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Precision Multipole Control in RF Cavities for Advanced Beam Manipulation

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We introduce the Azimuthal Modulation Method (AMM), a technique for precisely sculpting the electromagnetic fields in RF cavities to enable multipole-free acceleration or bespoke transverse kicking. The AMM provides fine control over multipolar field components, allowing suppression of unwanted multipoles (such as those arising from ancillary elements like single-slot power couplers) or the intentional introduction of desired multipoles for novel accelerator applications.

RF cavities are typically designed to operate in $TM_{\{m10\}}$ modes, with $m=0$ modes providing acceleration and $m>0$ modes delivering transverse kicks, analogous to the m -pole fields of magnets. These cavities often have circularly symmetric cross-sections; breaking this symmetry inevitably generates unwanted transverse multipoles that can degrade beam quality. The AMM offers a systematic approach to mitigate these effects while expanding the design space for next-generation particle accelerators.

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