Commun.Fac.Sci.Univ.Ank.Series A2-A3
Volume 62, Number 1, Pages 63-70 (2020)
DOI: 10.33769/aupse.660187
ISSN 1303-6009 E-ISSN 2618-6462
http://communications.science.ankara.edu.tr/index.php?series=A2A3

RF ANTENNA DESIGN FOR BUTTON-TYPE BEAM POSITION MONITORS USING BIO-INSPIRED OPTIMIZATION METHODS

Ayhan AYDIN and Erkan BOSTANCI

ABSTRACT. Accelerator based facilities are in a leading position for crafting many scientific and technical innovations for a wide range of application from aviation to medicine. Beam Position Monitors (BPMs) are critical diagnostics tools for such facilities. This study presents bio-inspired methods known as Particle Swarm Optimization and Evolutionary Algorithms in order to design RF antennas for button-type BPMs. Our results show that the antenna parameters obtained using this multiple objective approaches present suitable SNR and linearity values for signal processing. It is found that using an antenna radius of 5.5 mm and beam-pipe radius of 17.5 mm, we can obtain SNR values around 40 dB which can be electronically processed.

1. INTRODUCTION

Although the installation and operation costs of accelerator based facilities require huge investments, they play a major role in the development of science and technology. Particle beams produced in such facilities must be continuously diagnosed and be subject to correction processes in order to provide protection from any radiation damage. Beam Position Monitors (BPM) are one of the most important diagnostics tools to diagnose entire system and they are used to determine position of beam inside the beam-pipe [1-3]. There are three important concerns in this process which can be listed as: (1) BPM antennas should provide adequate signal, i.e. signal-to-noise ratio (SNR) for signal processing, (2) beam position measurement should be done accurately and (3) the measurement system should be non-destructive to the beam. Considering these requirements, studies were carried out to determine the geometry of button-type BPM antennas using numerical and

Received by the editors: December 16, 2019; Accepted: March 02, 2020.
Key word and phrases: Multiple objective evolutionary algorithms, RF antenna design, beam position monitors.

analytical approaches [4]. In this study, we focused on optimizing the geometric properties of BPM antennas such as diameter, thickness and gap by using bio-inspired optimization algorithms such as Particle Swarm Optimization (PSO) and Evolutionary Algorithms (EA) [5-7].

2. BPM ANTENNA DESIGN

Different techniques can be used to determine of the beam position. However, these techniques can damage structure of the beam or they can be very expensive. Therefore, BPMs are widely used for all kind of accelerators due to low cost and robustness. The mechanical system of BPMs are generally designed as a cylindrical structure with 4 antennas placed on. Determination of the beam position is directly related to geometry of the BPM. This geometric design can affect many parameters such as accuracy, resolution, bandwidth, dynamic range, SNR *etc*. Therefore, design and production stages are key to achieve these requirements. In this study, optimization methods are applied on the following basic formulas to find geometric features of the BPMs for Turkish Accelerator and Radiation Laboratory in Ankara (TARLA) [8].

The signal power depends on the geometric parameters of BPM including beam-pipe radius, antenna diameter and thickness [9]. Once an adequate signal level is obtained, this signal can then be processed electronically by a front-end electronic system [10]. Despite the fact that the signal level can be increased by extending the antennas, it is known that using larger fitting elements makes it difficult to achieve an ultra-high vacuum level.

For this reason, we optimized antenna radius along beam-pipe radius and thickness for admissible values considering TARLA beam parameters such as the beam-pipe radius between 17.5 mm and 21 mm, average beam current of 1 mA and bunch repetition rate of 13 MHz.

In order to find optimal antenna radius ***a*** and beam-pipe radius ***b*** parameters, we used the following formula for finding signal power (P_s) and noise power (P_n) defined by Smith [2] as an objective function:

$$P_s = \frac{2\pi^2 a^4}{b^2 \beta^2 c^2} Z A_m^2 f_0^2 I_{avg}^2 \qquad (2.1)$$

and

$$P_n = k_B TZB \tag{2.2}$$

Then the SNR can be calculated as:

$$SNR = \frac{P_s}{P_n} \tag{2.3}$$

3. Parameter Optimization

Finding optimal design parameters for BPM is a numerically expensive problem. Considering the complexity of the power and signal calculations for a large number of candidate solutions, following a numerical or analytical optimization approaches may be a challenge. Furthermore, the classical approaches also tend to get stuck at local optimum.

