



Multiphysics Modeling Describes the Processes of

Electrochemical Machining in Appliance Manufacturing

Redmer van Tijn, Philips DAP

To find the most efficient way to manufacture the caps for electric shavers, engineers at Philips use multiphysics modeling to study the best balance of process parameters.

Behind your clean, close shave there is an enormous amount of high technology, even in electric shavers that have been around for decades. Philips DAP is working with new materials for, among other components, the shaving cap that acts as a shell around the rotating cutter. On its next-generation shavers expected to reach the market in a couple of years, Philips is starting to use multiphysics modeling to optimize the process used to manufacture these caps.

In the manufacturing process, Philips first forms raw caps from transformation-induced plasticity (TRIP) steel. Because these are too thick and do not have the required precision shape, further manufacturing is required. For the low-end shaver range,

Philips used electrical discharge machining (EDM) to finish the low-end shaver caps, but it required costly and regular replacement of the component electrodes and therefore not applicable for complex shapes. High-end shavers also work with three cutters instead of one, so the cap has a much more sophisticated shape that requires a more complex manufacturing process (Figure 1). Philips turned towards electrochemical machining (ECM) to enable more complex shapes.

Nowadays, the demand of more closeness requires improved process understanding. Computational simulations, rather than running costly experiments throughout the entire evaluation and optimization process can provide this vital information.

ECM consists of the managed electrochemical dissolution of an anode (the cap) by passing current between it and a pre-shaped cathode (the tool). At the cap surface, metal is dissolved into metallic ions by an electrochemical reaction. The shape and placement of the tool—whose shape is not altered by the



Figure 1: Picture of a next-generation Philips shaver. The three-cutter system can be seen as well as the required precision in the manufacture of the shaver caps.

reaction—and setting the applied voltage results in a cap with an accurate shape.

Electrolyte flows between the cap and tool to remove metallic ions as well as a gas that evolves on the cap through a side reaction. The presence of this gas also contributes to the electrolyte’s electrical resistance, and, along with the cap’s changing surface area, the varying resistance must be compensated for by adjusting the system’s voltage. A mass balance

must also be considered to describe the electrochemical kinetics at the electrode as well as adjust for material-based properties such as density in the fluid flow.

Here ECM works with high currents in thin materials and small electrolyte channels, which leads to high temperatures and even boiling if electrolyte flow is not adequate. This, along with the fact that the cap’s structure also changes over time and is influenced by the high-pressure electrolyte flow, results in significant changes in the cap’s structural integrity, where phenomena such as spring-back can occur. High temperatures also affect density in the fluid flow. In all, Philips has a complex multiphysics problem to investigate (Figure 2).

These highly interrelated effects make it virtually impossible to optimize the process through experimentation alone. Computational simulations were required, and Philips employed COMSOL Multiphysics. This package could handle all the interrelated physics while providing the ability to couple these physics. It also allowed models that would be easily understood by all people in the modeling and manufacturing processes.

To model this process, Philips needed to consider the physics of the electrical current. COMSOL Multiphysics contains a modeling interface for this, where electrochemical kinetics can be freely entered directly to simulate the reactions at the cap-electrolyte interface. Furthermore, COMSOL’s interface also provides high flexibility whereby users can describe the conductivity that varies due to the presence of gas

