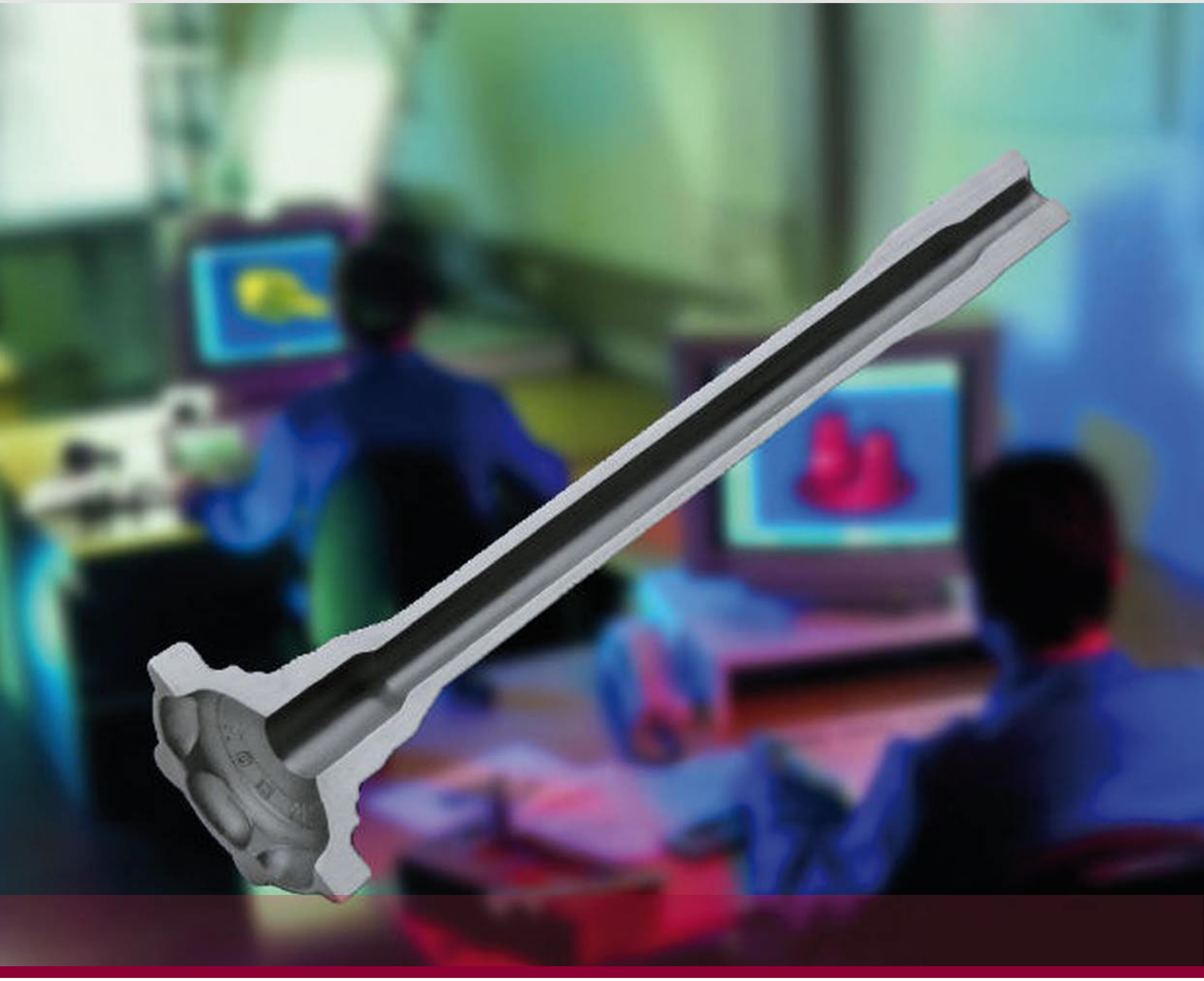

FEA-optimized Lightweight Hollow Shafts for the Transmission

When it comes to transmissions, considerable weight savings may be made by using hollow transmission shafts. Hirschvogel achieved success in transferring the same high loads in spite of less material use. These forged lightweight shafts may be used both in manual transmissions as well as in axle drives and transfer gearboxes of passenger cars or trucks.

