FORGED GEARS FOR TRANSMISSIONS AND POWERTRAINS

In the automobile, gears occur often in the powertrain as force transmitting elements. Hirschvogel renders to manufacture ready-for-assembly splines with near-net-shape geometry in a metal-forming process. Thus using forging instead of machining, a reduction of assembly length and cost is achieved within an advantageous fiber flow at the same time. If splines need to be produced in blind holes, the costly broaching or slotting process is not necessary anymore.

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ADVANTAGES OF THE FORGING PROCESS

Gears are frequently used geometrical elements in cars. They find application primarily in the transmission (gearwheels and planet gears) and in the powertrain (torque transmission shaft/hub, multi-disk clutches). Due to their complex geometry, production of these elements requires high levels of production engineering efforts and is thus costly.

The high cost-efficiency of forging processes renders the manufacture of ready-for-assembly gears less expensive. Even the production of gears with near-net-shape geometry using forging operations holds the potential of decreasing the overall production costs.

In this article, Hirschvogel outlines the possibilities of manufacturing gears through forging production processes [1] using various examples from series production as well as from development. Besides cost savings, these cases also reveal additional technical advantages, such as a reduction in the assembly length (geometrical restrictions of cutting tools do not apply), monoblock designs and manufacture of geometries that cannot be produced by machining (accessibility, gears in blind holes). From the entire spectrum of forging (hot, warm and cold forging) and of machining, these examples reveal how various types of cost-saving potential may be tapped and technical advantages exploited.

One principal task of gears lies in transferring speed and torque in the form of gearwheels from one shaft to the other and transforming them at the same time. Another important area of application for gears lies in the group of splines. In most transmissions, splines are more frequently used than gearwheels. The task of this machine element is to transfer torque on the same shaft. The fixed gearwheels of a transmission, for example, are connected to the shaft via splines. A further area of application for splines is the powertrain, for example the shaft ends of constant velocity joints, wheel hubs of driven wheels, connection elements of the drive shaft, etc. Producing these gears by means of forging represents a particularly cost-efficient process with technical advantages that will be outlined below.

FORGING FUNDAMENTALS

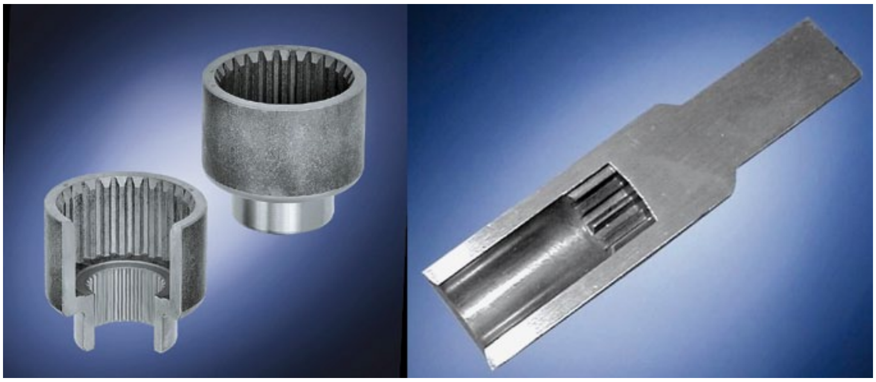
Forging is an extremely economical process for producing complex components in large volumes at minimum cycle times. Furthermore, forging processes are characterized by high material utilization as well as favorable mechanical material properties in the manufactured parts, particularly when these are subjected to dynamic load.

A significant differentiating factor between the various forging processes is the temperature of the billets at the start of the process. When hot forging steel, the metal is heated to temperatures of over 1200 °C. This decreases the force required and increases deformability. During cold forging, the billet has room temperature at the start of forging. As no shrinkage or scale formation occurs, cold forged parts demonstrate greater geometrical and dimensional accuracy than comparable hot forged parts. However, compared to hot forging, the deformability of cold forged parts is limited. When warm forging steel, temperatures between 600 to around 900 °C are required. The goal of warm forging is to combine the benefits of cold and hot forging.

METAL-FORMING PROCESS OF GEARS

The current precision requirements demanded of splines lie in the quality range of between 8 and 9 (according to DIN 5480). This can be achieved using state-of-the-art forging. In order to further increase accuracy when forging gears, optimum conditions must prevail prior to the forging process. This may be achieved by intermediate machining, for example. This eliminates any volume fluctuations caused by upstream processes that may otherwise have a negative impact on the quality of the gears.

Taking the overall quality of the gears into account, quality 7 (according to DIN 5480) currently represents the best that may be achieved reliably on an industrial scale. The precision of the tools needed is two or three quality classes better than the gears of the finished part. Some individual characteristics of the gears, for example the pitch, are transferred by the tools to the workpiece almost identically during the forging process, enabling indi-



❶ Output flange and sliding shaft

❷ Disk carrier

vidual deviations in the range of quality 5 to be achieved. It is highly important, therefore, to adapt the gear quality to the component function. In some cases, it is advisable to deviate somewhat from the rigid standard and to consciously shift from considerations of individual tolerances towards functional relevance in order to generate optimum components with respect to task fulfillment and costs.

Which type of forging is used for producing gears depends greatly on the part itself. By combining hot and cold forging processes, both complex geometries as well as the required accuracy may be achieved, for example through downstream cold forging of the gears. Savings potential arises if investments in costly gear milling machines are dispensed with, or if producing the gears by means of cutting processes involves disproportionate amounts of effort or requires special processes. Geometrically favorable designs that may be generated by means of forging can also bring about cost savings through the production of smaller parts.

