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Mold high speed milling processing technology

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The abstract Introduced the high speed milling in the mold processing application as well as the influence, and brief introduction high speed milling engine bed structure, control system and cutting tool. Has carried on the simple analysis to the high speed processing craft.

Key word **high speed milling; mold processing**

First, foreword

In the modern mold production, along with to models artistic and the function must obtain more and more high, models the internal structure to design more and more complex, the mold contour design day by day is also complex, the free curved surface accounts for the proportion to increase unceasingly, the corresponding mold structure also designs more and more complex. These all set a higher request to the mold processing technology, not only should guarantee the high manufacture precision and the surface quality, moreover must pursue the processing surface artistic. Along with is unceasingly thorough to the high speed processing engineering research, is processing the engine bed, the numerical control system, the cutting tool system, CAD/ especially Correlation technology and so on CAM software develops unceasingly under the impetus, high speed processes the technology more and more many to apply in the mold cavity processing and the manufacture.

The numerical control high-speed cutting processing took in the mold manufacture a most important advanced manufacture technology, is the collection is highly effective, high quality, the low consumption in a body advanced manufacture technology. Is opposite in the traditional machining, its cutting speed, entered to the speed had the very big enhancement, moreover cut the mechanism not to be same. The high-speed cutting caused the machining to have the leap, its specific power metal excision rate enhanced 30%~40%, the cutting

force reduced 30%, the cutting tool working durability enhanced 70%, remained hotly large scale reduces in the work piece cutting, the low step shudder vanished nearly. Along with the cutting speed enhancement, unit time semifinished materials material removing rate increased, the cutting time reduced, the processing efficiency enhanced, thus reduced the product manufacture cycle, enhanced the product market competitive power. At the same time, the high speed processing small amount entered quickly causes the cutting force to reduce, the scrap high speed discharged reduced the work piece cutting force and the thermal load distorts, enhances the rigidity to be bad and the thin wall components machining possibility. Because cutting force reducing, the rotational speed enhancement causes the cutting system the operating frequency to be far away the engine bed the low step natural frequency, but the work piece surface roughness is most sensitive to the low step frequency, from this reduced the surface roughness. In mold high hard steel stock (HRC45~HRC65) in the processing process, uses the high-speed cutting to be possible to substitute for the working procedure which the electrical finishing and rubs truncates polishes, thus has avoided the electrode manufacture and the time-consuming electrical finishing, large scale reduced fitter's polishing with to throw the light quantity. Thin wall mold work piece more and more needs which regarding some markets in, the high speed milling also may smoothly complete, moreover in the high speed milling CNC processing center, a mold attire clamps may complete the multiplex step of processing.

The high speed processing technology has had the huge influence to the mold processing craft, changed the traditional mold processing to use "the annealing → milling processing → heat treatment → to rub truncates" or "the electric spark machining → manually polishes, polishes" and so on the complex long technical process, even might use the high-speed cutting processing substitution original complete working procedure. The high speed processing technology besides may apply in the hard mold cavity direct processing (in particular half precision work and precision work), in EDM aspect and so on electrode processing, fast type manufacture also obtained the widespread application. The mass productions practice indicated that, the application high-speed cutting technology may save in the mold following processing 80% handwork to grind the time approximately, saves the processing cost expense nearly 30%, the mold face work precision may reach 1 m, the cutting tool cutting efficiency may enhance one time.

Second, high speed milling processing engine bed

The high-speed cutting technology is one of machining technology main development directions, it along with foundation technology the and so on CNC technology, microelectronic technology, new material and new structure development but steps a higher stair. Because the mold processes particular as well as high speed processing technology own characteristic, (processed engine bed, numerical control system, cutting tool to the mold high speed processing related technology and the craft system and so on) proposed processed a higher request compared to the traditional mold.

