Robust Design of the Field in Medical Electromagnetic Systems

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The field uniformity in a region as large as possible plays a great role in the design of medical electromagnetic systems, in the case both of Magnetic Resonance Imaging (MRI) and Electron Paramagnetic Resonance (EPR). However the inevitable uncertainty and tolerance on the design parameter due to the component derive and manufacturing processes can lead the system to work in an unexpected range of field value and with low uniformity. The field robustness in presence of that variation can be obtained performing a nominal system design that guarantees the operation in a low field sensitivity region of the parameter space.

In this paper we introduce a robust design approach based on Interval Analysis (IA) and Finite Element Method (FEM). In particular we show the using of FEM in conjunction to the Design of Experiment to obtain a v-variate polynomial expression of the field in the centre of the working volume as a function of the parameter $f(x_1, x_2, \ldots, x_v)$, where v is the number of parameter design. The robustness analysis of such polynomial function by means of the IA allows to select a region of low field variability in the parameter space, i.e. the robust nominal design $(x_{10}, x_{20}, \ldots, x_{v0})$ respect to a variation of $\pm\delta_i$ around each parameter nominal value. The robustness of a solution is obtained looking to the width of the complete Taylor series of the polynomial function around the nominal solution while the real variables, i.e., the v parameter design, and the real operations are substituted respectively with interval variables and operations. Such interval variables $X_i = [x_{i0}-\delta_i, x_{i0}+\delta_i]$, for $i = 1, \ldots, v$, are symmetric intervals, centred in the correspondent parameter nominal values $(x_{10}, x_{20}, \ldots, x_{v0})$ and with radius of variation equal to the particular variations δ_i.

In this paper an example of the proposed approach at the design of an EPR is reported while the robustness is checked by means of a Monte Carlo analysis.