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Two Stages Fault Detection Method Based on Error, Applied in EBM Facility

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Abstract. Data driven technique is a well-known method in fault detection and it is suitable for large industrial systems. In this article, this technique is applied in an electron beam (EB) facility to assist the technology available in that facility so that the number and cost of equipment/ component failures can be reduced. An example is on EB scanning, if not properly monitored and in case of beam scanning unit fails, it will damage EB accelerator tube which is one of the main components in EBM facility. For these two stages fault detection, the current data for both x- & y- coils are monitored and compared with the normal outputs that obtained from such as an ANFIS model. If either or both errors are larger than their threshold limits and it happened for a certain period of time then the beam current source shall be terminated and the high voltage power supply across the tube shall be quickly reduce to 0 kV in order to avoid heat developed on the 25 μm titanium foil window that due to electron beam penetration and will soon torn the window. Delays for three cases (x-, y- and both x&y coils) are pre-determined by the specialist and these will eliminate uncertainty of error signals.

Keywords. Data driven technique for fault detection, electron beam scanning, adaptive neuro-fuzzy inference system (ANFIS), Boolean comparator with delay, high voltage power supply.

INTRODUCTION

In an electron beam machine (EBM), the electron beam is accelerated in a high vacuum tube (~10^{-6} torr) from electron gun at the cathode to the anode and then it penetrates through a 25 μm titanium foil window to the sample, located underneath the window. Before it reaches the window in the extraction device, the beam is then scanned to the window's size (10 × 100 cm^2) by two perpendicular magnetic fields in x- and y- directions respectively. For ELV-4 type accelerator which is made by Budker Institute of Nuclear Physics (BINP), Russia [1], the voltage across the tube can be varied from 0.01 to 1.00 MV so the equivalent energy of accelerated electron is from 10 KeV to 1 MeV, with maximum beam current of 10 mA. A vertical cross section view of the accelerator is shown in Figure 1 where it requires a two storey 1.2 m thick of bunker for installation. The beam profile on the window is shown in Figure 2 where it uses a triangular waveform with scanning speeds of 1 kHz and 50 Hz in x-axis and y-axis respectively. This accelerator has been installed at Malaysian Nuclear Agency Complex, located at Bangi, Selangor since 2010. Reason for this scanning is to get a uniform distribution of electron beam on the sample.

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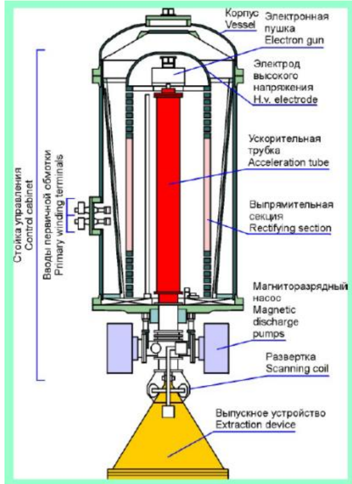

FIGURE 1. Cross section of electron beam machine of ELV-4 type, made by Russian BINP

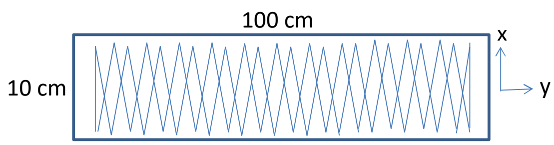

FIGURE 2. Botton view of the extraction device (window) showing electron beam scanning with speeds of 1 kHz in x-axis and 50 Hz in y-axis

Any equipment or facility can get malfunction after has been operated for a certain period of time. Sometimes, a small defect in a component will become a major failure if earlier and immediate corrective action was not done. A case study is in this accelerator where the current that required by each scanning coil in normal operation for the whole range of electron energy is shown in Figure 3. Here, I_x and I_y represent the current flows in coil –x and –y against the electron energy, E_e respectively. If the beam doesn't scan and stay at one location only then that location of window will develop extra heat on the titanium foil and soon will create hole and implosion (because of high vacuum) will happen and causes damage the whole accelerating tube. This tube is one of the major components in this facility and very expensive to replace it. Moreover, indication of scanning failure for both coils or either one of the coils is detected by the different in the actual coil current as compared to the normal one.