1. High stable engine bed strut part

The high-speed cutting engine bed lathe bed and so on supports the part to be supposed to have very well moves, the static rigidity, hot rigidity and best damping characteristic. The majority of engine beds all use high grade, the high rigidity and Gao Kangzhang the gray iron took the strut part material, some engine bed companies also increase the high damping characteristic in the foundation polymer concrete, by increases its vibration-proof and the thermostability, this not only may guarantee the engine bed precision is stable, also may prevent when cutting the cutting tool inspires trembles. Uses the enclosed lathe bed design, the overall casting lathe bed, the symmetrical lathe bed structure and has the densely covered stiffener and so on also enhances the engine bed stable important measure. Some engine bed companies' research and development departments in design process, but also uses the modality analysis and the finite element structure computation and so on, optimized the structure, stably causes the engine bed strut part to be reliable.

2. Engine bed main axle

The high speed engine bed main axle performance is the realization high-speed cutting processing important condition. The high-speed cutting engine bed main axle rotational speed scope is 10000~100000m/Min, the main axle power is bigger than 15kW. Is not bigger than 0.005mm through the main axle compressed air of or axial play between the cooling system control hilt and the main axle. Also requests the main axle to have the fast vertical speed, to assign the performance which the position is fast stops (namely to have extremely high angle addition and subtraction speed), therefore the high speed main axle often uses the liquid static pressure bearing type, the air static pressure bearing type, the thermo-compression nitriding silicon (Si3N4) the ceramic bearing magnetism aerosol bearing type isostructuralism form. Lubricates uses technology and so on oil gas lubrication, splash lubrication. The main axle cools uses the main axle interior water cooling generally or air cooled.

3. The engine bed actuates the system

In order to satisfy the mold high speed processing the need, high speed processes the engine bed the actuation system to be supposed to have the following characteristic:

(1) high entering for speed.

The research indicated that, regarding the minor diameter cutting tool, enhances the rotational speed and each tooth enters for the quantity is advantageous in reduces the cutting tool attrition. At present commonly used entering for the speed range is 20~30m/Min, like uses leads greatly the ball bearing guide screw transmission, enters may reach 60m/ for the speedMin; Uses the straight line electrical machinery then may enable to achieve 120m/ to the speedMin.

(2) high acceleration.

Has the good acceleration characteristic to the three dimensional complex curved surface silhouette high speed processing request actuation system, the request provides the driver which the high rapid advance or progress gives (to enter speed approximately 40m/ quicklyMin, the 3D outline processing speed is 10m/Min), can provide 0.4m/S2 to 10m/The s2 acceleration and reduces the speed.

The engine bed manufacturer mostly uses the entire closed loop position servo-control slightly to lead, the great size, the high grade ball bearing guide screw or leads greatly many guide screws. Along with the electrical machinery technology development, the advanced straight line electric motor already was published, and the success applied in the CNC engine bed. The advanced straight line direct motor drive enable the CNC engine bed no longer to have the mass inertia, in advance, question and so on lag and vibration, sped up the servo speed of response, increased the servo-control precision and the engine bed processing precision.

4. Numerical control system

The advanced numerical control system is guaranteed the mold complex curved surface high speed processing quality and the efficiency key aspect, the mold high-speed cutting processing to the numerical control system basic request is:

A. High speed numerical control return route (Digital control loop), including: 32 or above 64 bit parallel processors and 1.5Gb hard disk; Extremely short straight line electrical machinery sampling time.

B. Speed and acceleration feed-forward control (Feed forward control); Digital actuation system crawling control (Jerk control).

C. Advanced inserts makes up the method (to insert based on the NURBS transect makes

up), by obtains the good surface quality, the precise size and the high geometry precision.

D. Pretreatment (Look-ahead) function. The request has the large capacity cushion register, may read in advance and inspects many segments (for example the DMG engine bed to be possible to reach 500 segments, the Simens system may reach a 1000~2000 segment), in order to when is processed the superficial shape (curvature) changes may promptly adopt changes for measure and so on speed by avoids cutting and so on.

E. The error compensatory function, including because the straight line electrical machinery, the main axle and so on gives off heat the hot error which causes to compensate, the quadrantal error compensates, the measurement system error compensates and so on the function. In addition, the mold high-speed cutting processing very is also high to the data transmission speed request.