The literature presents bio-inspired optimization methods such as PSO and EA [11-14] which are both stochastic computation techniques inspired by the flocking behavior of the birds and the basic law of survival of the fittest, respectively. Such optimization methods do not require prior knowledge about the solution, rather use a fitness function to choose among candidates that are promising to yield better solutions through a heuristic process.

In this paper, the design problem for the BPM was modeled using both approaches with two optimization goals as (1) to increase P_s, (2) decrease antenna radius, gap and thickness subject to three constraints as having (1) SNR larger than 30 dB (2) resolution smaller than 20 micrometer and (3) capacitance larger than 1 pF.

4. Results

Results show that the electron beam located anywhere in the beam-pipe (with radius 17.5 mm and antenna radius of 5.5 mm) can be measured linearly in the first 10 mm region of by using 11 mm diameter antennas as depicted in Fig.1.

Fig. 1a. and Fig. 1b. depict the extreme examples for the antenna size for 2.5 mm and 10 mm, respectively. It can be seen that the measurements can overlap for a short antenna (Fig. 1a), which means that there will be accuracy problems, *i.e.* linearity problems can be faced, in the measurement, whereas in case of using a long one (Fig. 1b.), more accurate readings can be achieved. The problem with using a long antenna is that they are not always of practical use due to manufacturing process since antennas with a larger volume may counteract the vacuum permittivity constraints.

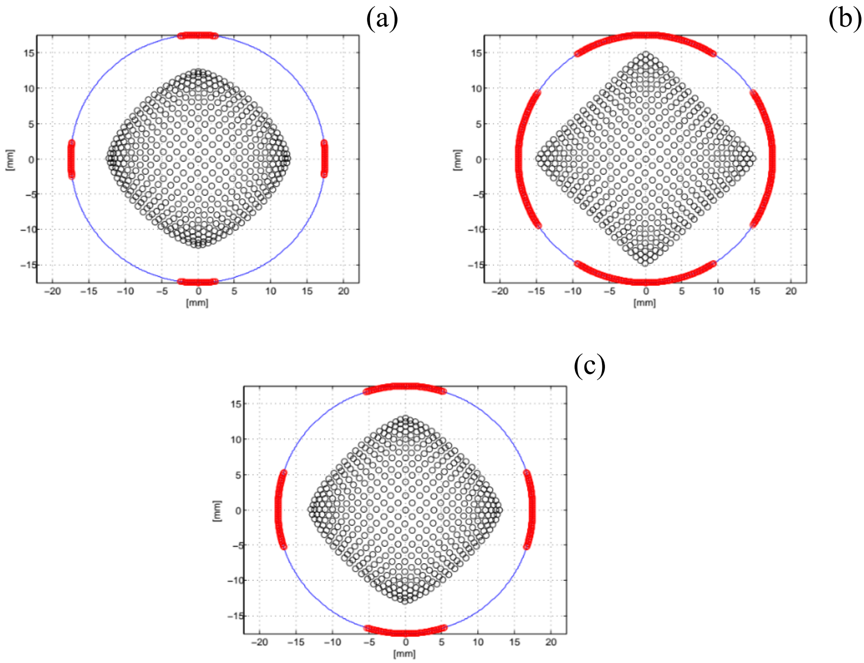

FIGURE 1. Linearity maps for the electron beam for varying antenna lengths (a) 2.5 mm (b) 10 mm (c) 5.5 mm.

The optimized length of 5.5 mm (Fig. 1c.) can achieve accurate measurement in 10 mm range of the beam-pipe. For the non-linear part (beyond 10 mm), mathematical interpolation methods such as curve fitting can be applied to determine beam position.

The beam position calculated in terms of voltages is depicted in Fig. 2 for small displacements from the beam-pipe center as described in [2].

