Optimized tomographic reconstruction applied to Electric Currents in Fuel Cells

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We suggest two novel tomographic diagnostic methods for analyzing the electric currents in a fuel cell and a fuel cell stack. The first method is quite general and can be used for any tomographic procedure. It leads to an essential reduction of measuring points and at the same time to an increase of the precision. Applied to a single fuel cell the reduction amounts to 90% while the precision is increased by a factor of 3. The second method exploits the high electrical conductivity of slitted metallic (e.g. aluminum) plates to induce surface currents whenever the electric current density in the stack becomes inhomogeneous. These currents can be measured either directly or by measuring their magnetic field thus leading to a basic information about the state of every fuel cell in the stack.

The characteristic of fuel cells and fuel cell stacks is their large internal current densities (typical values are $250\, mA\, cm^{-2}$) generated by catalytic reactions in the $\mathbf{M}$embrane $\mathbf{E}$lectrode $\mathbf{A}$ssembly (MEA) of each cell. This suggests a noninvasive diagnostics, the so called magnetotomography, by measuring the external magnetic fields and then, applying tomographic methods, to determine the internal currents [1]. Of course the question arises where to place the measuring points. An intuitive and - from the experimental point of view - easy method would be to distribute as many as possible measuring points *homogeneously* on a cuboid around the fuel cell.

We have shown that a homogeneous distribution is in general not at all a very good procedure since every measuring point provides information *and* an error. There are measuring points delivering extremely important information and small errors, but others that contribute nearly nothing of information but large errors. The latter points have to be excluded. We have found a ζ function evaluating each measuring point and discarding the latter ones [2]. This procedure can be applied to any given set of measuring points. Furthermore it can be systematically optimized and various constraints can be taken into account (e.g. measurements at certain locations may be more difficult or more expensive) [3]. The procedure turned out to be very successful. In the case of the fuel cells only $\approx 10\%$ of the original set were relevant measuring points and restriction to this subset increased the precision typically by a factor of 3, cf Fig.1. It should be pointed out that the optimized selection of the relevant measuring points could be applied to any tomographic problem (e.g. computer tomography in medicine).

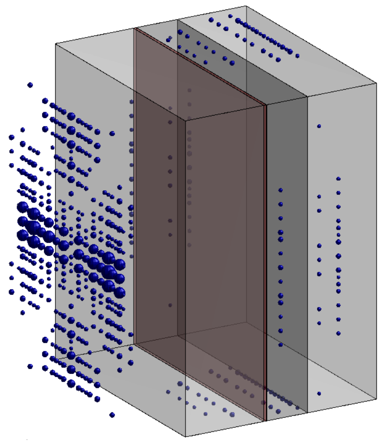

FIG. 1: Reduced measuring point distribution for the magnetotomography of a single fuel cell with a cross section of $138mm \times 178mm$. The size of the spheres denotes the importance of the measuring points. Their number, originally 6702, is reduced to 498. It is obvious, that the most important ones are located on the front side of the fuel cell.

The evaluation of the measuring points show also that for magnetotomography of a fuel cell the relevant measuring points are located close to the front-side and back side of the fuel cell. This makes it awkward to diagnose a fuel cell in a stack consisting of about 100 fuel cells connected in series.

Therefore we suggest a modified procedure: Place a thin ($\approx 1\ [mm]$), slitted metal (e.g. copper or aluminum) plate between each of the fuel cells[4], cf Fig.2. This leads to detectable surface currents whenever there is an inhomogenuity of electric current generation in the MEA of an individual fuel cell.

An example may clarify the phenomenon further: Consider one plate m of perfect conductivity between two fuel cells $M1$ and $M2$ both having an effective MEA area A. Assuming a damaged area a with zero conductivity in the first fuel cell $M1$, the lacking current through this area

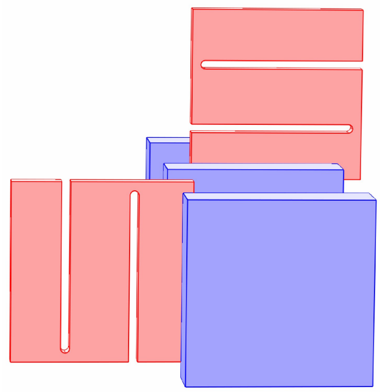

FIG. 2: Exploded view of the diagnostic scheme. The blue plates represent individual fuel cells, while the red ones represent the slitted metal plates.

$$i = I\frac{a}{A},$$ I is the total electric current

has to be compensated. Assuming the resistance of plate m to be negligible the normal component of the current density must be the same everywhere in the remaining fuel cell

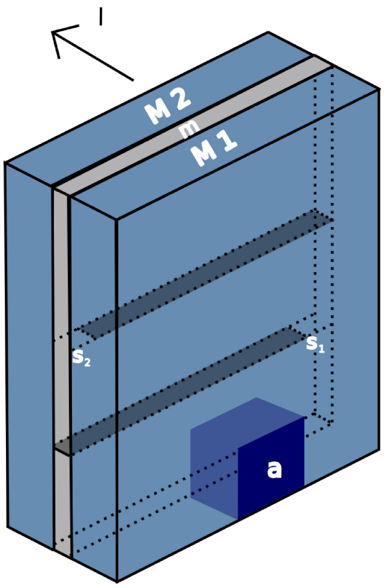

FIG. 3: Schematic view showing a plate m of a material (e.g. aluminum) with very high conductivity. The plate is located between the fuel cells $M1$ and $M2$ and split into stripes (slits indicated by shaded areas). The main direction of the current is indicated by an arrow. It is assumed that the MEA of $M1$ has a damaged area a acting as an insulator. Because of the very high conductivity in m, the current density in each of the cells is practically constant - except in the area a where it is zero. Due to current conservation, transverse currents will rise in m flowing through the connections between the stripes at locations s_1 and s_2.

area of $M1$. This requires a transverse compensation current and because of the slits, part of this current has to pass the locations s_i . If there are two slits in the plate m as shown in Fig.2 and Fig.3, two different currents are detected, one at s_1 the other at s_2 . If the damaged area is e.g. in the lower part of the MEA (cf Fig.3) the currents are

$$i_{s_1} = \frac{2}{3}\frac{Ia}{A-a}$$

and

$$i_{s_2} = \frac{1}{2}i_{s_1}$$

These currents have to pass the bridges connecting the slits where they can be detected either by measuring the current directly or by measuring the magnetic field generated by these surface currents. It turns out that the information obtained by this scheme is sufficient to determine the state of a fuel cell located between two metal plates[4].

The thin metallic plates have another favorable effect: They smoothe inhomogenuities in the electric current generation of a fuel cell preventing a disturbance from penetrating to a previous or next fuel cell as it will happen without metallic plates between the MEAs. Thus the metallic places lead to a better diagnostics *and* to a stabilization of the fuel cell stack.

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