1 Introduction

Currently there are three objectives when optimizing transmission components. These are to decrease CO_2 emissions, to reduce costs and to retain good mechanical properties. The reduction in CO_2 emissions is achieved primarily by lightweight design measures, as the lower the vehicle weight, the lower the fuel consumption. When it comes to transmissions, considerable weight savings may be made by using hollow transmission shafts. These lighter parts still need to transfer the same high loads, however.

In order to keep the mechanical properties at the high level required, stiffness and strength analyses need to be carried out using FEA when designing the hollow geometry. Besides weight reduction the cost factor also needs to be considered. To achieve lower costs it is essential to reduce bar material usage and to design the process chain in a skillful way [1].

2 Lightweight Design

Hollow lightweight shafts, **Figure 1**, may be used both in manual transmissions as well as in axle drives and transfer gearboxes. Particularly in the case of bevel gear shafts hollow design allows a considerable weight reduction of over 1 kg per shaft in passenger cars without compromising strength. Heavy shafts for commercial vehicles yield material savings of between 4 and 6 kg. Halfshafts, too, may be produced with a hollow geometry if the available space allows such a design. Front wheel drives require a long and a short halfshaft. The design of the long shaft, with a length of approximately 600 mm, provides excellent opportunities for reducing weight while increasing torsional stiffness.

Production of lightweight shafts often requires a combination of special manufacturing processes such as deephole drilling and swaging. The flange with intricate geometry is produced by hot forging. In some applications shafts

Figure 1: Types of hollow shafts for transmission applications

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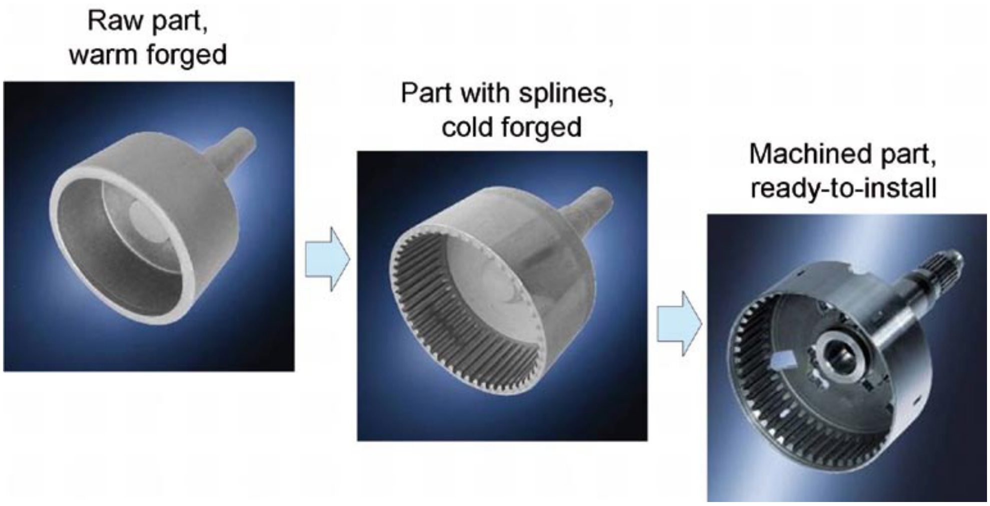

Figure 2: Cost-optimized production process for a disk carrier – from the warm forged raw part (left) over the cold forged part with gearing (center) to the ready to install machined part (right)

with closed ends are needed. This requirement can be met with a two-piece joined part. The production costs in this case increase to such a considerable extent, however, that the use of a plug represents a possible alternative.

3 Cost Reduction

It is already apparent from these initial examples that the cost situation in the case of hollow shafts needs to be viewed with a critical eye. Producing the hollow space by means of drilling, forging or by tube rolling in steelworks represents an additional process step involving extra costs. In order to reduce the costs, it is therefore important to minimize the volume of material used on the one hand and to consistently exploit the benefits in the process chain on the other. Forging, in particular, allows additional geometrical elements to be integrated into the forming process without additional costs.