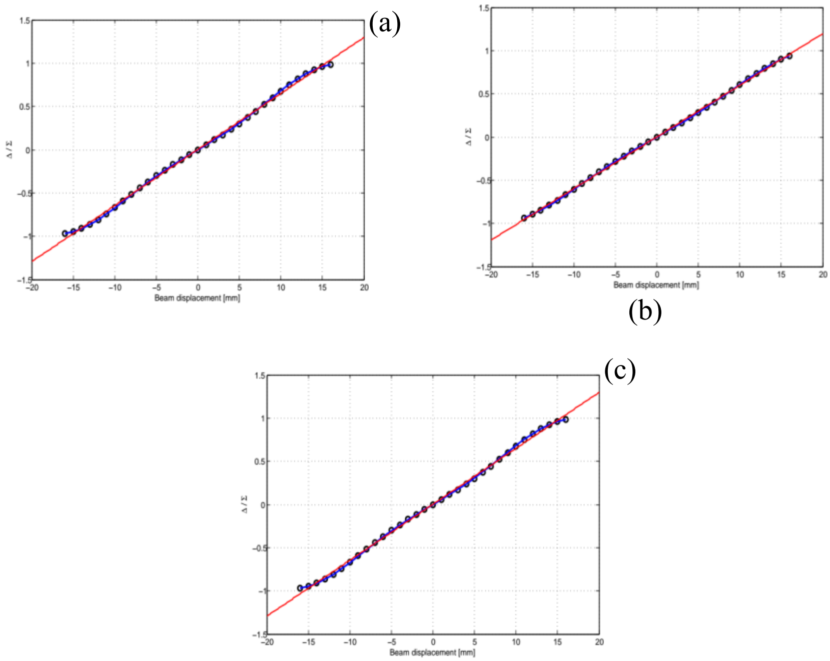

FIGURE 2. Sensitivities for the ***xy*** plane. Asterisks for ***x*** axis, line for ***y*** axis. Red line is added to compare linearity of the results. (a) 2.5 mm (b) 10 mm (c) 5.5 mm.

Here, it can be seen that the sensitivities are consistent for both axes on the ***xy*** plane. Difference over sum for the signals obtained from opposite antennas. It is clear that the sensitivity increases with the length of the antenna, the optimized length is given in Fig. 2c.

Fig. 3. shows the relation between SNR, beam-pipe radius and resolution for the solutions obtained using the bio-inspired approaches. It can be seen that as the SNR increases, BPM can achieve better resolution values.

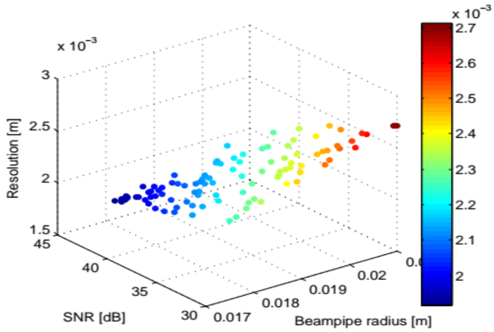

FIGURE 3. Relation between SNR, beampipe radius and resolution.

A comparison between EA and PSO is presented in Fig. 4. It can be seen that both approaches can find similar SNR values and both approaches can yield SNR values above 40 dB. These results are in an acceptable range for the isolation of the power signal from the noise signal.

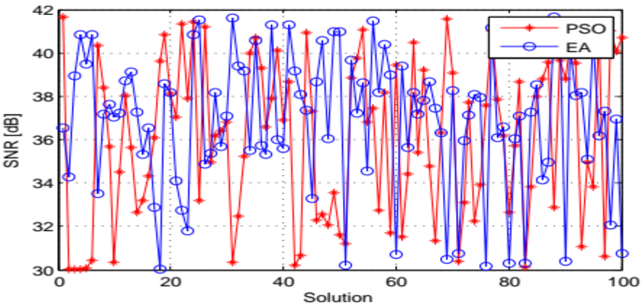

FIGURE 4. Comparison of EA and PSO.

Table 1. shows the capacitance and SNR values for the given antenna lengths. All capacitance and SNR values are in a range that is appropriate for signal processing.

Table 1. Relation between antenna length, capacitance and SNR

Antenna Length (mm)	Capacitance (pF)	SNR (dB)
2.5	1.22	13.957
5.5	2.55	30.001
10	4.55	39.720

The findings obtained here are for the button-type BPMs which are employed in the TARLA facility due to limited space available on the beam-pipe since other BPM types require larger space.