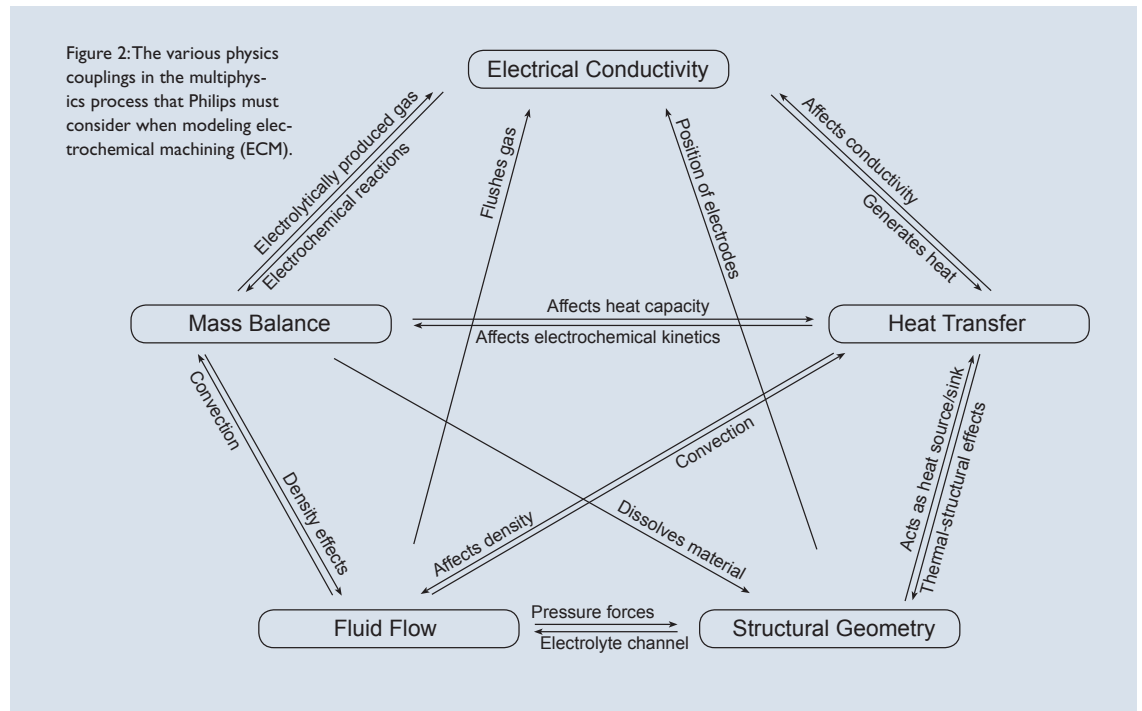
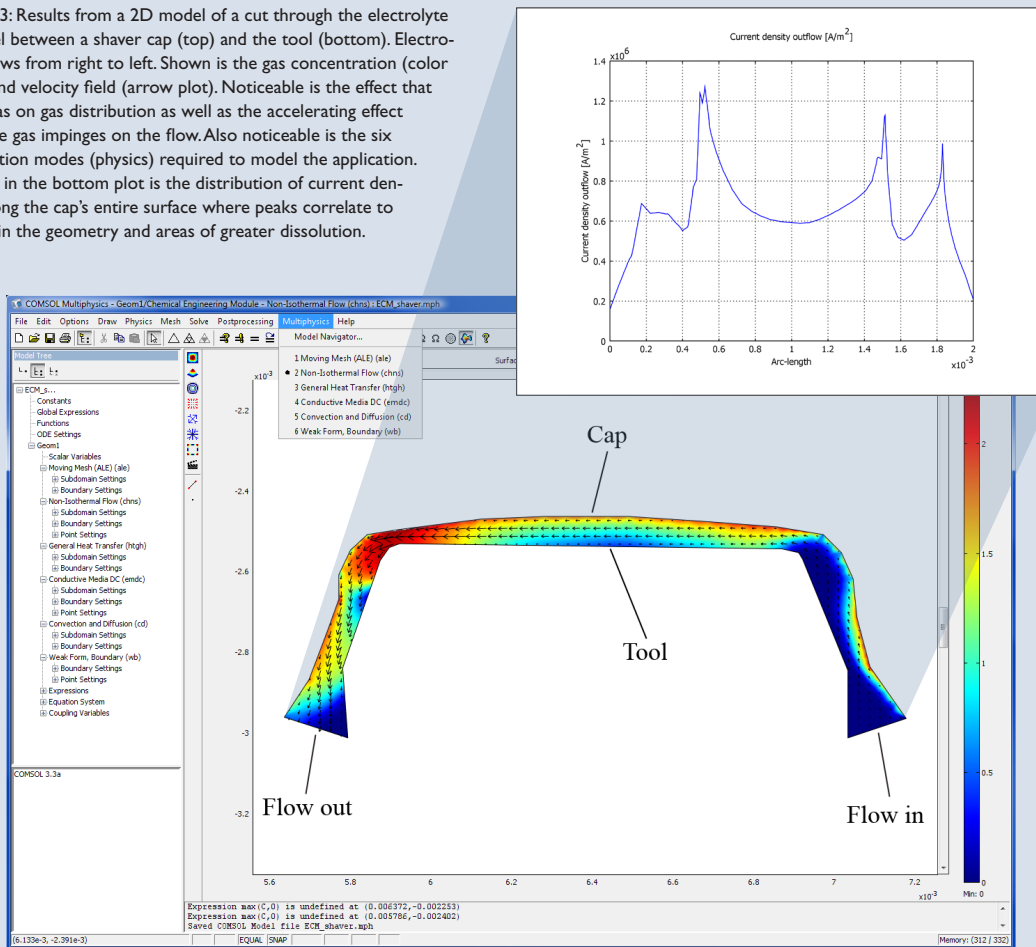


Figure 3: Results from a 2D model of a cut through the electrolyte channel between a shaver cap (top) and the tool (bottom). Electrolyte flows from right to left. Shown is the gas concentration (color plot) and velocity field (arrow plot). Noticeable is the effect that flow has on gas distribution as well as the accelerating effect that the gas impinges on the flow. Also noticeable is the six application modes (physics) required to model the application. Shown in the bottom plot is the distribution of current density along the cap's entire surface where peaks correlate to bends in the geometry and areas of greater dissolution.



bubbles and heat. This was all then coupled directly to other modeling interfaces that describe the fluid flow (non-isothermal flow) and heat transfer (convection and conduction), where a source term in the heat transfer equations depends directly on the electrical current. An equation was also entered in the density term of the fluid-flow modeling interface to represent the effects of temperature and gas-mixture makeup. To save computational memory, heat flux was represented at the tool and cap interfaces with the electrolyte in order to simulate their energy storage capabilities.

The cap's structural geometry was also considered with respect to its effect on the other physics. The shape of the pre-formed cap was imported and could easily be updated during the modeling process based on intermediate model results. Furthermore, a special 'moving mesh' modeling interface was utilized

for simulating the changing shape of the cap when it was coupled to the electrochemical reactions that simulated the dissolving TRIP steel. This resulted in an adequate description of the electrolyte channel and fluid flow.

With this model (Figure 3), Philips is well on the way to generating a manufacturing process for these new caps, to improve closeness. Validation studies are in progress, and then these models will become the driving force for improving the manufacturing process and the production lines.

Dr. ir. Redmer van Tijum
R&D engineer
Metal Forming/CAE Advanced Technology Center
Domestic Appliances and Personal Care Business Unit
Royal Philips Electronics NV
Drachten, Netherlands