

# Structural concepts for lightweights and cost-effective end plates for fuel cell stacks

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## Abstract

For the end plate of a fuel cell stack different structural concepts will be discussed. Starting from the main functions and requirements of such end plates, the idea of a bomb shaped contact surface between the end plate and the electrical isolation layer will be presented in detail. This technique ensures a constant pressure distribution on the contact surface despite a lightweight construction that normally leads to a significant deformation of the end plate.

Bomb shaping therefore is the key-technique for the development of new structural concepts for fuel cell end plates. This technique has been successfully applied to the Hy.Power and PowerPac, both PEM fuel cell projects. To qualify the resulting end plates a performance index will be derived to measure the structural quality of the individual concept. As a result of this research end plates of minimum weight and high performance can be developed. Due to the method of construction the presented end plates are ready for series production. In addition, the proposed concept allows the use of cost-effective materials.

## Introduction

To discuss the requirements of end plates we look at a typical fuel cell stack shown in figure 1. We see a stack made of bipolar plates, two collectors, electrical isolation and the end plates that are connected to each using discrete

tie bolts. The electrical Isolation is needed to prevent electrical shortcut through the tie bolts. The fuel- and cooling supply line, is supposed to run through the upper end plate.

We define a system boundary cutting the tie bolts, the stack between the electrical Isolation and the collector and finally the fuel- and cooling supply line (see figure 2). To make this subsystem work we have to introduce the cutting forces on the bolts and the pressure distribution on the electrical Isolation. The fuel- and cooling supply lines cause only low pressure (0.3 MPa) acting on the end plate compared to typical stack pressure values (3 MPa). From structural point of view the boreholes needed for the fuel- and cooling supply lines cause notch stresses increasing the weight of the end plate.

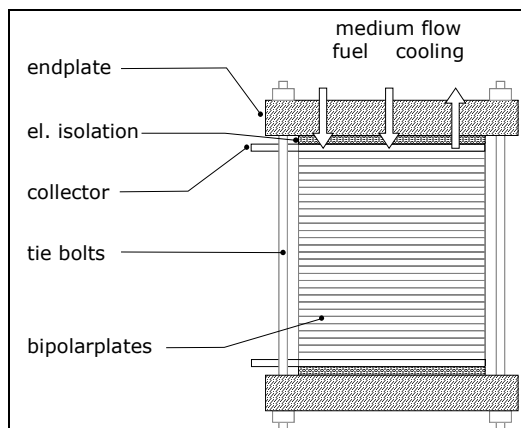


Figure 1: Principle assembly of a typical fuel cell stack

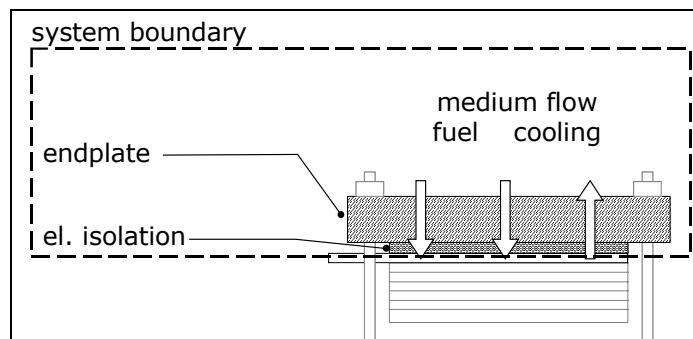


Figure 2: System boundary

The main requirements of fuel cell end plates are:

- Enhance the current in the stack by reducing the contact resistance between the bipolar plates.
- Supply sufficient sealing forces for the different media flows. These effects may lead to increased stack pressure along the boundary of the bipolar plates.

- Stabilize the stack to resist external forces and moments in real conditions (e.g. satellite start, vehicle accelerations)
- Stack fixation to the surrounding system
- Connection of the fuel and cooling supply lines.

These requirements strongly depend on the individual fuel cell concept. In the following we look at PEM Fuel Cells with pressurized fuel- and/or cooling supply line.

The inactive parts of the fuel cell should be as lightweight as possible but also cost effective for series production. At the same time the semi finished product for the end plates is heavy and therefore cannot be cost effective for series production from principle. In figure 3 typical today's end plate concepts are shown.

