# AXIAL FORMING – A TECHNOLOGY THAT HAS BEEN REDEFINED

Numerous workpieces used in the automobile and other industries are provided with splines for the purpose of transmitting torque. In the motor industries, such shafts are used, amongst others, in the transmission, the steering and the gearbox. Whilst, for solid parts, a range of metal cutting and forming methods is readily available, the forming of external splines on hollow shafts presents special problems. Due to the latest developments at FELSS, amongst which recursive (frequency modulated) axial forming is particularly noteworthy, a method is now available for the manufacture of precise internal splines also in a hollow workpiece or a blind hole.

## ADVANTAGES AT A GLANCE

### *Internal and external splines*

Internal and external splines can be formed using the same basic technology and, in most cases, a single machine.

### *Serrations and involute splines*

Involute splines as well as serrations can be formed. There are no limitations regarding the possible pressure angles. The number of teeth can be an even or an odd number and it is also possible to form splines with block teeth and tooth gaps.

### *Precision even after hardening*

Both with the internal and external splines highest qualities are obtained. In many cases the quality classifications 5 or 6 under the DIN 3960-3962 standard can be achieved. In particular, the pitch error is minimal and with the dimension over pins a tolerance within 0.03 or 0.04 mm can be maintained.
In most cases, the distortion in hardening is less than that experienced on similar parts produced using metal cutting methods and is often within the range of a single quality classification.

### *Light weight*

Even in the case of weight-optimised workpieces with minimised wall thickness at the base circle, the process of forming the splines remains reliable. However, the wall thickness in this area has to be at least twice the height of the splines.

### *Short cycle times*

It is generally possible to achieve a speed of 15 to 30 mm/sec for the forming operation.

### *Die costs*

As in the case of other cold forming operations, the costs of dies for axial forming are low. Due to the long working life of the dies, the dies can be monitored using statistical process analysis to maintain tight tolerances.

### *Materials*

Essentially all tube, bar or partially finished workpieces made of any ductile material can be formed. The elongation should not be less than 8%. In particular low-, high- or micro-alloy steels or stainless steels as well as non-ferrous metals and their alloys, e.g. aluminium, can be used.

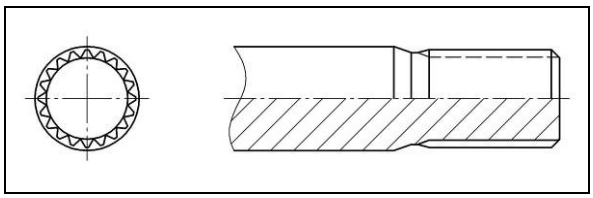
### *No demanding blank preparation*

Tolerances in diameter of the blanks used do not have any effect on pitch error but only on achieving a fully filled shape - thus only affecting the tolerance of the major diameter. The accuracy of a standard NC lathe, i.e. 0.03 mm, is normally adequate.

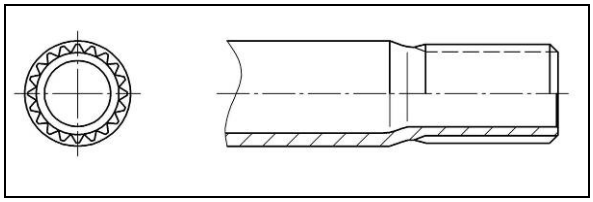
### *Optimum production solutions*

Axial forming can be combined with other forming or metal cutting processes using equipment ranging from hand fed individual machines to production cells and right up to fully automatic transfer lines. All machine concepts are batch tested and available from our modular construction system.

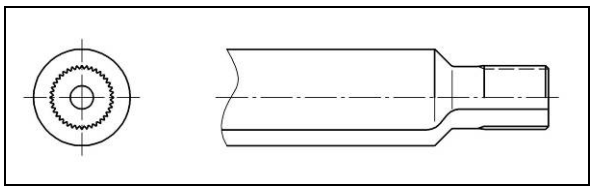
# POSSIBILITIES



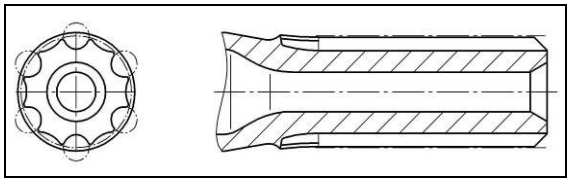
**Forming involute splines (on solid blanks)**



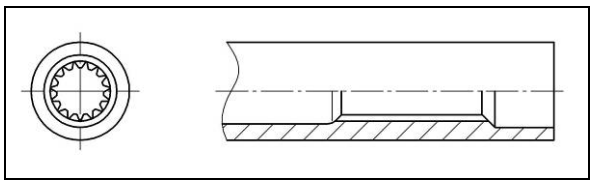
**Forming involute splines (on hollow blanks)**