F. The traditional data connection, like the RS232 serial mouth transmission speed is 19.2kb, but many advanced processings centers have used the ether local area network (Ethernet) to carry on the data transmission, the speed may reach 200kb.

5. Cooling lubrication

The high speed processing uses the belt coating the hard alloy tools, in high speed, the high temperature situation does not need the cutting compound, the cutting efficiency to be higher. This is because: The milling main axle high speed revolves, the cutting compound if achieved the cutting area, first must overcome the enormous centrifugal force; Even if it overcame the centrifugal force to enter the cutting area, also was possible as a result of the cutting area high temperature but to evaporate immediately, the cooling effect very small did not even have; At the same time the cutting compound can cause the cutting tool edge of a sword the temperature intense change, is easy to cause the crack the production, therefore must pick the oil used/Gas cooling lubrication dry type cutting way. This way may use the compressed gas rapidly the cutting which the cutting area produces, thus the massive cuttings hotly will carry off, at the same time might forms extremely thin microscopic protective film after the atomization lubricating oil in the cutting tool edge of a sword and the work piece surface, but effectively will lengthen the cutting tool life and enhances the components the surface quality.

Third, high-speed cutting processing cutting tool

The cutting tool is in the high-speed cutting processing one of most active important factors, it is affecting the processing efficiency, the production cost and the product

processing precision directly. The cutting tool must withstand load and so on high temperature, high pressure, friction, impact and vibration in the high speed processing process, the high-speed cutting cutting tool should have the good machine capability and the thermostability, namely has the good anti- impact, the wearability and resists heat the weary characteristic. The high-speed cutting processing cutting tool technological development speed is very quick, application many like diamonds (PCD), cubic boron nitride (CBN), ceramic cutting tool, coating hard alloy, (carbon) titanium nitrides hard alloy TIC (N) and so on.

In the processing cast iron and in the alloy steel cutting tool, the hard alloy is the most commonly used cutting tool material. Hard alloy tools resistance to wear good, but the solidity ratio cube boron nitride and the ceramics are low. In order to enhance degree of hardness and the superficially attractive fineness, uses the cutting tool coating technology, the coating material for the titanium nitrides (TiN), the aluminium nitride titanium (TiALN) and so on. The coating technology causes the coating by the sole coating development for multilayered, the many kinds of coating material coating, has become one of enhancement high-speed cutting ability essential technical. The diameter in the 10~40mm scope, also has the carbon titanium nitrides coating the hard alloy bit to be able to process the Luo river degree of hardness to be smaller than 42 materials, but the titanium nitrides aluminum coating cutting tool can process the Luo river degree of hardness is 42 even higher materials. When high-speed cutting steel products, the cutting tool material should select the hot rigidity and the fatigue strength high P kind of hard alloy, the coating hard alloy, the cubic boron nitride (CBN) and the CBN compound cutting tool material (WBN) and so on. The cutting cast iron, should select the fine grain K kind of hard alloy to carry on the rough machining, selects the compound nitrided silicon ceramics or the crystal combination cube boron nitride (PCNB) the compound cutting tool carries on the precision work. When precise processing non-ferrous metal or nonmetallic material, should select crystal combination diamond PCD or the CVD diamond coating cutting tool. When choice cutting parameter, in view of the circular shear blade and a ball milling cutter, should pay attention to the effective diameter the concept. The high speed milling cutting tool should press the balance design manufacture. The cutting tool front angle must be smaller than the conventional cutting tool front angle, the clearance angle is slightly big. The host vice-cutting edge attachment point should the cavetto or the lead angle, increases the vertex angle, prevents the knife point place hot attrition. Should enlarge nearby the knife point the cutting edge length and the cutting tool material volume, enhances the cutting tool rigidity. Is safe

in the guarantee and satisfies the processing request under the condition, the cutting tool hangs extends as far as possible short, cutter body central toughness is friends with. The hilt must be sturdier than the cutting tool diameter, connects the handle to assume but actually the pyramidal, by increases its rigidity. As far as possible central the refrigerant hole in the cutting tool and the cutting tool system. A ball end mill must consider effectively cuts the length, the cutting edge must be as far as possible short, two spiral grooves balls end mill usually uses in the thick mill complex curved surface, four spiral grooves balls end mill usually uses in the fine mill complex curved surface.