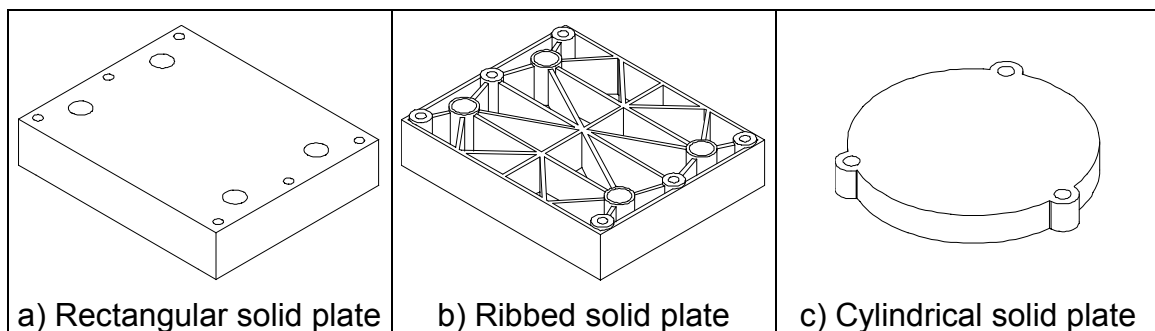


Figure 3: Typical today concepts

From engineering point of view figure 3 a) and c) are straightforward concepts used mainly in research projects concentrating on the electro-chemical process. Figure 3 b) already needs enhanced engineering know how. But in case of die-casting such end plates we face limited strength of material and due to the internal bending effects a significant volume fraction is under low mechanical stress.

Almost all of the today concepts of end plates are based on a simple aluminium plate. The end plates have to be quite thick - much more as would be needed to reach the strength of material – but to form a stiff end plate to obtain a constant pressure distribution inside the stack.

To overcome these shortcomings new concepts for the subsystem (figure 2) will be discussed.

### **Bomb shaped end plates**

In this chapter the idea of a bombage of the end plate (figure 2) will be explained. In the following examples a uniform stack pressure distribution is considered but the concept is applicable to any non-uniform pressure distribution. The concept has been described in detail in (1).

To reach a uniform pressure distribution, a very stiff end plate is needed. Figure 4 shows a stiff solid end plate with 0.1 mm deformation of the bottom side. Due to the forces of the external tie bolts bending of the plate occurs. The deformation can be adjusted with the plate thickness.

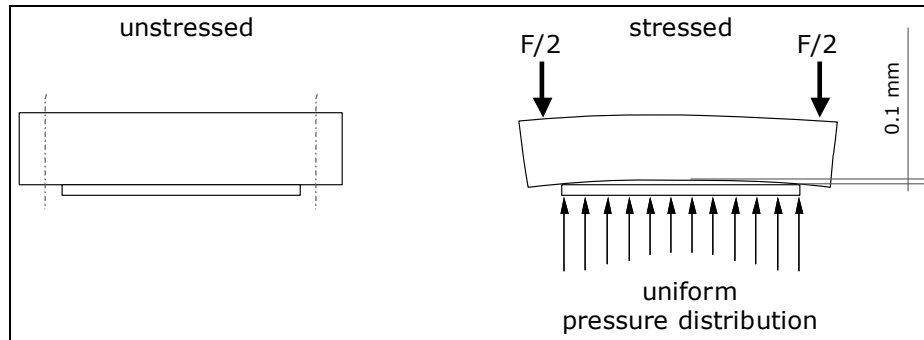


Figure 4: nearly uniform pressure distribution using a thick end plate

A reduction of the end plate thickness is shown in figure 5. A design of a solid end plate using high-strength aluminium reduces the weight significantly. On the same time the deformation of the bottom side increases and the expected pressure distribution cannot be obtained.

