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均匀半空间表面大定源瞬变电磁响应的快速算法

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A rapid algorithm for calculating time domain transient electromagnetic responses of a large fixed rectangular loop on the space

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摘要 大定源是地面瞬变电磁观测的主要方式之一, 该方式在大深度、高密度的面积测量时具有明显的优势. 但当接收点偏离发射框中心时, 由于场源的非对称性(即框边影响), 数据处理和解释比较困难, 特别是全程瞬变响应的精确计算相当耗时. 本文介绍一种数值算法, 它既能实现快速计算, 又能满足精度要求. 该算法通过对瞬变场垂直分量(b_z)及其时间变化率(b_z/ t)的核函数$Y(Z)$和$Y'(Z)$表现特性的研究, 以参数Z把整个瞬变过程分为早期阶段($Z\rightarrow 0$), 中期阶段和晚期阶段($Z\rightarrow\infty$). 计算全程响应时, 早期和晚期阶段分别采用$Y(Z)$和$Y'(Z)$的渐近表达式;对中期阶段, 内层积分(即误差函数erf)采用有理Chebyshev渐近展开式, 外层积分采用Romberg数值积分法. 理论模型计算表明, 利用该算法可以快速计算空间任意点(除发射边框)的全程响应核函数$Y(Z)$和$Y'(Z)$. 当测点到边框的距离大于边长的25%时, 计算速度比常规数值积分算法快7倍;其它测点处计算速度比常规数值积分算法快4倍. 全程时段的相对误差<0.0002%.

关键词 大定源, 瞬变电磁法, 渐近展开式, 有理契比雪夫展开式, Romberg积分

Abstract: Large fixed loop is popularly used in time domain transient electromagnetic prospecing (TDEM/TEM) for areal deep soundings, which offers many major advantages especially for areas with large depth and density. Due to the inhomogeneity near the loop sides that is referred to as the side effect, data processing and interpretation is very difficult when the receiver deviates from the loop center. Particularly it would take a long time to calculate all-time TEM response and present algorithms are inefficient for such mass data. The article proposes a numerical algorithm which not only can decrease calculating time but also satisfy the required precision. According to the behaviors of the kernel function $Y(Z)$ and $Y'(Z)$ respectively for b_z and b_z/ t, the transient field is divided into early-time ($Z\rightarrow 0$), middle-time and late-time ($Z\rightarrow\infty$) stages for a rectangular loop. In late- and early-time stages, asymptotic series for $Y(Z)$ and $Y'(Z)$ are used. For middle-time, the error function is calculated by rational Chebyshev approximations, and the fixed-integral relevant to radial distance is calculated by Romberg's rule integration. With this method $Y(Z)$ and $Y'(Z)$ can be calculated at any point except on the loop path. Model calculation shows that our method can speed up by at least four times with the relative error less than 0.0002% for both $Y(Z)$ and $Y'(Z)$. When the measure point is away from loop edges more than 25% of the loop size, required CPU time is only 1 second which is seven times as fast as the conventional method. For other measure points, CPU time is about 3 seconds which is four times faster.

Keywords Large fixed loop, TEM, Asymptotic expressions, Rational Chebyshev Approximations, Romberg's rule integration

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