Fourth, mold high speed processing craft

The high speed processing including take removes the remainder as the goal rough machining, the residual rough machining, as well as take gains the high grade processing surface and the slight structure as the goal half precision work, the precision work and the mirror surface processing and so on.

1. Rough machining

The mold rough machining essential target is pursues in the unit time material removing rate, and is half precision work preparation work piece geometry outline. In the high speed processing rough machining should adopt the craft plan is the high cutting speed, Gao Jin giving rate and the small cutting specifications combination. The contour processing way is one processing way which the multitudinous CAM software uses generally. Using is spiral contour and so on the Z axis contour two ways which are many, also is in processes the region only time to feed, in does not lift the knife in the situation to produce continuously the smooth cutting tool way, enters, draws back the knife way to use the circular arc to cut into, to cut. The spiral contour way characteristic is, has not waited the high level between the knife road migration, may avoid frequently lifting the knife, feeding to the components surface quality influence and mechanical device nonessential consuming. To is steep and the flat site processes separately, the computation suits contour and suits the use similar 3D bias the region, and may use the spiral way, in very little lifts the cutting tool way which the knife in the situation produces optimizes, obtains the better surface quality. In the high speed processing, certainly must adopt the circular arc to cut into, to cut the connection way, as well as the circular arc transition, avoids changing the cutting tool to enter suddenly for the direction, the prohibition use direct under knife connection way, avoids burying the cutting tool the work piece. When processes the mold cavity, should avoid the cutting tool vertical insertion work piece under, but should use inclines the knife

way (commonly used angle of bank for 20°~30°), best uses the screw type under knife by to reduce the cutting tool load. When processes the mold core, should under the knife then level cut into the work piece as far as possible first from the work piece. The cutting tool cuts into, cuts when the work piece should use as far as possible inclines the type (or round arc-type) cuts into, cuts, vertically avoids cutting into, cutting. Uses climbs up the type cutting to be possible to reduce the cutting heat, reduces the cutting tool stress and the work hardening degree, improves the processing quality.

2. Half precision work

The mold half precision work essential target is causes the work piece outline shape smoothly, surface finish remainder even, this especially is important regarding the tool steel mold, because it will affect time the precision work cutting tool layer of cutting area change and cutting tool load change, thus influence cutting process stability and precision work surface quality.

The rough machining is based on the volume model, the precision work then is based on the face mold. Before develops CAD/The CAM system to the components geometry description is not continual, after because has not described in front of the rough machining, the precision work processes the model the average information, therefore the rough machining surface surplus processing remainder distribution and the great surplus processing remainder is unknown. Therefore should fifty-fifty the precision work strategy carry on the optimization after to guarantee half precision work the work piece surface has the even surplus processing remainder. The optimized process includes: After the rough machining the outline computation, the great surplus processing remainder computation, the biggest permission processing remainder determination, is bigger than the biggest permission processing remainder the profile district (for example transition radius and so on scoop channel, corner is smaller than rough machining cutting tool radius region) as well as when half precision work the knife heart path computation to the surplus processing remainder and so on.

The existing mold high speed processes CAD/The CAM software has the surplus processing remainder analysis function mostly, and can act according to the surplus processing remainder the size and the distribution situation uses the reasonable half precision work strategy. After like the MasterCAM software provided has tied the shape milling (Pencil milling) and the surplus milling (Rest milling) and so on the method eliminates the rough machining the surplus processing remainder big quoin by to guarantee the following

working procedure even processing remainder.