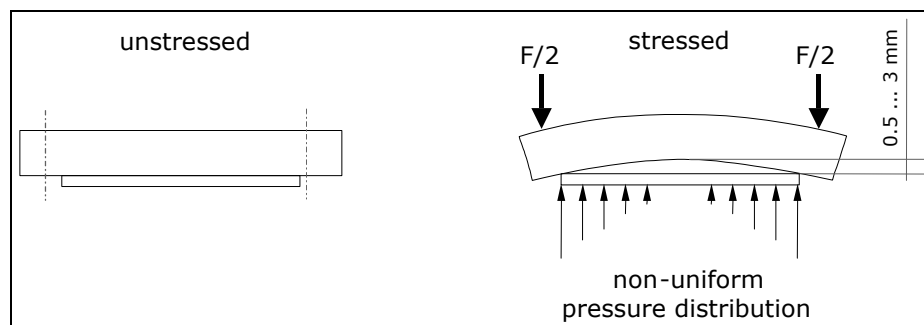


Figure 5: non-uniform pressure distribution using a thin end plate

To make lightweight structures for end plates possible we shape the contact face between the end plate and the electrical isolation in a way that the deformation of the end plate can be compensated. In unstressed situation we only have contact in the middle of the end plate. We design a gap with increasing gap width towards the tie bolts. The gap can be designed to form the needed pressure distribution (uniform and non-uniform).

This concept is called *bomb shaping* and can be applied to the end plate (figure 6) or to the electrical isolation (figure 7). It also can be applied to both parts (figure 9).

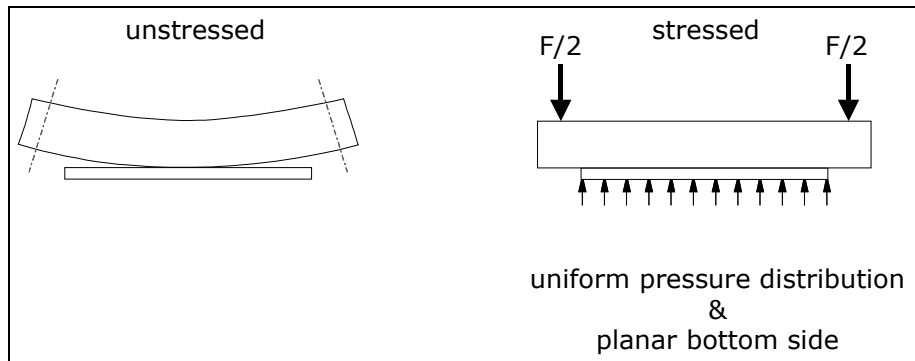


Figure 6: bomb shaped end plate, uniform pressure distribution

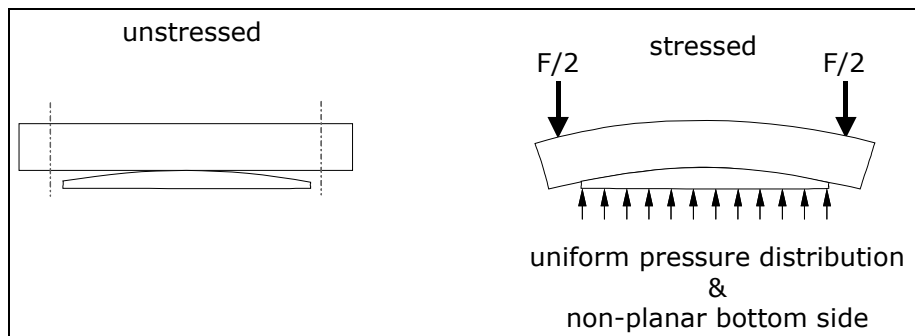


Figure 7: bomb shaped isolation, uniform pressure distribution

The bomb shaping technique is the key to lightweight construction for fuel cell end plates with significant stack pressure.

Without bobbage a lightweight end plate which has to be very stiff (figure 4) will only be possible in a high end application using extensive manufacturing techniques and material with high specific strength (e.g. Carbon fibre composites).

### Application examples

In this chapter two PEM Fuel cell stacks will be shown. The end plates are both based on the bomb shaping technique shown in figure 6 and figure 7.

#### Hy.Power fuel cell stack

The Hy.Power-Stack shown in figure 8 was developed by the PSI and the ETHZ for a fuel cell vehicle. Six of these stacks power a VW Bora. Each has an output of 8 kW (2)

The end plate is designed as a ribbed aluminium part with a bomb shaped bottom side. The structure has been optimised using a genetic algorithm FEM-code (3). For the 3D-CAD construction free form modelling techniques had to be introduced to shape the bottom side of the end plate. The maximum gap width is about 1.5 mm.

