MICRO-SKIVING — (R)EVOLUTION OF A KNOWN PRODUCTION PROCESS
Micro-skiving has been developed that allows users access to the skiving technique for machining inner micro-teeth.

By PIERRE FALBRIARD and HERVÉ BAOUR

Production of internally toothed gear wheels is possible in many different ways. Different techniques such as gashing, broaching, wire EDM, or shaving make it possible to achieve these profiles. However, skiving seems to be the optimal solution for reducing production time of this type of gears when large production batches are required.

This internal gear cutting technique has been known for several years and widely used in the industry for modules over 0.50 (DP>50).

However, cutting an internal gear with a module below 0.50 (DP>50) is not an easy task. The profile becomes very small and requires an optimized cutting tool, which can only be manufactured on special grinding machines that can cope with micron (µm) accuracy.

Micro-skiving has been developed allowing users to have access to the skiving technique for machining inner micro-teeth. The basic principle is similar to standard modules, with higher requirements in terms of shape, burr, and surface finish. Modules as low as 0.15 have already been produced, and the technical limits to go even lower are regularly crossed.

These developments expand the possibilities for fast and high-volume production of parts with internal micro-teeth. The production of micro-subassemblies, medical micropumps or micro-reducers can now be considered without the current manufacturing challenges of cycle time and quality level.

That being said, micro-skiving internal gear cutting requires suitable, high accuracy machines with fine adjustment options. In addition, a perfect synchronization between the spindles of the part and the tool is necessary. Once all these parameters are mastered, machining times, and therefore productivity, are matchless.

1 INTRODUCTION AND MOTIVATION

The Power Skiving principle has already been around for many years. Several manufacturers and suppliers are offering tools, devices, and machines for this type of operation. Until now, producing parts with module lower than 0.50 (DP>50) was simply impossible with that method.

Evolution of the means of production available for this type of parts, both in terms of machine and tool, makes possible to lower this limit.

As an evolution of the Power Skiving methodology, internal cut of gear parts with a module of 0.10 and 220 teeth is today possible. (Courtesy: Louis Bélet SA)

Figure 1: Part to be cut. (Module 1.0 / Z 27 teeth / nonstandard shape.)

As an evolution of the Power Skiving methodology, internal cut of gear parts with a module of 0.10 and 220 teeth is today possible. (Courtesy: Louis Bélet SA)

Figure 2: Part’s profile [mm].
general remark, the micro-skiving term is
used for modules below 0.50 (DP > 50).

This document explains the Power-Skiving process’ details. This principle also
applies to the micro-skiving cutting method.

It will also illustrate a comparison
between the different methods for produc-
ing the same part: inner gear with a small
module.

Constraints-related analysis will be based
on machining time, cost, and quality for
each means of production.

Finally, potential improvements and
future trends for this production method
are in the conclusion of this report.

2 BASE PRINCIPLE
Skiving is a machining process by chip
removal allowing cutting by generation
inner or outer teeth. This manufacturing
principle mainly shows its full potential
when cutting the inside tooth. (Figures 1
and 2)

Tool could look like Figure 3:

where

\[ \Phi D_t \] is addendum diameter [mm].

\[ \Phi D \] is pitch diameter [mm].

\[ \Phi D_f \] is dedendum diameter [mm].

\[ V_c \] is cutting speed [m/min].

\[ V_p \] is part peripheral speed [m/min].

\[ V_f \] is cutter peripheral speed [m/min].

\[ A_t \] tool’s tilt angle [°].

The tool’s profile is adapted to the tilt
angle intended for the cutting (Figure 4).

The tilt angle (A_t) is directly proportional
with the cutting speed (V_c). See Figure 5.

The skiving process has many significant
advantages over other gear machining meth-
ods:

- Production speed.
- Finishing quality.
- Precision.
- Can be used on standard machines with
suitable equipment.

Most of the suppliers offer skiving tools
starting from module 0.50 (DP 50). Until
now, other techniques have been used for
smaller modules. Some of these techniques
are acceptable but not very efficient, and, in
many cases, they are very slow.

The main reasons for this include:

- Complexity in manufacturing the tool.
- Precision of the tool, clamping system,
  etc.

- High accuracy required on grinding
  machines.

Whereas easiness is not suitable to describe the grinding of
the tool, improvements in the means of production and tools now allow
the manufacture of skiving tools for much smaller modules (Figure 6).