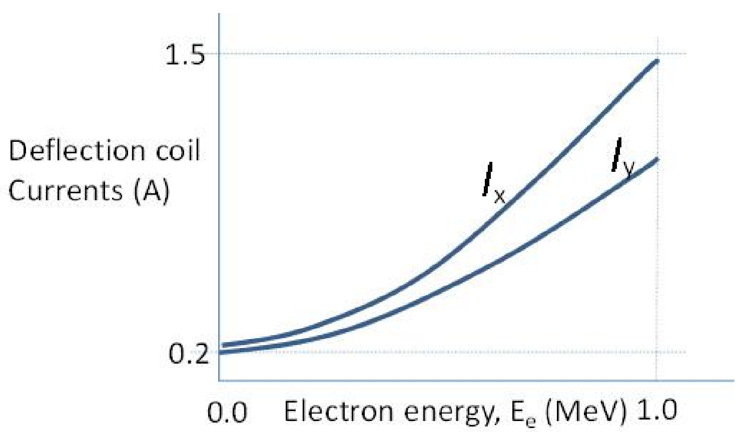

FIGURE 3. Deflection coil currents I_x and I_y for x- and y- axis respectively versus electron energy, E_e in order to maintain the electron scanning area coverage on the window of ≅ 9 cm x 90 cm.

FAULT DIAGNOSIS METHOD

In an electron beam facility, it is divided into five main areas namely, the high voltage (HV) power supply, the electron gun's current, vacuum, interlocking and beam scanning systems. Here, we have selected the beam scanning system to be the case for study and improve the fault diagnosis method in case of component failure. A method as described by the flowchart in Figure 4 is implemented in this article. During operation, the operator will set for the required HV, i.e. the electron energy as well as the beam current. The scanning coils will also automatically operate and the actual currents, I_{xa} in x-coil and I_{ya} in y-coil will depend on the electron energy as explained earlier (Figure 3). These currents are then monitored and compared with the coil currents in normal operation, I_x and I_y in term of their errors, e_x and e_y respectively which is given by:

$$e_x = I_x - I_{xa} \text{ and } e_y = I_y - I_{ya} \tag{1}$$

The threshold errors, e_{Tx} and e_{Ty} for both x- and y- coils respectively need to be setup and their magnitudes are given by the specialists. For the case of potential failure where $e_x > e_{Tx}$ or $e_y > e_{Ty}$ or both $e_x > e_{Tx}$ and $e_y > e_{Ty}$, actions such as the operator shall reduce the HV supply to 0 V, or to cut off the beam current as quickly as possible in order to avoid heat develop at the window, so that the accelerating tube is safe from a major failure. Since due to the human weaknesses [2] such as the operator is not always hear the buzzle or look at the indicator (if any) when these large errors could happen, it is essential that to make it works in automatic mode, i.e. to cut off the beam current by switching off the current supply to the electron gun, and then followed by reduction of the HV supply to 0 V when a large current error happens.

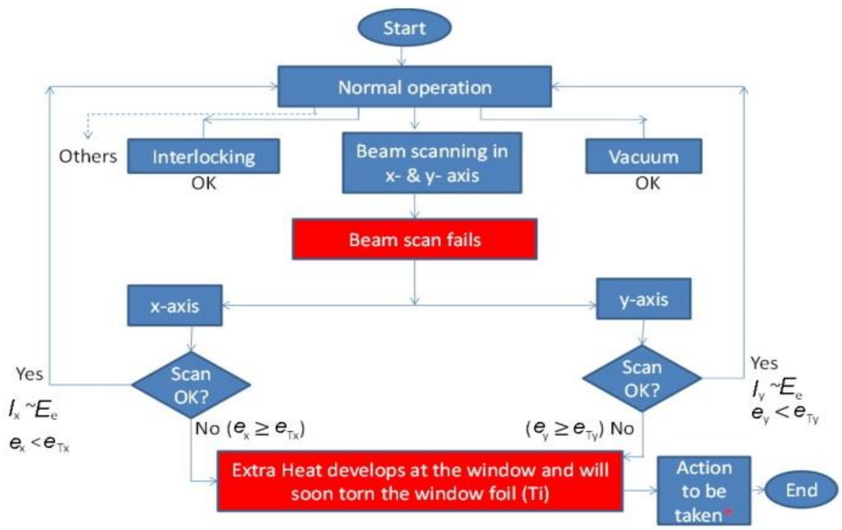

FIGURE 4. Fault detection strategy for beam scanning.