The end plate has a weight of 950 grams and is milled out of high strength aluminium material. For die casting the end plate height would have to be increased to match the lower material strength possible with this manufacturing process.

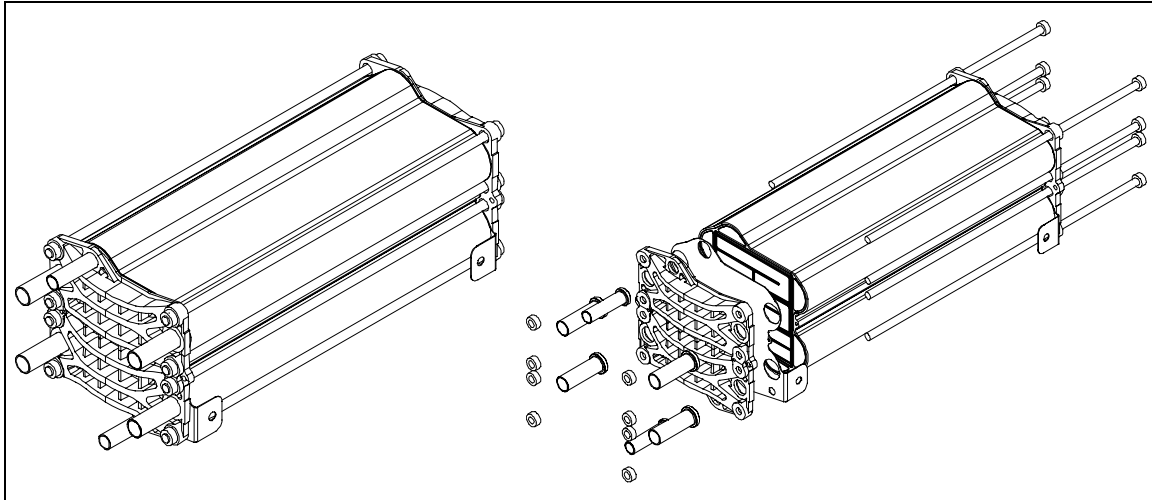


Figure 8: Stack of the Hy.Power-Project (bomb shaped end plate)

#### **PowerPac fuel cell stack**

PowerPac is a mobile power generator with an output of 1kW, developed by ETHZ, PSI, Tribecraft AG and other industrial partners. (4)

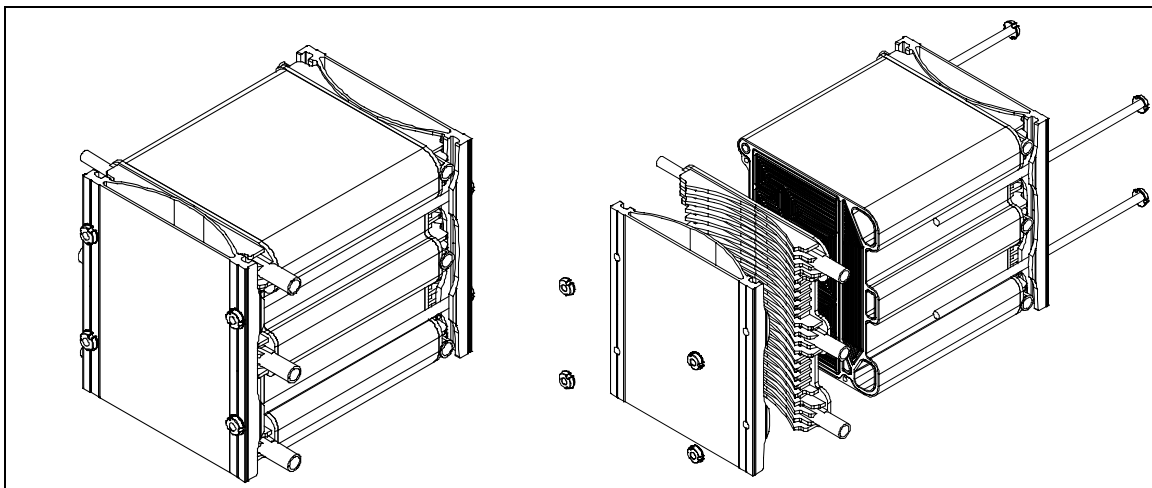


Figure 9: Stack of the PowerPac with D-Bow end plates

For the end plate of the PowerPac fuel cell stack, shown in figure 9, a new structural concept is used (see chapter 'Dbow-concept'). The electrical isolation plate has integrated fuel- and cooling supply lines. This allows a place-saving

