduce the acquisition parameters and executing instructions independently of the master PC.

C. Electronic Motor Control (Charlyrobot)

The electronic motor control used is the model C244 Charlyrobot; it allows the piloting of 1 to 3 step by step engines 2 or 4 phases. It is equipped with a controlling card programmed through a PC using serial RS232C.

IV- Mechanical Support of the Gauge

The gauge consists of:

- a bottom box which contains the Acquisition Unit and the Charlyrobot electronic control.
- a moving system moves in translation the three sensors (two heads are interdependent). This system is pulled by a Charlyrobot engine provided with an Alpha-reducer of 1/20.

V- CONCLUSION

In the face of technological problems, nuclear techniques made it possible to bring an adequate solution, by proposing reliable and economic models making it possible to improve quality, to gain the satisfaction of the customers and to increase profitability. Within this framework, and through the realization of this project (fig.2), the Moroccan industrial company improves its production by using a system based on a radiometric Gauge for control on line of the galvanization coatings on steel sheet. This technique allowed the company to reduce the losses rate of the zinc from 18% to 3% and saving about 100 000 EUR/year. This system was installed on the line of galvanization of the company and calibrated in order to adapt it to the installation requirements of the industrial plant. Radiation Protection Measurements were taken around the Gauge to protect the personnel. The results obtained by using this gauge are better than those obtained by the chemical technique currently used by the company. More than that, the gauge allows a real time and uninterrupted control compared to the traditional techniques.

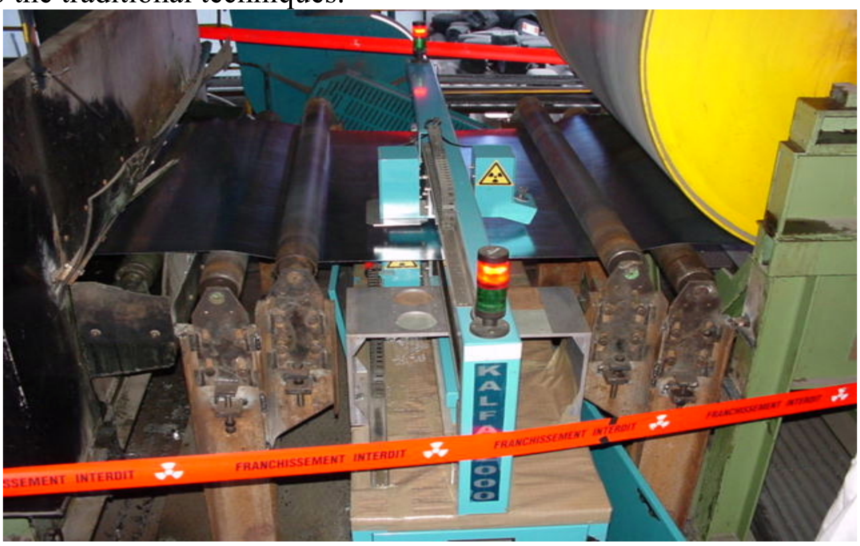

Fig.2: Gauge KALFAN Installed on line of galvanization coatings on steel sheet

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