3. Precision work

The mold high speed precision work strategy is decided by the cutting tool and the work piece contact point, but the cutting tool and the work piece contact point but changes along with the processing surface curved surface slope and the cutting tool effective radius change. Regarding by the complex curved surface processing which many curved surface combination but becomes, should carry on the continuous treating as far as possible in a working procedure, but is not carries on the processing separately to each curved surface, by reduces lifts the knife, under the knife number of times. However, because processes the superficial slope change, if only defines the processing the side to eat the knife quantity (Step over), possibly creates on the slope different surface the actual step of distance non-uniformity, thus influence processing quality.

In the ordinary circumstances, the precision work curved surface radius of curvature should be bigger than the cutting tool radius 1.5 times, by evades the no admittance to the direction suddenly transformation. In the mold high speed precision work, when each time cuts into, cuts the work piece, enters for the direction change should as far as possible use the circular arc or the curve switches over, avoids using the straight line to switch over, by maintains the cutting process the stability.

Fifth, concluding remark

The high-speed cutting technology is one of machining technology main development directions, at present mainly applies in the automobile industry and the mold profession, in the processing complex curved surface domain, work piece itself or the cutting tool system rigidity request high processing domain and so on, is the many kinds of advanced processings technology integration in particular, its is highly effective high grade, esteems for the people. It not only involves to the high speed processing craft, moreover also includes high speed processes the engine bed, the numerical control is systematic, the high-speed cutting cutting tool and CAD/CAM technology and so on. The mold high speed processing technology generally has applied at present in the developed country mold manufacturing industry, but still waited for in our country's application scope and the application level the enhancement, because it had the tradition to process the incomparable superiority, still will be the next processing technology inevitable development direction.

模具高速铣削加工技术

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摘 要 介绍了高速铣削在模具加工中的应用以及影响，并简要的介绍了高速铣削机床的结构、控制系统和刀具。对高速加工的工艺进行了简单的分析。

关键词 高速铣削；模具加工

一、 前言

在现代模具生产中，随着对塑件的美观度及功能要求得越来越高，塑件内部结构设计得越来越复杂，模具的外形设计也日趋复杂，自由曲面所占比例不断增加，相应的模具结构也设计得越来越复杂。这些都对模具加工技术提出了更高要求，不仅应保证高的制造精度和表面质量，而且要追求加工表面的美观。随着对高速加工技术研究的不断深入，尤其在加工机床、数控系统、刀具系统、CAD/CAM 软件等相关技术不断发展的推动下，高速加工技术已越来越多地应用于模具型腔的加工与制造中。

数控高速切削加工作为模具制造中最为重要的一项先进制造技术，是集高效、优质、低耗于一身的先进制造技术。相对于传统的切削加工，其切削速度、进给速度有了很大的提高，而且切削机理也不相同。高速切削使切削加工发生了本质性的飞跃，其单位功率的金属切除率提高了 30%~40%，切削力降低了 30%，刀具的切削寿命提高了 70%，留于工件的切削热大幅度降低，低阶切削振动几乎消失。随着切削速度的提高，单位时间毛坯材料的去除率增加了，切削时间减少了，加工效率提高了，从而缩短了产品的制造周期，提高了产品的市场竞争力。同时，高速加工的小量快进使切削力减少了，切屑的高速排出减少了工件的切削力和热应力变形，提高了刚性差和薄壁零件切削加工的可能性。由于切削力的降低，转速的提高使切削系统的工作频率远离机床的低阶固有频率，而工件的表面粗糙度对低阶频率最为敏感，由此降低了表面粗糙度。在模具的高淬硬钢件(HRC45~HRC65)的加工过程中，采用高速切削可以取代电加工和磨削抛光的工序，从而避免了电极的制造和费时的电加工，大幅度减少了钳工的打磨与抛光量。对于一些市场上越来越需要的薄壁模具工件，高速铣削也可顺利完成，而且在高速铣削 CNC 加工中心上，模具一次装夹可完成多工步加工。

高速加工技术对模具加工工艺产生了巨大影响，改变了传统模具加工采用的“退火→铣削加工→热处理→磨削”或“电火花加工→手工打磨、抛光”等复杂冗长的工艺流程，甚至可用高速切削加工替代原来的全部工序。高速加工技术除可应用于淬硬