and lightweight construction of the end plate. The isolation plate is designed as an injection moulded part, the pressure plate is supposed to be an extrusion profile with simple finishing. Each end plate inclusive the isolation weights about 500 grams.

The concept of the arched bottom side of the end plate will be discussed in the following chapter.

### **The Dbow concept**

In this chapter a new structural concept for fuel cell end plates will be presented. It is called '*Dbow-concept*'. The '*D*' has similarity with the shape of the pressure plate shown in figure 10 whereas the '*bow*' describes the curvature shaped compression member of the pressure plate.

The main idea of the new concept is the curvature shaped bottom side. Comparable with a water dam, the stack pressure acts in normal direction on the bottom side of the pressure plate. In case of the right curvature of the bottom side pure compression will occur in the compression member of the pressure plate. The former evolution of end plate concepts has been presented in (5).

The fuel cell stack shown in figure 9 has two end plates using the end plate shown in figure 10. We call this end plate a 'head plate' indicating that the fuel and cooling supply lines can easily be connected to the isolation plate from the side.

On the opposite side of the fuel cell stack no supply lines are needed. We can use a different end plate for this side called 'foot plate'. Figure 11 shows a footplate with an additional vertical compression member. This reduces the volume of the isolation plate.

Figure 12 shows a footplate with two additional compression members. The volume of the isolation plate is minimized and a lightweight end plate with minimum height can be realized. The bottom side is still curvature shaped!

The concepts shown in figures 10-12 allow the use of extrusion profiles and injection moulding. Therefore these end plates are cost effective and ready for series production.

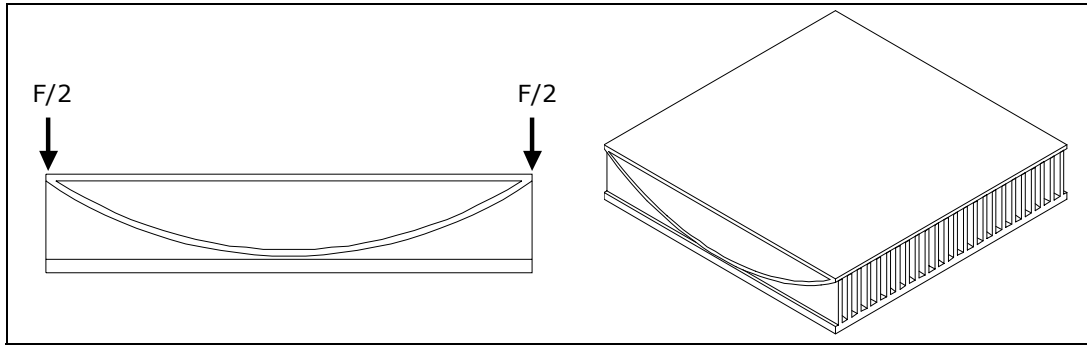


Figure 10: end plate based on Dbow-concept, head plate, schematic view

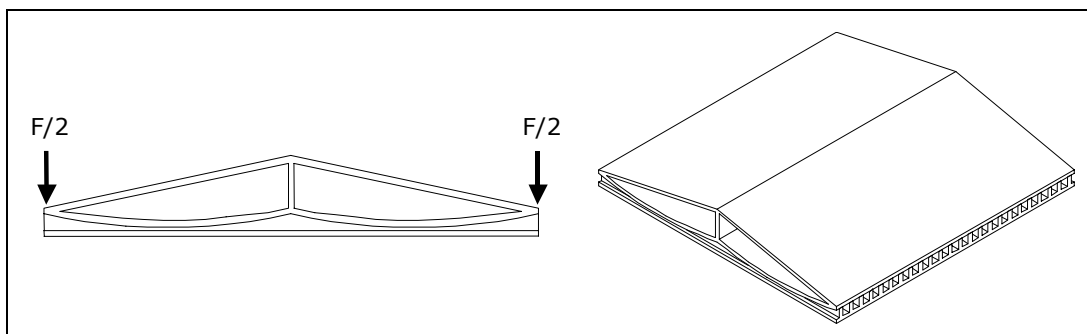


Figure 11: end plate based on Dbow-concept, one vertical compression member, footplate, schematic view