Figure 2 shows a cost-optimized disk carrier with shaft and internal splines. Originally this component consisted of three individual pieces that were welded together. Design optimizations resulted in a single-piece forged design. The omission of the joining process as well as of the cutting operation to produce the splines or gearing led to a significant reduction in production costs. As strain hardening occurs when forging the splines, the target strength of the disk splines is achieved without the need for expensive heat treatment.

When producing such complicated dimensionally accurate geometrical elements such as splines or teeth for lamellae, the forging quality is monitored and optimized in advance using FEA material flow simulations. **Figure 3** shows the forging of a spline with and without process optimization. On the left it may be seen that, during the production of splines, material is pushed up, leading to a disruption of the fiber flow and a reduction in part quality. On the right of Figure 3, the simulation result of the zero-defect forged part is shown.

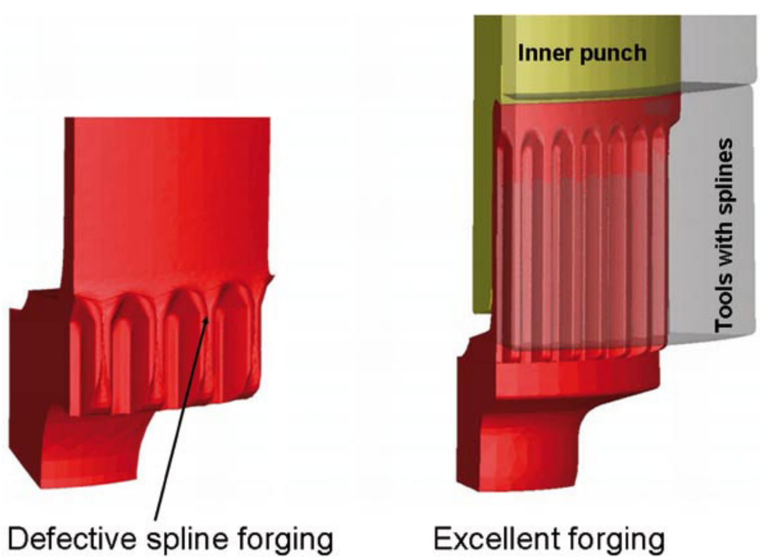

Figure 3: FEA forging simulation with excellent forged part (right)

4 Design Optimization by FEA

Prior to material flow optimization, the part geometry is optimally designed using linear-elastic FEA analyses. When carrying out part design, good mechanical properties need to be achieved while at the same time attaining reductions in weight and in production costs.

In **Figure 4**, left, the classic geometry of an intermediate shaft is shown. At a torsional load of 2400 Nm, a maximum equivalent stress of 690 MPa and a maximum torsion of 0.65 mm occur. The goal of optimization efforts is to achieve higher strength at the same load. After checking the space available, it may be possi-

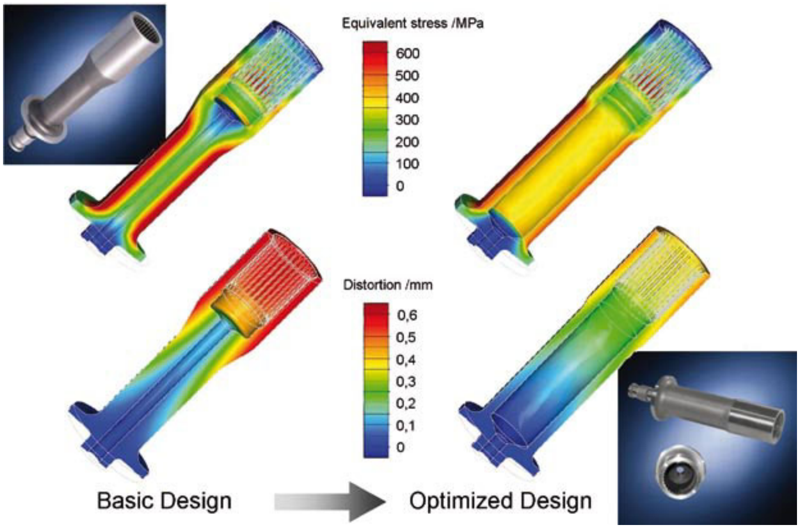

Figure 4: Design optimization of an intermediate shaft into optimized design (right)

