3.3. Ball nose milling tools

A ball nose milling tool has a ball-shaped (spherical) cutting edge. This means that the cutting edge is a part of a sphere (Fig. 36). Nothing other than a ball has the common normal to a surface; and actually only a spherical cutting tool can ensure theoretical pinpoint contact with a required 3-D surface. Thus the tool does not cause deformation of the needed shape while milling (Fig. 37).

**Ball mill**

From time to time (especially in shoptalk of the die and mold professional environment) the ball nose cutters are said to be "ball mills". Such a definition should be avoided because ball mills refer to grinding devices of the specific design principle and relate to grinding materials into powder, but not to material removal by milling.

The die and mold industry feature no lack of complex shaped parts - the ball nose milling tools excellently meet the requirements for machining these parts. It is little wonder when speaking about specific features of the cutting tools in die and mold making, the reference is to the ball nose and the toroidal cutting profiles.

In the ball nose cutters, one of the important engineering factors is the angular value of a ball-shaped cutting edge. Usually it is 180° (hemisphere, Fig. 38); but tools with the edge more than hemisphere (half-type cutters, Fig. 39), typically 220°-250°, and the edge less than hemisphere (taper or tapered ball nose cutters, Fig. 40), basically 80°-89°, are common in die and mold making.

The ball nose milling tools with the ball-shaped cutting edge as a hemisphere often have also a cylindrical cutting portion. The portion allows for better surface finish, while machining near straight walls and enables for increasing step down for milling passes (compare cases a and b in Fig. 41).
The ability to generate exact, true-to-form surfaces is the prime advantage of the ball nose milling tools. However, the ball-shaped cutting edge, which determines this important feature, has one significant drawback: the zero velocity (and hence the zero cutting speed) of the cutter tip. This phenomenon makes cutting near to the tip difficult. Further, the points of a ball-shaped cutting edge are on an unequal distance from the tool axis, varying from zero (at the tip) to the radius of the corresponding sphere. Such a variation means that the points cut with different cutting speeds. The chip thinning effect considered in the previous sections of the guide also plays a role here. The combination of unequal cutting speeds and dissimilar chip thickness leads to a substantial difference in loading the points of the cutting edge along its profile, which makes cutting harder and intensifies wear in the certain areas of the cutting edge.

Cutting tool engineers take into account the mentioned negative effect when designing the cutting geometry of a ball nose tool. Additionally, machining practice advances different methods that improve the performance of the ball nose tools and make them more effective. For instance, milling with a tool whose axis is not perpendicular to the machined surface ("milling", Fig. 42) makes loading on the cutting edge more uniform. Another example: replacing rampdown milling (case a, Fig. 43) on rampup milling (case b, the same figure) in a machining process at once changes the cutting conditions for the better. Under the same programmed spindle speed and feed (in case a), the most stressed portion of the cutting edge is the area near the cutter tip that features low cutting speeds; while in case b), the cutting edge area, which carries the main load, is in a much better situation when a more acceptable cutting speed corresponds to this area. Of course, machining specific parts can demand various milling strategies; and the examples only illustrate some particular properties associated with the ball nose cutting geometry. The correct process planning requires taking the properties into consideration.

ISCAR carries a wide range of ball nose milling cutters of diverse types: indexable and solid, single-insert and with interchangeable solid cutting heads. Normally these are endmills with shank and they vary in dimensions and obtainable accuracy. In addition, the cutters of the single-insert and indexable types are available not only as tools with integral body but in most cases as replaceable cutting heads with a FLEXFIT or MULTI-MASTER adaptation. For the tools with integral body (Fig. 44), there are different design configurations with straight (type A) and tapered (conical) neck (types B and D). Usually type B features an operating angle α equal to 5°, and type D –2°. Table 68 shows the most popular ISCAR families of the ball nose endmill cutters.

**Historical background: copy mill**

In many cases the ball nose milling tools are called "copy milling cutters", "copying style mills" or plainly "copy mills". These terms trace their history to not so long ago when the contoured surfaces were produced on conventional milling machines of a copying arrangement – the copy milling machines. The machines operated manually or having a follow-up drive of hydraulic, electric, etc. type, feature the ability to follow a master model (template) and thus to generate the contoured surfaces by cutting. As a matter of course, the copy milling machines use mainly the cutters of ball-shaped or toroidal cutting profile that were called "copy mills" accordingly.

Introduction of the CNC machines dramatically changed the technology of generating the contoured surfaces by cutting. In contrast to the traditional copy milling that allowed machining for the most part 2-D profiles, modern CNC technology is capable of producing very complicated 3-D shapes by metal cutting; and today "template", which defines tool paths, is a computer solid model. The model built with the use of CAD/CAM software is intended for generating corresponding CNC programs. Therefore sometimes used terms "copy milling" and correspondingly "copy mills", now substantially differ from their original meanings.
Fig. 42

Fig. 43 a

Fig. 43 b

Fig. 44

Type A

Type B and D