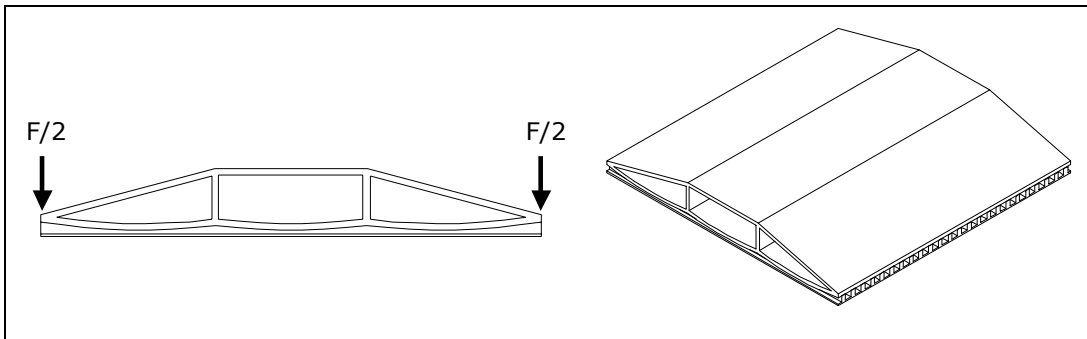


Figure 12: end plate based on Dbow-concept, two vertical compression members, footplate, schematic view

For axisymmetric fuel cell stacks the bomb shaping technique and the Dbow-concept form a different end plate as shown in figure 13. The outer ring replaces the tension member. The compression member is still curvature shaped.

For connecting the fuel and cooling supply line the end plate shown in figure 14 can be used.

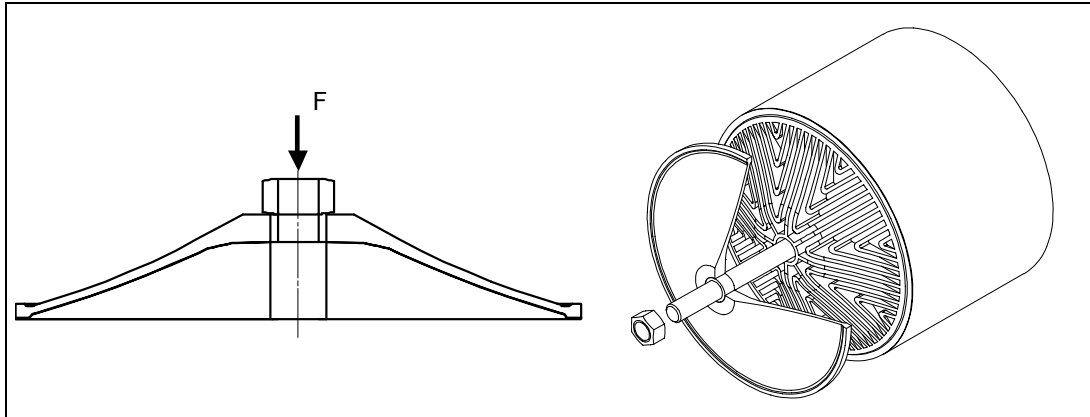


Figure 13: end plate for axisymmetric fuel cell stack based on Dbow-concept, footplate, schematic view