模具型腔的直接加工(尤其是半精加工和精加工)外，在 EDM 电极加工、快速样件制造等方面也得到了广泛应用。大量生产实践表明，应用高速切削技术可节省模具后续加工中约 80%的手工研磨时间，节约加工成本费用近 30%，模具表面加工精度可达 1 m，刀具切削效率可提高 1 倍。

二、 高速铣削加工机床

高速切削技术是切削加工技术的主要发展方向之一，它随着 CNC 技术、微电子技术、新材料和新结构等基础技术的发展而迈上更高的台阶。由于模具加工的特殊性以及高速加工技术的自身特点，对模具高速加工的相关技术及工艺系统(加工机床、数控系统、刀具等)提出了比传统模具加工更高的要求。

1. 高稳定性的机床支撑部件

高速切削机床的床身等支撑部件应具有很好的动、静刚度，热刚度和最佳的阻尼特性。大部分机床都采用高质量、高刚性和高抗张性的灰铸铁作为支撑部件材料，有的机床公司还在底座中添加高阻尼特性的聚合物混凝土，以增加其抗振性和热稳定性，这不但可保证机床精度稳定，也可防止切削时刀具振颤。采用封闭式床身设计，整体铸造床身，对称床身结构并配有密布的加强筋等也是提高机床稳定性的重要措施。一些机床公司的研发部门在设计过程中，还采用模态分析和有限元结构计算等，优化了结构，使机床支撑部件更加稳定可靠。

2. 机床主轴

高速机床的主轴性能是实现高速切削加工的重要条件。高速切削机床主轴的转速范围为 10000~100000m/min，主轴功率大于 15kW。通过主轴压缩空气或冷却系统控制刀柄和主轴间的轴向间隙不大于 0.005mm。还要求主轴具有快速升速、在指定位置快速准停的性能(即具有极高的角加减速度)，因此高速主轴常采用液体静压轴承式、空气静压轴承式、热压氮化硅（Si3N4）陶瓷轴承磁悬浮轴承式等结构形式。润滑多采用油气润滑、喷射润滑等技术。主轴冷却一般采用主轴内部水冷或气冷。

3. 机床驱动系统

为满足模具高速加工的需要，高速加工机床的驱动系统应具有下列特性：

(1) 高的进给速度。

研究表明，对于小直径刀具，提高转速和每齿进给量有利于降低刀具磨损。目前常用的进给速度范围为 20~30m/min，如采用大导程滚珠丝杠传动，进给速度可达

60m/min；采用直线电机则可使进给速度达到 120m/min。

(2) 高的加速度。

对三维复杂曲面廓形的高速加工要求驱动系统具有良好的加速度特性，要求提供高速进给的驱动器(快进速度约 40m/min，3D 轮廓加工速度为 10m/min)，能够提供 0.4m/s2 到 10m/s2 的加速度和减速度。

机床制造商大多采用全闭环位置伺服控制的小导程、大尺寸、高质量的滚珠丝杠或大导程多头丝杠。随着电机技术的发展，先进的直线电动机已经问世，并成功应用于 CNC 机床。先进的直线电动机驱动使 CNC 机床不再有质量惯性、超前、滞后和振动等问题，加快了伺服响应速度，提高了伺服控制精度和机床加工精度。

4. 数控系统

先进的数控系统是保证模具复杂曲面高速加工质量和效率的关键因素，模具高速切削加工对数控系统的基本要求为：

a. 高速的数字控制回路(Digital control loop)，包括：32 位或 64 位并行处理器及 1.5Gb 以上的硬盘；极短的直线电机采样时间。

b. 速度和加速度的前馈控制(Feed forward control)；数字驱动系统的爬行控制(Jerk control)。

c. 先进的插补方法(基于 NURBS 的样条插补)，以获得良好的表面质量、精确的尺寸和高的几何精度。

d. 预处理(Look-ahead)功能。要求具有大容量缓冲寄存器，可预先阅读和检查多个程序段(如 DMG 机床可多达 500 个程序段，Simens 系统可达 1000~2000 个程序段)，以便在被加工表面形状(曲率)发生变化时可及时采取改变进给速度等措施以避免过切等。