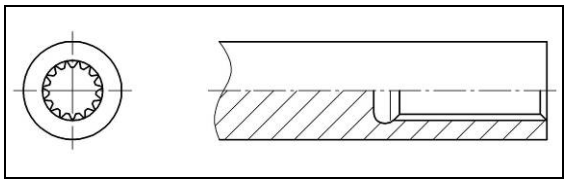
**Forming serrations**



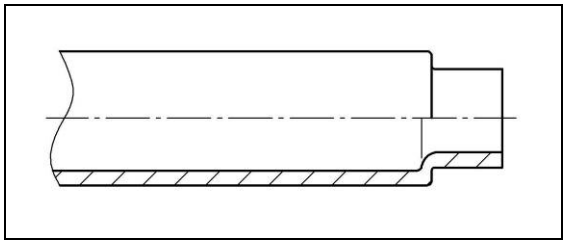
**Forming longitudinal raceway grooves**



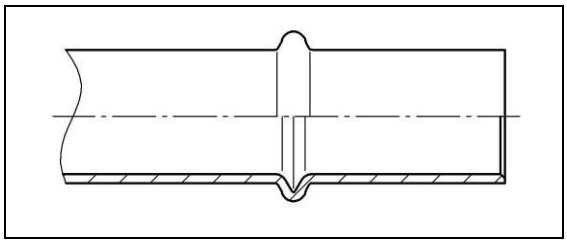
**Forming internal splines**



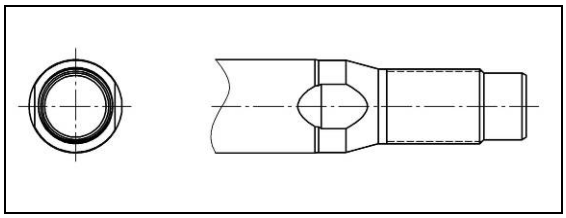
**Forming internal splines (blind hole)**



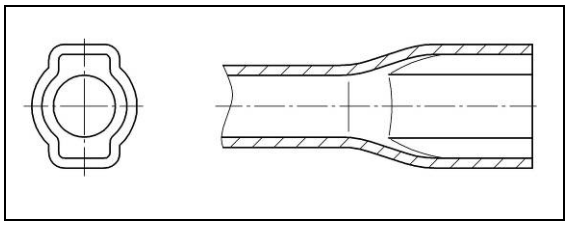
**Forming shoulder**



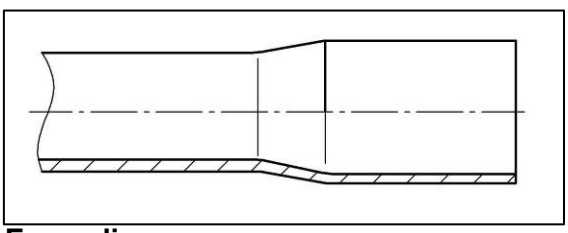
**Forming bead**



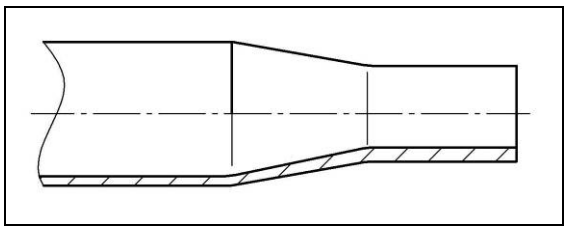
**Forming lock recess**



**Forming yoke**



**Expanding**



**Reducing**

## PRINCIPLE OF AXIAL FORMING

In principle, axial forming is similar to axial extrusion. However, there are very significant differences in the machine technology and in the fields of application. The expression axial forming is used to differentiate between this and other methods.

### *Axial forming dies*

Reinforced carbide dies for the external shape are pushed or pulled over the workpiece in the axial direction. This can be done in combination with a mandrel acting as internal die which, especially in the case of thin-walled tubing, will prevent flow of material to the inside.

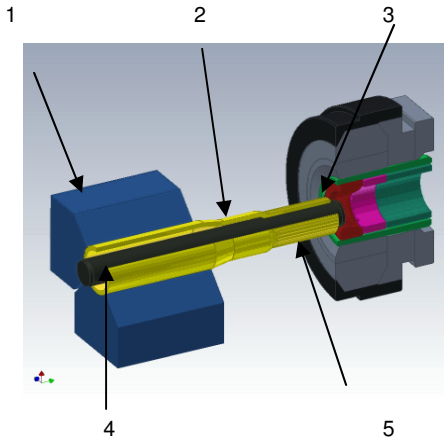
### *Forming process using a mandrel*

Mandrels with special profile splines or cylindrical are pushed in the axial direction into the hollow blank or bored hole. Where required, the workpiece can be supported in a die or clamping device during this process.