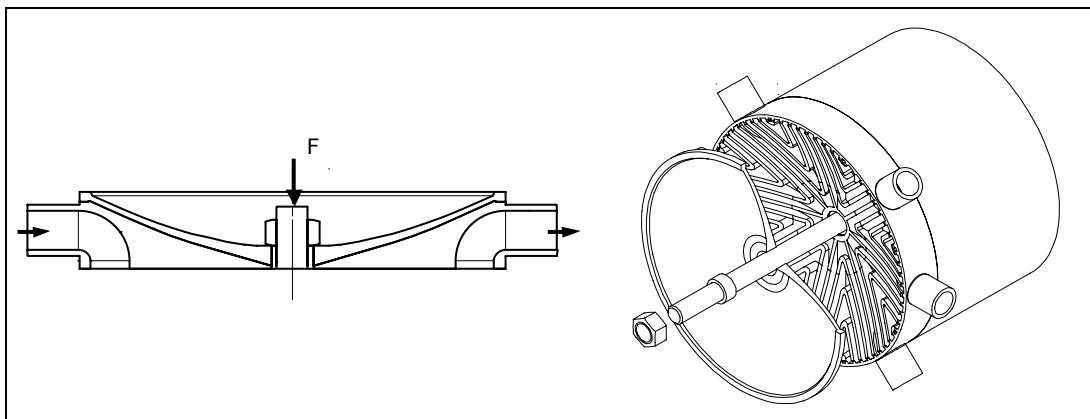


Figure 14: end plate for axisymmetric fuel cell stack based on Dbow-concept, head plate, schematic view

The design of end plates using the Dbow concept will not be discussed in detail. The resulting force diagram and the mechanical stresses can easily be found assuming a plane framework. Due to the Dbow-concept the material expenditure is minimized as mostly only tension or compression occurs in the pressure plate. Certain material expenditure is still needed for the transfer of forces from the tie bolts to the pressure plate.

## End plate Performance Index

In this Chapter we derive the performance Index  $I$  to compare the different end plate concepts. The presented application examples have different active area, different stack pressure and are made of aluminium with different strength. Therefore just to look at the total mass of the end plate is not a suitable measure.

In a first approach we assume a performance index  $I$  that takes into account the parameters active area  $A$ , stack pressure  $p$ , tensile strength  $\sigma$  and the mass  $M$  of end plate. We could also think of the modulus of elasticity and the material density. These parameters have not been included in the Index as all end plates are made of aluminium.

In addition we want  $I$  to be constant in the case of varying one or more parameters using the same structural concept! This can be expressed with

$$I = f(A, p, \sigma_{\max}, M) \quad (1)$$

and

$$f(A_1, p_1, \sigma_{1_{\max}}, M_1) \stackrel{\text{equal concept}}{=} f(A_2, p_2, \sigma_{2_{\max}}, M_2) \quad (2)$$

This means e.g. using a material with higher strength is not a better concept in terms of the performance index. As a first step in defining  $I$  we look at a quadratic end plate with tie bolts on two opposite sides as shown in figure 15. The limitation to a quadratic section makes the formalism easier to understand. A generalized performance index taking into account rectangular section can be derived but will not be discussed here. In real applications the discrete tie bolts cannot be as close to the stack as shown. Therefore  $I$  will be smaller in that case. The configuration in figure 15 can be realised replacing bolts with strip steel along the two edges.

To derive the equivalent stress (e.g. von MISES), which occurs in the middle of the end plate, the EULER-BERNOULLI beam theory is used. Compared to the plate theory the deviation is less than 5 % and can therefore be neglected for the motivation of the performance index.

The mass  $M$  is a function of the other three parameters

$$M = g(A, p, \sigma_{\max}). \quad (3)$$

For the maximum bending moment  $M_b$  we find

$$M_b = \frac{F}{2} \cdot \frac{L}{4} = \frac{pL^3}{8}. \quad (4)$$

The section modulus  $W$  is used to derive the maximum stress



$$I = c \frac{\sqrt{A^3} \sqrt{p}}{\sqrt{\sigma} \cdot M}$$

(11)

In table 1 different end plates, their parameters and the individual performance index are shown.