Up to now, different cuttings processes were available among
others.

4 BROACHING
Broaching (Figure 7) is a machining process that uses a toothed tool,
called a broach, to remove material. The broaching process has a
good accuracy for producing a small quantity. However, deburring is
often necessary, and the production time is very slow. Furthermore,
distortion is frequent when the holding of the part is not well done.
This manufacturing process is widely used in the industry thanks to its simple use.

5 UV-LIGA
The technique known as UV-LIGA (Figure 8), is used to manufacture micro-components and is inspired by microelectronic technologies. It combines the processes of photolithography and electroforming, is highly accessible in terms of production costs, and is easily and rapidly implementable through suppliers. For gear manufacturing, we can mention that this process has an excellent precision with neither distortion nor burrs. It is meant to be used for small parts, but it needs to be flat. The production cost is rather high, and production time is slow.

6 WIRE EDM
Wire Cut Electrical Discharge Machining (Wire EDM) (Figure 9) is a metal working process where electrical erosion is used to separate material from a conductive work piece. This process allows for good precision parts with no burrs nor distortion. It’s meant to be used for prototyping or for small batches. It’s a very slow process with a relative high production cost, especially for larger batches.

7 SHAPING
Gear shaping (Figure 10) is a machining process for creating teeth on a gear using a cutter in the form of a pinion. Gear shaping is a convenient and versatile method of gear cutting. It involves the continuous, same-plane rotational cutting of a gear. This process is rather slow but is relatively low in cost for small batches. Its precision is excellent with no distortion. Few burrs can be seen.

8 MICRO-SKIVING
The micro-skiving process follows the same principles as Skiving and can be compared to it in terms of execution. However, designing and using the tools with modules in the order of 0.10 are completely different. The tool as well as the machine settings correspond to a complete order of magnitude in terms of values and precision. In addition, tooth profiles are generally irregular, topping, and non-standard.

9 DESIGNING OF THE TOOL
Micro gears do not necessarily follow AGMA, DIN, or ISO standards to define their profiles. Material resistance or space constraints are some of the parameters the designers have to take into consideration. This sometimes leads to very strange profiles.

Figures 11, 12, and 13 are representations of some custom profiles asked for by some users. You can see in black the profile of the gear, and in red the shape of the cutter. Sometimes, custom shapes or profiles asked by users are simply not feasible.
The profile seen in Figure 14 is not achievable with micro-skiving, and the user has to consider another way of achieving it. The tool profile must be calculated, and the tilt angle implies a deformation of the shape. This must be taken into account without modifying the profile height.

It is recommended that the ratio between the Zgear and the Zcutter be relatively round with a maximum of two digits after the decimal point. Some machine commands do not handle synchronization ratios well with many decimal digits.

The larger the ratio between the Zgear and Zcutter, the more the tool profile is different from that of the part to be cut.

10 TOOL’S PROFILE DEVELOPMENT

Given the frequent absence of a standard definition for internal micro-tooth cutting, a geometric method for defining the tool profile from the part had to be developed.

Let’s take the example seen in Figure 15:

\[ m = 0.1800. \]
\[ Z_{\text{gear}} = 144 \text{ teeth.} \]
\[ Z_{\text{cutter}} = 120 \text{ teeth.} \]
\[ \text{Gear } \Omega = m \times Z_{\text{gear}}. \]
\[ \text{Cutter } \Omega = m \times Z_{\text{cutter}}. \]
\[ \text{Offset } C_1; C_2 = \left( \text{Gear } \Omega - \text{Cutter } \Omega \right)/2. \]

Figure 16 shows a logigram of the tool’s profile generation.

This leads, in a partial representation so as not to overload the drawing, to the profile shown in Figure 17.

Because of the tilt angle needed, the tool’s profile is then “corrected” as follows:

\[ \text{A } \cos^{-1} \left( \frac{A_i}{A} \right) \text{ factor is applied to compensate the inclination shown in Figure 18.} \]

11 CUTTER GRINDING

11.1 CHALLENGES

The profile’s accuracy with respect to the borehole stands in the micrometer range, and geometric tolerances must be maintained at a very tight level. (See Figure 19.)

Radii at the bottom of the tooth profile can become extremely tiny. (See Figure 20.)