Both in the case of forming operations on the outside or the inside, the external die and the internal mandrel can be moved either simultaneously or in sequence. The workpiece is clamped in a segmented clamp that holds the workpiece central relative to the dies. An axial support or counter-pressure holder on the end face can be provided in addition or alternatively.

## MACHINE PRINCIPLE

1 Clamping jaws
2 Workpiece
3 Splining die
4 Mandrel
5 Spline




Beyond the basic equipment as described, a large number of optional items can be included. This may, for example, include an automatic die changing device, either suitable for totally different dies or just for dies that are a member of a family of dies.

The machine modules can also be used to perform several forming operations in a single setting. In this way several sets of external splines can be formed on a workpiece in precise alignment with each other. For machine data see page 8.

## CHARACTERISTICS OF AXIAL FORMING

Like every other forming process for spline forming, axial forming shows certain characteristics regarding the geometries on the entry and exit sides. If these characteristics can be fully accommodated, this will be advantageous from the point of view of the forming force required, the working life of the dies and, in some cases, also the surface quality of the parts produced.

A running angle of between 15° and 30° is ideal. The tip of the spline and the spline faces will be less than complete at the end of the spline in the axial direction since the material will be free to flow in the length direction in this area. The effect can be influenced to some extent by the preparation of the pre-form.

# MACHINE AND AUTOMATION ALTERNATIVES

A modular layout makes it possible to configure a custom-made machine for every application. Maximum attention is paid to flexibility, precision and rigidity, taking also ease of changeovers and ergonomic layout into account. The component parts of the modular system have been optimised over many years of continuous development and innovation. All machines can, of course, be supplied with CNC.

Handling and magazine systems supplement the basic machine. We can supply manually fed or semi-automatic machines, flexible reduction cells or fully interlinked transfer lines, to suit the requirements of each individual customer.

We differentiate between 2 fundamentally different types of axial forming machines, namely machines in horizontal and in vertical configuration. Internal and external forming is equally possible with either type.

## *Horizontal layout*

Axial forming machines in horizontal layout are particularly suited to long workpieces such as axles and shafts. Generally the contour of these workpieces allows them to be positioned by passing through a segmented clamp to a position in front of the die close to the forming zone. The risk of buckling, which arises particularly with tubing, is thus avoided. In addition, handling and storing of workpieces orientated to the longitudinal axes is also generally easier with the horizontal configuration.



## *Vertical layout*

Vertical axial forming machines are applied for short workpieces or components which cannot and do not have to be clamped on the outside diameter. These components are held in an intermediate holding device or counter pressure holder, or they are simply placed on a recess in the table plate. Where required, it is possible to provide a centring or clamping device additionally.

In many cases, further operations are required before or after axial forming and, for this, the vertical position is advantageous. The vertical axial forming machine offers optimum integration possibilities in such process lines.

## *Transfer lines*

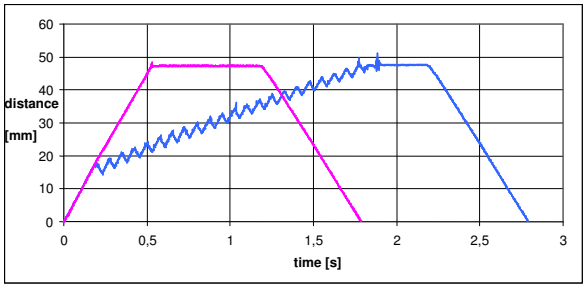
In particular, horizontal axial forming equipment can be supplied in the form of a transfer line. If desired, other forming operations such as rotary swaging or metal cutting operations can also be integrated.

# RECURSIVE AXIAL FORMING (FREQUENCY MODULATED AXIAL FORMING)

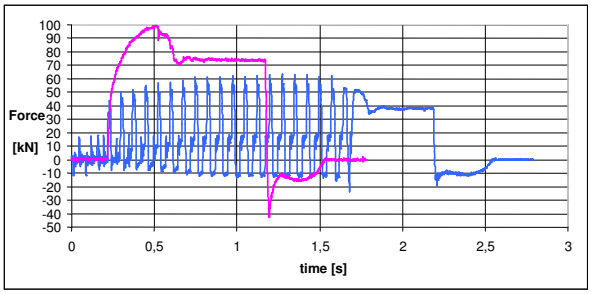
In conventional axial forming, the dies advance at a constant speed. Because of the forces needed to form the part and overcome friction, very high axial forces between the holding device and the die result. If the cross section of the workpiece is not adequate, this can lead to buckling of the workpiece. In addition, this effect may also be experienced if, due to the geometry, the part is held between points rather than on the periphery.