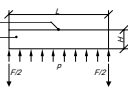
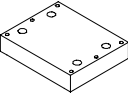
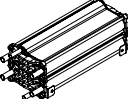
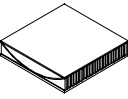
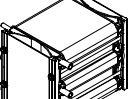
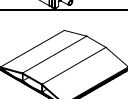

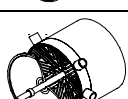
end plate	sketch	status	L [mm]	B [mm]	H [mm]	force [kN]	stress $\sigma$ [MPa]	area A [mm <sup>2</sup> ]	mass M [g]	pressure $p$ [MPa]	Index [%]
Quadratic, foot plate, figure 15		theory	150	150	14.0	78.8	300	22'500	852	3.5	<b>100</b>
Quadratic, head plate, figure 3a)		possible	190	150	15.0	79.0	300	22'500	1155	3.5	<b>74</b>
Hy.Power head plate, figure 8		tested	190	200	28.0	70.0	360	34'409	960	2.0	<b>117</b>
Dbow head plate, figure 10		theory	150	150	15.0	35.2	215	22'500	396	1.6	<b>172</b>
PowerPac Dbow head plate, figure 9		tested	166	147	30.0	35.2	215	22'078	532	1.6	<b>124</b>
Dbow foot plate, figure 12		theory	150	150	15.0	35.2	215	22'500	301	1.6	<b>226</b>
Dbow foot plate, figure 13		possible	Ø170	35	45	250	22'500	350	2.0	<b>199</b>	
Dbow head plate, figure 14		possible	Ø170	25	45	250	22'500	530	2.0	<b>132</b>	

Table 1: performance Index for different end plate concepts

The concept with the lowest performance is a solid plate. Although it is easy to manufacture it has already significant deformation. Bomb shaping of the electrical isolation layer is needed. To avoid this deformation the plate should

be 37mm thick. In this case the overall deformation is less than 0.1mm, but the performance lowers to 30%!

The concept with the highest performance Index is the Dbow footplate (figure 12). This end plate is thin and lightweight. The extruded profile would have a minimum wall thickness of 2 mm. For high-end applications the use of wire spark eroding again allows a weight reduction.

Looking at realised plates (Hy.Power and PowerPac) we see that we haven't reached the theoretical optimum. This has mainly to do with the use of discrete bolts.

In this chapter the performance index  $I$  has been introduced. It has been shown that it is a valid measure to compare different end plates for fuel cell stacks. Using the performance index we can expect that there is still quite a potential for the development of lightweight end plates.

## **Conclusions**

In this paper different structural concepts have been discussed. It has been shown that the combination of the bomb shaping technique and the presented Dbow-concept result in fuel cell end plates with minimum weight and high flexibility in terms of the fuel- and cooling supply line. The presented technology can be applied to series and high-end applications. For series production the existing manufacturing processes are ideal for cost-effective end plates. For high-end applications the use of high specific strength materials applied to the presented concept will result in extremely lightweight end plates.

Tribecraft AG patents the Dbow-concept.

## **Outlook**

It has been shown, that depending on the subsystem we look at (including the electrical isolation!), major steps in terms of specific power of the fuel cell stack were possible. Further research and development has to be drawn to the other structural parts in the stack. Especially the design of the bipolar plates and the manifolds has a certain potential in saving volume and mass.

## **Acknowledgements**

This research was done during the PowerPac project. We would like to thank the Swiss federal office of energy, Mr. Hintermann for funding the project.

Thanks to Martin Ruge (ETHZ), Felix Büchi (PSI) and Daniel Schmid (ETHZ) for their spirit, teamwork and cooperation during the project.

## References

- (1) Ruge, Martin; Entwicklung eines flüssigkeitsgekühlten polymer-Elektrolyt-Membran-Brennstoffzellenstapels mit einer Leistung von 6,5 kW, VDI, ISBN 3-18-349406-x, 2003
- (2) [http://www.psi.ch/news\\_events/pressemitteilungen/kurzmit\\_brennstauto.html](http://www.psi.ch/news_events/pressemitteilungen/kurzmit_brennstauto.html); newsflash, Paul Scherrer Institut, Villigen, 2002
- (3) König, Oliver; Uebersax, Marion; Gätzi, Roman; Structural Optimization Tool using Genetic Algorithms and Ansys, 18<sup>th</sup> CAD-FEM User's Meeting 2000 International Congress on FEM Technology, Friedrichshafen, 2000
- (4) [www.powerpac.ch](http://www.powerpac.ch); a mobile fuel cell system, Switzerland, 2003
- (5) Evertz, Jörg; Strukturkonzepte für die Endplatte einer Brennstoffzelle, Swiss Computer Graphics Association SCGA, Fuel Cell, Zurich, 2002