e. 误差补偿功能，包括因直线电机、主轴等发热导致的热误差补偿、象限误差补偿、测量系统误差补偿等功能。 此外，模具高速切削加工对数据传输速度的要求也很高。

f. 传统的数据接口， 如 RS232 串行口的传输速度为 19.2kb，而许多先进的加工中心均已采用以太局域网(Ethernet)进行数据传输，速度可达 200kb。

5. 冷却润滑

高速加工采用带涂层的硬质合金刀具，在高速、高温的情况下不用切削液，切削效率更高。这是因为：铣削主轴高速旋转，切削液若要达到切削区，首先要克服极大的离心力；即使它克服了离心力进入切削区，也可能由于切削区的高温而立即蒸发，冷却效果很小甚至没有；同时切削液会使刀具刃部的温度激烈变化，容易导致裂纹的

产生，所以要采用油/气冷却润滑的干式切削方式。这种方式可以用高压气体迅速吹走切削区产生的切削，从而将大量的切削热带走，同时经雾化的润滑油可以在刀具刃部和工件表面形成一层极薄的微观保护膜，可有效地延长刀具寿命并提高零件的表面质量。

三、 高速切削加工的刀具

刀具是高速切削加工中最活跃重要的因素之一，它直接影响着加工效率、制造成本和产品的加工精度。刀具在高速加工过程中要承受高温、高压、摩擦、冲击和振动等载荷，高速切削刀具应具有良好的机械性能和热稳定性，即具有良好的抗冲击、耐磨损和抗热疲劳的特性。高速切削加工的刀具技术发展速度很快，应用较多的如金刚石(PCD)、立方氮化硼(CBN)、陶瓷刀具、涂层硬质合金、(碳)氮化钛硬质合金 TIC(N)等。

在加工铸铁和合金钢的切削刀具中，硬质合金是最常用的刀具材料。硬质合金刀具耐磨性好，但硬度比立方氮化硼和陶瓷低。为提高硬度和表面光洁度，采用刀具涂层技术，涂层材料为氮化钛(TiN)、氮化铝钛(TiALN)等。涂层技术使涂层由单一涂层发展为多层、多种涂层材料的涂层，已成为提高高速切削能力的关键技术之一。直径在 10~40mm 范围内，且有碳氮化钛涂层的硬质合金刀片能够加工洛氏硬度小于 42 的材料，而氮化钛铝涂层的刀具能够加工洛氏硬度为 42 甚至更高的材料。高速切削钢材时，刀具材料应选用热硬性和疲劳强度高的 P 类硬质合金、涂层硬质合金、立方氮化硼（CBN）与 CBN 复合刀具材料（WBN）等。切削铸铁，应选用细晶粒的 K 类硬质合金进行粗加工，选用复合氮化硅陶瓷或聚晶立方氮化硼（PCNB）复合刀具进行精加工。精密加工有色金属或非金属材料时，应选用聚晶金刚石 PCD 或 CVD 金刚石涂层刀具。选择切削参数时，针对圆刀片和球头铣刀，应注意有效直径的概念。高速铣削刀具应按动平衡设计制造。刀具的前角比常规刀具的前角要小，后角略大。主副切削刃连接处应修圆或导角，来增大刀尖角，防止刀尖处热磨损。应加大刀尖附近的切削刃长度和刀具材料体积，提高刀具刚性。在保证安全和满足加工要求的条件下，刀具悬伸尽可能短，刀体中央韧性要好。刀柄要比刀具直径粗壮，连接柄呈倒锥状，以增加其刚性。尽量在刀具及刀具系统中央留有冷却液孔。球头立铣刀要考虑有效切削长度，刃口要尽量短，两螺旋槽球头立铣刀通常用于粗铣复杂曲面，四螺旋槽球头立铣刀通常用于精铣复杂曲面。