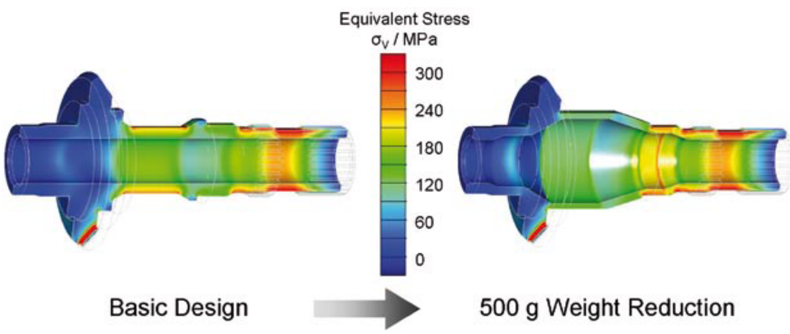

Figure 5: Weight optimization of an axle drive shaft of 20 % or 500 g

ble to enlarge the outer diameter of the shaft. In order to limit increases in weight, the inner hollow space also needs to be extended, that is the wall thickness needs to be reduced. The optimized design is shown in Figure 4, right. It demonstrates lower stress values of a maximum of 500 MPa and torsional distortion of below 0.45 mm. Furthermore, a weight reduction of 13.6 % is achieved and ultimately also a decrease in production costs, as the machining efforts on the outside are lower, and the deep-hole drilling on the inside is omitted.

A similar case can be described in the example axle drive shaft. This drive shaft is driven on the left flange via a surrounding ring gear that has been welded on and subjected to a torque of 2000 Nm up to the right spline. Here, too, the space limitations need to be defined at the start of the design optimization process, as the enhanced part geometry generally leads to a reduction in wall thickness and to an enlargement of the outer diameter of the shaft.

Figure 5 shows the FEA results of the stiffness/strength analyses for the classic design (left) of the axle drive shaft and the weight-optimized geometry (right). The highest load is generated on the spline. However, the diameter and the wall thickness cannot be varied here due to reasons of packaging. The bearing diameters, too, remain unchanged. Variable design can be achieved for the inner contour and the wall thickness between the bearing and the ring gear seat.

In the classic design the wall thickness beneath the bearing seat is barely subjected to load and is thus overdimensioned. In the weight-optimized geometry, this wall thickness is reduced and designed appropriate to load, so that noncritical stresses of a maximum of 250 MPa are generated. Up to the ring gear seat, the space available is fully exploited and the shaft contour has grown radially. This leads to a reduction in stress to below 120 MPa. Theoretically the wall thickness could thus be reduced even further in this area. The production process renders this impossible, however. The hollow space cannot be produced efficiently using cutting processes. Such a contour can only be generated using forging. The main advantage of the optimized geometry is the reduction in part weight amounting to 20 % or 500 g.

5 Summary

In the examples Hirschvogel outlined that transmission shafts hold considerable optimization potential with respect to weight and costs, without the need to compromise the good mechanical properties of the part. Forging, deep-hole drilling and swaging lead to dimensionally accurate hollow lightweight shafts for cars and trucks.

Such optimized designs need to be defined jointly by the user and the supplier at the earliest possible development stage. This is because any changes made at a later point – following production release – are mostly associated with high costs. Only if the part design, the material and the production process are harmonized comprehensive optimization measures can be achieved. In order to develop such optimized products at an early stage, the Hirschvogel Automotive Group can assist its customers with modern development tools, experienced employees and innovative ideas across the globe.

Reference

[1] Raedt, H.-W.: Hochleistungsbauteile aus massivumgeformten Werkstoffen. In: ATZ 108 (2006), Nr. 9. S. 732-737