In recursive axial forming, which is a patented development of conventional axial forming, the forward movement is superimposed by an incrementally small return (recursive) movement in a frequency which depends on the process and can be modulated.

The return movement is decisive for the reduction of the axial forces




conventional recursive




Due to small forming steps the axial forces are reduced by 40 %

As a result, the axial force required is significantly reduced. The reduction in this force, which can be up to 50 %, results from the change in the behaviour of the flow of the material, and the improved and constantly replenished lubricant film. For this it is essential that the die is actually lifted off the workpiece at each return movement in the oscillation so that the stress in the material is released and the lubricant can enter.

Recursive axial forming (also known as frequency modulated axial forming) has been in use for high volume production for several years and the advantages the technique offers have been clearly demonstrated.

## ADVANTAGES

### *Extended process limitations*

Resulting from the significantly reduced axial forces, axial forming can also be applied to workpieces which could not take the forces that arise in axial extrusion by the conventional techniques.

### *Improved dimensional accuracy*

No radial forces arise so that the radial elongation of the die is reduced. This leads to improved dimensional accuracy of the workpiece, especially regarding taper on the formed surface. In some cases, the recursive movement in combination with optimised die geometry and reinforced dies, it is possible to improve quality by up to two classification steps. Process reliability is also increased.

### *Increased die life*

Low radial expansion of the die during the forming of external splines, leads to increased die life. The continuous periodic release of force on the workpiece resulting from the recursive movement is also very advantageous for tribology since the lubricant film can be continuously replenished.

# QUALITY

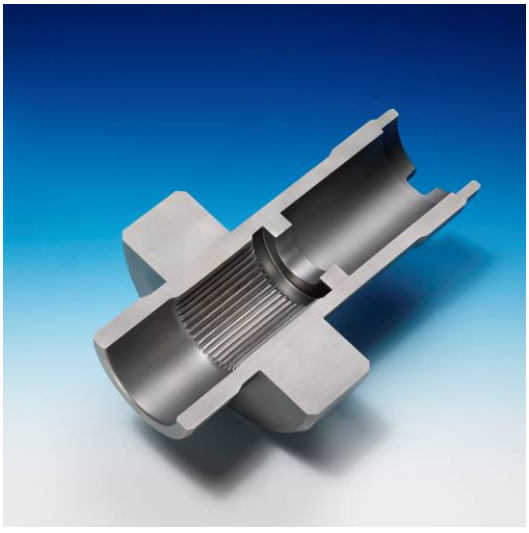
Compared with splines formed by other processes, splines formed by axial forming may show significant improvements in quality. The following examples illustrate this point. The examples can be used for assessing the likely quality achievable with other similar workpieces.

### *Tolerances on external splines*

| Involute splines similar to DIN 5480 with 23 teeth, module 1.0583, pressure angle 45°, length 35 mm, major diameter 28.45 mm | |
|---|---|
| Dimension over balls | 16 µm |
| Dimension taper over balls | 10 µm |
| Profile variation $F_a$ | max. 5 µm |
| Flank variation $F_b$ | max. 7 µm |
| Pitch error $F_p$ | 8 µm |
| Major diameter | 0.1 mm |
| Spline classification acc. to DIN 3962 | 5 |

### *Tolerances on internal splines*

| Involute splines in accordance with 32/46 DP, with 39 teeth, module 0.9375, pressure angle 30°, length 33.5 mm, minor diameter 30.2 mm, base circle 32.48 | |
|---|---|
| Dimension over balls | 30 µm |
| Dimension taper over balls | 10 µm |
| Profile variation $F_a$ | max. 31 µm |
| Flank variation $F_b$ | max. 18 µm |
| Pitch error $F_p$ | 30 µm |
| Minor diameter | 0.1 mm |
| Spline classification acc. to DIN 3962 | 6 |



### *Run-out tolerance in reducing*

| Propeller shaft reduced at both ends, wall thickness sized | |
|---|---|
| Run-out in the reduced area | max. 0.20 mm |