PRACTICAL EXAMPLE 1 – SPLINES

While shafts are usually provided with external teeth on the shaft end, hubs normally have internal teeth introduced during a broaching process. The teeth must have good accessibility from both sides. If splines need to be produced in blind holes, a costly slotting process is often unavoidable, as broaching is not an option due to lack of accessibility. Here, forging can offer an alternative that is advantageous from both a quality and a cost perspective as the following examples show.

The output flange, ❶, has splines which extend to the base plane of the component without a transitional geometry. Such a design is not economically feasible using cutting processes. The sliding shaft with internal teeth on the cup floor is produced in a three-stage cold forging process. As the nature of this production method results in practically no inlet and outlet geometries, the total height of the splines can be used. Both the splines and the adjoining cup are produced entirely by means of forging, leading to a very high level of material utilization. This represents an additional benefit in the face of an ever scarcer supply of resources.

The absolute size of forged splines has no effect on the production speed, ❷. Both the large internal as well as the small external splines were produced by means of forging. A combination of warm and cold forging plus machining allows the ready-for-assembly manufacture of this part. Whereas the smaller shaft splines need to be induction hardened due to the small diameter, this process step may be omitted for the larger splines in the cup. In spite of high local compressive loads due to the thin clutch disks, the strain hardening from the forging process is sufficient. The disk carrier is assembled as a central component in a transfer clutch, which is responsible for the torque balance between the front and rear axle.

The production of splines by means of forging means that inlet and outlet zones are eliminated, leading to a significant shortening of the part. The example link shaft in ❸ shows a connecting part that was shortened in length by approximately 25 % by switching from milling to forging. The use of a forging process even allowed the possible load to be increased. The preform of this part is generated in a multiple stage warm forging process followed by the production of the ready-for-assembly splines using cold forging.

❸ Link shaft

❹ Parts with face gears (Hirth joint)

	REDUCTION OF WEIGHT RAW/FINISHED	SAVING OF SPACE/ LENGTH
OUTPUT FLANGE	≈ 20 % / –	≈ 11 %
SLIDING SHAFT	≈ 15 % / –	–
LINK SHAFT	≈ 20 % / ≈ 14 %	≈ 25 %
FACE GEARS	≈ 10 – 20 % / ≈ 15 %	≈ 10 – 20 %
NEAR NET SHAPED GEARS	≈ 8,5 % / –	–

❺ Percentage savings for running gears as well as the other gear types

PRACTICAL EXAMPLE 2 – HIRTH JOINT

Face gears allow maximum torques to be transmitted across a minimum amount of space. Radial connection of the teeth, ❹ Centre, even increases this potential further. This is also known as a Hirth joint and has been recognized for a long time. One reason that has so far prevented wider use of this geometrical element lies in the production costs. Producing the Hirth joint in sufficient volumes by means of forging now opens up the possibility of large-scale industrial application.

With Hirth joints produced by machining, the teeth always need to protrude above the neighboring geometries. When forging these joints, the teeth may be located almost anywhere. The teeth of a part that tends to be weaker may be designed in a more stable way through radial connection of the teeth, for example. Even the forming of the tooth flank angle which, up to now, usually amounted to 60°, is barely subject to limitation. Crowning in both an axial as well as a radial direction is also possible if required.

PRACTICAL EXAMPLE 3 – RUNNING GEARS

Pre-forged running gears with complex geometry also hold cost-savings potential with respect to material and thus resources. ❺ shows the percentage savings for running gears as well as the other gear types. Due to using less material, the essential cutting volume is reduced. This has a positive effect on working time and tooling waste. Pre-forged gears have a little bit higher cost but can be integrated in the raw part.

Differential bevel gears that rotate slowly can be produced with ready-for-assembly forged running teeth today, as noise problems here are almost non-existent. Due to their high rotational speed, normal running gears have quality requirements that may usually only be met by means of grinding, honing or lapping.

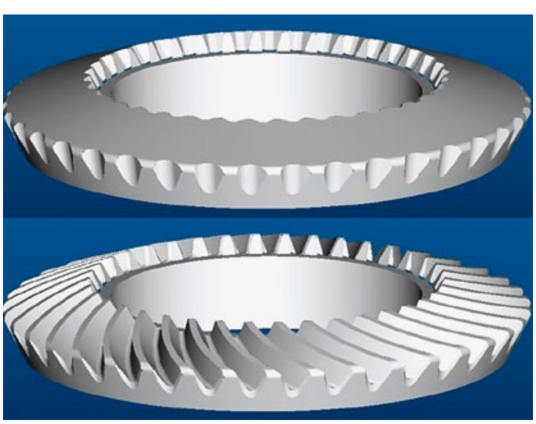
PRACTICAL EXAMPLE 4 – NO BURRS

However, producing running gears by means of machining is problematic due to the generation of burr or sharp edges. For this reason, usually great efforts are made in an additional operation to chamfer the edges generated during machining. Using a new concept for producing chamfers at crown gears, ❻, this costly process step may be omitted. As the chamfers need to fulfill considerably fewer requirements than the tooth flanks, these may be produced by means of forging. The machine tool then no longer exits in the original end faces of the tooth gaps, but rather in the preforged chamfers.

This minimizes or even prevents burr formation. Introducing the chamfers by means of forging is much more cost-efficient than a subsequent mechanical removal process. Apart from the initial alignment of the rotational position during soft machining, the existing production concept does not need to undergo any changes.

CONCLUSION

Forged splines and gears offer a lot of opportunities. It is possible to produce parts more economically, with optimised design or with higher fatigue life. For this customer and forging manufacturer need to cooperate closely. An early interaction in the product development process is beneficial for both sides.



❻ Crown gear with pressed chamfers

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