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Optimal Placement of Beam Position Monitors for the Australian Synchrotron 2

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The deflection of relativistic electron beams by magnetic fields leads to synchrotron radiation, which has found broad use in the fields of materials science, biology, medicine, cultural heritage, and more. Although the performance of synchrotron light sources may be quantified by various metrics, their spectral brightness, which is in turn inversely proportional to the electron beam emittances, is a practically relevant and computable quantity. Therefore, the development of fourth-generation synchrotrons, including the proposed next generation Australian Synchrotron (AS2), aims to achieve ultra-low emittance by mitigating the beam dynamics effects, such as feed-down from off-axis motion and magnet misalignments. More specifically, AS2 aims to deliver an ultra-low emittance of ~100 pm-radians and highly coherent, bright light. Constraints on emittance place tight demands on beam optics correction techniques like linear optics of closed orbit (LOCO), and consequently, constraints on accurate estimation of the beam centroid along the orbit. For this purpose, synchrotrons employ Beam Position Monitors (BPMs) which measure the beam centroid position and hence, play an essential role in controlling the beam orbit and correcting these perturbations. However, existing BPM placement strategies rely on heuristic rules rather than formal optimization which may limit their performance.
In this work, we propose a Fisher Information Matrix (FIM) -based method for optimising BPM placements. To achieve this, we use the fully differentiable accelerator code Cheetah, which integrates accelerator modelling with automatic differentiation to enable fast simulations and efficient computation of partial derivatives - including the FIM from the second derivative. Using this, we derive optimal BPM placements that minimise variance in estimation of the beam centroid parameters for a segment of the AS2 system and demonstrate an extension of the methodology to the entire AS2 sector

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