## *Further examples of external splines*

| Diametral Pitch spline with 42 teeth, module 1.25, pressure angle 45°, length 27 mm, major diameter 53.38 mm | |
|---|---|
| Dimension over balls | 20 µm |
| Profile variation $F_a$ | max. 8 µm |
| Flank variation $F_b$ | max. 18 µm |
| Pitch error $F_p$ | 31 µm |
| Major diameter | 0.2 mm |
| Spline classification acc. to DIN 3962 | 8 |

| Diametral Pitch spline with 32 teeth, module 1.058, pressure angle 30°, length 120 mm, major diameter 34.93 mm | |
|---|---|
| Dimension over balls | 20 µm |
| Profile variation $F_a$ | max. 7 µm |
| Flank variation $F_b$ | max. 20 µm |
| Pitch error $F_p$ | 14 µm |
| Major diameter | 0.15 mm |
| Spline classification acc. to DIN 3962 | 7 |

| Spline for plug connection to DIN 5480 with 30 teeth, module 1.000, pressure angle 30°, length 26 mm, major diameter 31.80 mm | |
|---|---|
| Dimension over balls | 17 µm |
| Profile variation $F_a$ | max. 8 µm |
| Flank variation $F_b$ | max. 4 µm |
| Pitch error $F_p$ | 11 µm |
| Major diameter | 0.1 mm |
| Spline classification acc. to DIN 3962 | 5 |

# DIES

### *External die*

The forming die consists of a die core in the shape of a negative form of the workpiece to be produced, and a housing acting as reinforcement for the core. The die core is in most cases made of carbide, specially coated after shaping by eroding and polishing.

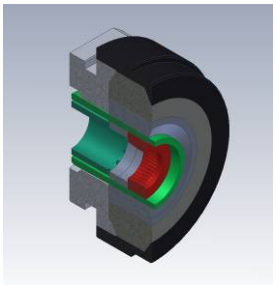
When forming splines there is a choice between several geometries on the feed and feed-out sides, depending on requirements regarding shape and surface quality. It is necessary to take into account that the diameter prior to forming the splines may change depending on the die geometry selected.

### *Internal die/ mandrel*

The mandrel is made of high speed steel or carbide which is coated after forming by eroding or grinding.

# REINFORCEMENT

The housing/reinforcement of the die provides a pre-stress force on the die core. In many cases, a hardened steel ring is used for this application. Depending on the forming work required and the desired tolerances, the die may expand during the pressing operation. This could result in tolerances in the diameters on the splined workpiece. In such cases, the rigidity of the location can be increased by a reinforcing strap arrangement. Compared with a simple steel ring, this form of reinforcement has the additional advantage that the die core can be changed several more times than is possible with a steel ring, before a replacement becomes necessary due to fatigue of the material.



Adjustable splining die

### *Adjustment possibility*

The strapping reinforcement system is also to be recommended to provide a possibility for adjusting the die core, for example to make it possible to respond to dimensional variations due after hardening caused by differences in material. In the case of dies for spline forming, the spline data can be varied such that the dimension over pins can be corrected by up to 0.1 mm by adjusting the depth of inward forming derived from the die core.

# LUBRICATION

Due to the high surface pressures between the workpiece and the die, good lubrication is essential. In most cases, so-called forming oils are applied. The application of a special lubricant carrier surface is not necessary and can be avoided without any disadvantage. The lubricant is applied either in the form of continuous oil flow or using an aerosol lubricant for minimum quantity lubrication.

# TECHNICAL DATA

| | |
|---|---|
| Axial force | 700 kN conventional -> 400 kN with recursive movement |
| Forming stroke | 300 mm |
| Power required | ca. 45 kW |
| Speed rapid traverse | 100 mm/s |
| Speed working traverse | 30 mm/s |
| Workpiece ø max. | 80 mm |
| Workpiece length | 500 mm max. in case of vertical machine design, on the horizontal machine also longer workpiceces can be processed. |

We welcome enquiries for applications requiring machines to other specifications.

# THE ENTERPRISE

### *Tradition demands …*

FELSS is a medium-sized enterprise with core skills in cold forming and can look back on almost 100 years of history. Many times we have been able to make decisive steps forward in process technology as a result of our technical know-how and innovation skills. Alongside rotary swaging we now offer the innovative processes of axial forming and tangential forming.

### *… to shape the future*

Close co-operation with our customers is part of our philosophy. This is the basis for our work on customer projects and a starting point for market-orientated onward development. To combine science and practice is a FELSS tradition – and this will continue into the future, systematically making use of numerous contacts to the universities and combining this with inspiration derived from practical demands.

The enthusiasm for innovation and the high level of motivation of our team enable us to constantly develop new applications for forming technology, to meet your production and your product requirements precisely.

The international approach of our management ensures the future presence of our Group and hence the continuing support for our customers world-wide, and in all important development areas.

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