5. Conclusion

The findings for the infrared RF realm accelerators showed that the use of bio-inspired optimization methods, namely EA and PSO for antenna and BPM geometry design can yield more practical solutions than analytical and FEM methods. It is shown that parameters such as SNR and sensitivity are in a suitable range for signal processing techniques.

This approach can be used for all types of BPMs such as button, cavity and stripline as it offers a wide range of solutions while offering flexibility during design and production of BPMs.

Acknowledgements. The study is supported by TUBITAK 2219-International Postdoctoral Research Fellowship Program. The authors would also like to thank TARLA for the collaborative research support.

References

[1] Shafer, Robert E., Beam position monitoring, *AIP conference proceedings*, (1992), 601–636.

[2] Smith, Stephen R., Beam position monitor engineering, *AIP conference proceedings*, (1997), 50–65.

[3] Forck, P., Liakin, D. and Kowina, P., Beam position monitors, CERN Accelerator School on Beam Diagnostics, (2009), 187–228.

[4] Nosych, A., Iriso, U. and Olle, J., Electrostatic finite-element code to study geometrical nonlinear effects of BPMs in 2D, *4th International Beam Instrumentation Conference (IBIC2015)*, Melbourne, Australia, (2015) 418-422

[5] Yiğit, S. S., Ar, Y. and Bostanci, G. E., Evolutionary approaches for weight optimization in collaborative filtering-based recommender systems, *Turkish Journal of Electrical Engineering & Computer Sciences*, (2019), 27.3, 2121-2136.

[6] Karim, A. M., Güzel, M. S., Tolun, M. R., Kaya, H. and Çelebi, F. V., A new generalized deep learning framework combining sparse auto encoder and Taguchi method for novel data classification and processing, *Mathematical Problems in Engineering*, (2018).

[7] Mohammed, S. N., Guzel, M. S. and Bostanci, E., Classification and Success Investigation of Biomedical Data Sets Using Supervised Machine Learning Models, *In*

3rd International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), IEEE, (2019), 1-5.

[8] Aksoy, A., Karsli, O., Aydin, A., Kaya, C., Ketenoglu, B., Ketenoglu, D. and Yavas, O., Current status of Turkish accelerator and radiation laboratory in Ankara: the TARLA facility, *Canadian Journal of Physics,* 96(7), (2018), 837-842.

[9] Aydin, A., Bostanci, E. and Tanriover, Ozgur O., A Multiple Objective Evolutionary Algorithm Approach to Find Optimal Design Parameters for Beam Position Monitoring Systems, *International Journal of Modern Physics C*, (2019) doi: 10.1142/ S0129183120500382

[10] Aydin, A. and Kasap, E., Design studies for the beam position monitor (BPM) front-end electronics of the Turkish accelerator and radiation laboratory in Ankara (TARLA). *Turkish Journal of Physics*, 41(3), (2017), 269-276.

[11] Eberhart, R. C. and Shi, Y., Comparison between genetic algorithms and particle swarm optimization, *International conference on evolutionary programming, (1998), 611–616.*

[12] Nebro, A. J., Durillo, J. J., Garcia-Nieto, J., Coello, C.A., Luna, F. and Alba, E., SMPSO: A new PSO-based metaheuristic for multi-objective optimization, *IEEE Symposium on Computational Intelligence in Multi-Criteria Decision-Making (MCDM)*, (2009), 66–73.

[13] Kollat, J. B. and Reed, P. M., Comparison of multi-objective evolutionary algorithms for long-term monitoring design, *World Water and Environmental Resources Congress, (2005).*

[14] Ketenoğlu, D., Bostanci, G. E., Aydin, A. and Ketenoğlu, B., A hard X-ray self-amplified spontaneous emission free-electron laser optimization using evolutionary algorithms for dedicated user applications, *Turkish Journal of Physics*, *43*(6), (2019), 551-555.

Current Address: Ayhan AYDIN: Ankara University, Computer Engineering Department, Ankara, TURKEY
E-mail: ayaydin@ankara.edu.tr
ORCID: https://orcid.org/0000-0001-7938-0509

Current Address: Erkan BOSTANCI: Ankara University, Computer Engineering Department, Ankara, TURKEY
E-mail: ebostanci@ankara.edu.tr
ORCID: https://orcid.org/0000-0001-8547-7569.