四、 模具高速加工工艺

高速加工包括以去除余量为目的的粗加工、残留粗加工，以及以获取高质量的加工表面及细微结构为目的的半精加工、精加工和镜面加工等。

1. 粗加工

模具粗加工的主要目标是追求单位时间内的材料去除率，并为半精加工准备工件的几何轮廓。高速加工中的粗加工所应采取的工艺方案是高切削速度、高进给率和小切削用量的组合。等高加工方式是众多 CAM 软件普遍采用的一种加工方式。应用较多的是螺旋等高和等 Z 轴等高两种方式，也就是在加工区域仅一次进刀，在不抬刀的情况下生成连续光滑的刀具路径，进、退刀方式采用圆弧切入、切出。螺旋等高方式的特点是，没有等高层之间的刀路移动，可避免频繁抬刀、进刀对零件表面质量的影响及机械设备不必要的耗损。对陡峭和平坦区域分别处理，计算适合等高及适合使用类似 3D 偏置的区域,并且可以使用螺旋方式,在很少抬刀的情况下生成优化的刀具路径,获得更好的表面质量。在高速加工中，一定要采取圆弧切入、切出连接方式，以及拐角处圆弧过渡，避免突然改变刀具进给方向，禁止使用直接下刀的连接方式，避免将刀具埋入工件。加工模具型腔时,应避免刀具垂直插入工件,而应采用倾斜下刀方式(常用倾斜角为 20°~30°)，最好采用螺旋式下刀以降低刀具载荷。加工模具型芯时，应尽量先从工件外部下刀然后水平切入工件。刀具切入、切出工件时应尽可能采用倾斜式(或圆弧式)切入、切出，避免垂直切入、切出。采用攀爬式切削可降低切削热，减小刀具受力和加工硬化程度，提高加工质量。

2. 半精加工

模具半精加工的主要目标是使工件轮廓形状平整，表面精加工余量均匀，这对于工具钢模具尤为重要，因为它将影响精加工时刀具切削层面积的变化及刀具载荷的变化，从而影响切削过程的稳定性及精加工表面质量。

粗加工是基于体积模型，精加工则是基于面模型。以前开发的 CAD/CAM 系统对零件的几何描述是不连续的，由于没有描述粗加工后、精加工前加工模型的中间信息，故粗加工表面的剩余加工余量分布及最大剩余加工余量均是未知的。因此应对半精加工策略进行优化以保证半精加工后工件表面具有均匀的剩余加工余量。优化过程包括:粗加工后轮廓的计算、最大剩余加工余量的计算、最大允许加工余量的确定、对剩余加工余量大于最大允许加工余量的型面分区(如凹槽、拐角等过渡半径小于粗加工刀具半径的区域)以及半精加工时刀心轨迹的计算等。

现有的模具高速加工 C A D /CAM 软件大都具备剩余加工余量分析功能，并能根据剩余加工余量的大小及分布情况采用合理的半精加工策略。如 MasterCAM 软件提供了

束状铣削(Pencil milling)和剩余铣削(Rest milling)等方法来清除粗加工后剩余加工余量较大的角落以保证后续工序均匀的加工余量。

3. 精加工

模具的高速精加工策略取决于刀具与工件的接触点，而刀具与工件的接触点随着加工表面的曲面斜率和刀具有效半径的变化而变化。对于由多个曲面组合而成的复杂曲面加工，应尽可能在一个工序中进行连续加工，而不是对各个曲面分别进行加工，以减少抬刀、下刀的次数。然而，由于加工中表面斜率的变化，如果只定义加工的侧吃刀量(Step over)，就可能造成在斜率不同的表面上实际步距不均匀，从而影响加工质量。

一般情况下，精加工曲面的曲率半径应大于刀具半径的 1.5 倍，以避免进给方向的突然转变。在模具的高速精加工中，在每次切入、切出工件时，进给方向的改变应尽量采用圆弧或曲线转接，避免采用直线转接，以保持切削过程的平稳性。