Modeling of Scanning Coil Currents

There are many ways to model the relationship between input and output. The simplest case is to use a set of input and output data at steady state condition, which is not depend on time and the relationship is simply obtained via a curve fitting method [3]. A set of data in Figure 3 is an example where the relationship can be approximated by:

$$I_x = 0.2 + E_e^2 \text{ and } I_y = 0.2 + E_e^{2.2} \tag{2}$$

for $0 < E_e < 1$ MeV, and I_x and I_y are in Amperes.

Note that a minimum current of 0.2 Amp is required at electron energy of 0 MeV in order to drive the power amplifier circuitry when no current flows to the coil.

A more practical method is to consider dynamics of the system where the output parameter at present will depend on both previous data of input and output parameters. For this case, we require a set of input and output data that is acquired for a certain period of data samplings in normal operation. This data is then analyzed using a data driven technique [4] and a well-known method of input/ output modeling is obtained via a system identification method [5]. In this technique, a more accurate model is to use intelligent methods, and an adaptive neuro-fuzzy inference system (ANFIS) [6, 7] is one of them. Here, two ANFIS models are used to obtain the coil currents, I_x and I_y respectively. We can use a set of data acquired during normal operation (without faulty) sampled at every T second, and for various set values of electron energy, E_e. For a 2nd order ANFIS model, I_x at time, t is:

$$I_x(t) = F_{ax}[I_x(t\text{-T}), I_x(t\text{-2T}), E_x(t\text{-T}), E_x(t\text{-2T})], \quad (3)$$

and,

$$I_y(t) = F_{ay}[I_y(t\text{-T}), I_y(t\text{-2T}), E_y(t\text{-T}), E_y(t\text{-2T})] \quad (4)$$

where F_{ax} and F_{ay} are the ANFIS functions that depends on the 1st and 2nd previous values of the beam current as well as the electron energy.

Fault Diagnosis Design

In design of a fault diagnosis strategy, the currents $I_x(t)$ and $I_y(t)$ in Equations (3) and (4) are then subtracted with the actual monitored coil current values $I_{xa}(t)$ and $I_{ya}(t)$ respectively in order to obtain their absolute errors in an online manner,

$$e_x(t) = \left| I_x(t) - I_{xa}(t) \right| \text{ and } e_y(t) = \left| I_y(t) - I_{ya}(t) \right| \quad (5)$$

We are also interested to know the error of total current of $I_x(t)$ and $I_y(t)$, with $I_{xa}(t) + I_{ya}(t)$.

$$e_{xy}(t) = I_{xy}(t) - I_{xya}(t) \quad (6)$$

A block diagram for these three cases is given in Figure 5. The errors for all cases namely e_x, e_y and e_{xy} are then compared with its threshold errors e_{Tx}, e_{Ty} and e_{Txy} respectively, and by using Boolean logics,

$$C_x \text{ is High if } e_x(t) > e_{Tx}, \text{ else } C_x \text{ is Low} \quad (7)$$

$$C_y \text{ is High if } e_y(t) > e_{Ty}, \text{ else } C_y \text{ is Low} \quad (8)$$

and,

$$C_{xy} \text{ is High if } e_{xy}(t) > e_{Txy}, \text{ else } C_{xy} \text{ is Low.} \quad (9)$$

So, if any or all of C_x, C_y and C_{xy} are in High state, then the high voltage power supply as well as the electron beam current shall be reduced to zero as quickly as possible. This will prevent the heat developed at the windows foil that due to the electron beam stays at one position only. For the comparator output, C_i (i = x, y, xy) is High, most likely because of the beam is stationary (not scanning), or if it is scanning but not at a full swing. This feature shall be added into the computer based control system available at the control room of the facility, or else the operator shall take action manually. Note that at any energy range of the electron beam, the scanning area on the window is required to be almost constant, i.e. within 90 x 9 cm^2 of the window area, so more coil current is required as the electron energy increases [8].