11.1.1 SOLUTIONS

- Tool blank must be perfect.
- No disassemble of the cutter from its arbor and real-time profile check during grinding.
- Grinding machine with linear motors on each axis.
- High thermal stability and stiffness of the machine.
- Suitable grains and binders for the grinding wheel.
- Mastery of the shaping for the grinding wheel.

12 CUTTER USE

In order to use the cutting tool optimally, the adjustments must be
made with the highest precision. A minimal runout (<2µm) is essential to produce a perfect part. The positioning of the tool in relation to the part is shown in Figure 21. The tilt angle is equal to the angle on the tool teeth.

If this crossing is not aligned, the teeth may be asymmetrical and marked as shown in Figure 22.

The screw-machines of the latest generation in Figure 23 have a positioning axis (B) that can be set and include a spindle that is perfectly synchronized with the main spindle (C1).

Accuracy of the cutting directly depends on the accuracy of the machine.

Other machines as machining centers or dedicated machines (Figure 24) are available for such operations.
13 RESULTS

An example of cutting for the reference part m0.1800 Z 144 is seen in Figure 25.

Taking the same comparison table as for the other processes, let’s now take the micro-skiving way of producing the reference part in Figures 26 and 27.

13.1 FUTURE IMPROVEMENTS

Here are some different points and questions that still may be improved:

- Tilt angles optimization ($\theta_i$).
- Different carbide grades or other materials.
- Coating on the cutter.
- Determine the limits of cutting speed and feed rates according to the specific materials.
- Cutter lifetime definition.
- Influence of the coolant type on the cutting quality.

14 CONCLUSION

Micro-skiving is in its very early stages, and there is still a lot to improve. But it certainly comes at an opportune time as the miniaturization of manufactured objects is on the rise:

- Micro-factory in the Industry 4.0 trend.
- Robotics that are always looking to reduce the size of their devices.
- A maximum of ultra-portable devices for medical devices.
- Smaller and smaller engines (thermal or electric) in transport.
- New watch movement designs.

Until now, micro wheels with internal teeth were avoided; designers knew their high manufacturing cost.

Thanks to micro-skiving, they now can let their imagination run wild, both in the degree of miniaturization and in the shape of the tooth profile — all this with a lower manufacturing cost of a wheel with a lower internal cutting edge while increasing quality.

Micro gear suppliers finally have a simple, durable, and economical solution that can be used on a large number of machines.

The use of micro-skiving for the part used as an example in this paper allowed the user to cut the machining time by 70, reducing it from 30 minutes with Wire EDM down to 25 seconds per part, all of this with an excellent quality.

ABOUT THE AUTHOR

Pierre Falbriard and Hervé Baour are with Louis Bélet SA.
### Table: Micro-skiving cutter m0.1800 Z120

<table>
<thead>
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<th>Module</th>
<th>0.180000</th>
<th>Zw/Zc Ratio</th>
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<tr>
<td>Z wheel</td>
<td>144</td>
<td>Z Cutter</td>
<td>120</td>
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<tr>
<td>Specification</td>
<td>Special</td>
<td>Ai</td>
<td>15.0°</td>
</tr>
</tbody>
</table>

#### Wheel

| Ø Dt       | 26.4020  |
| Ø D        | 25.9200  |
| Ø Df       | 25.5260  |

#### Cutter

<table>
<thead>
<tr>
<th>Ø Dt</th>
<th>Theoretical at 0°</th>
<th>Real at 15°</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>22.6820</td>
<td>22.8440</td>
</tr>
</tbody>
</table>

| Ø D          | 21.6000            | 22.3620      |
| Ø Df         | 21.2060            | 21.9680      |
| Offset       | 2.1500             | 1.7790       |

#### Machine

<table>
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<th>Cutting speed</th>
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<th>m/min</th>
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<tbody>
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<td>V wheel</td>
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<td>m/min</td>
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<tr>
<td>V cutter</td>
<td>373</td>
<td>m/min</td>
</tr>
<tr>
<td>N wheel</td>
<td>4583</td>
<td>tr/min</td>
</tr>
<tr>
<td>N Cutter</td>
<td>5500</td>
<td>tr/min</td>
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</tbody>
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**Figure 25:** Micro-skiving cutter m0.1800 Z120.

**Figure 26:** Profile results with DXF overlay.

**Figure 27:** Profile results.