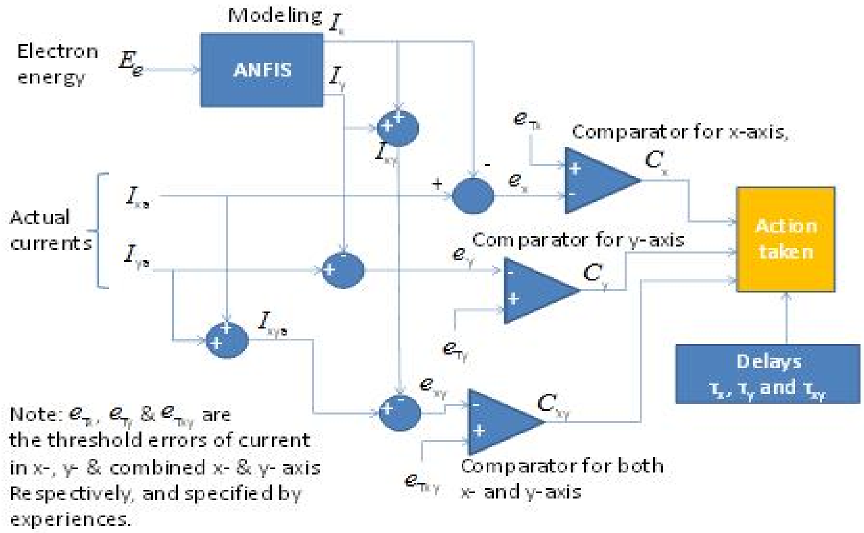

FIGURE 5. Proposed fault diagnosis with delays included

As mentioned earlier, 'the HV supply and beam current shall be reduced to zero as quickly as possible' when the comparator output is in High state. Before these actions take place, we shall allow some delays, τ_x, τ_y and τ_{xy} for the beam being not scanning in x, y and combined x&y axis respectively. As an example, if only C_x is High means that the beam is not scanning in x-axis but it still scans in y-axis, i.e. scanning in one dimensional only. Similarly, if only C_y is High means that the beam is not scanning in y-axis but it still scans in x-axis. If both C_x and C_y are High, these show that the beam is not scanning at all, so this will cause heat develop at that particular point of the window and will soon tear the window and damage the accelerating tube. Moreover, these delays are necessary because to confirm the scanning coil failure is really happened and is not the unwanted intermittent reading. Figure 6 shows the delays allowed τ_x, τ_y and τ_{xy} before action as describe above being taken. The values of these delays have to be determined, and as a rule of thumb, we make:

$$\tau_x \approx \tau_y \text{ and } \tau_{xy} \approx \tau_y/2 \tag{10}$$

The magnitudes of τ_x, τ_y and τ_{xy} will inversely depend on the beam energy, i.e. the high voltage power supply, E_e in keV as well as the beam current, I_e in mA.

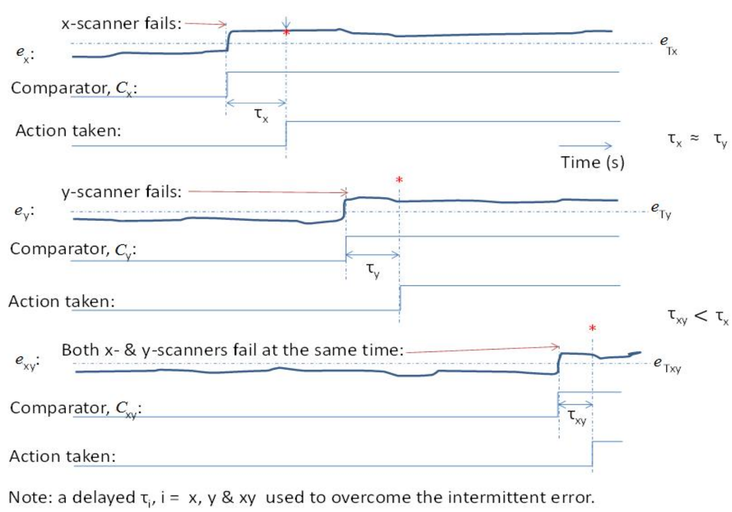

FIGURE 6. Delayed action for three different cases.

One possible relationship can be written as:

$$\tau_x = k\, E_e^{-m} I_e^{-n} \tag{11}$$

where *k*, *m* and *n* are constant. This relationship means that the delay is shorter when the beam energy and/ or the beam current are both high or either one is high. The value of these constants are rather subject to further research, but for simplicity we can make $m = n = 1$ and left *k* to be chosen with certain accuracy.

CONCLUSION

In this paper, a method of fault detection is proposed by introducing delays before the action can take place. It is implemented for the case of faulty at the electron beam scanning in a1 MeV, 50 mA electron accelerator facility. This method can be extended to design the failure detection of other important features in the facility. Moreover, it can also apply to other similar technological facilities as well.

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