

HIGH SPEED MACHINING (HSM) – THE EFFECTIVE WAY OF MODERN CUTTING

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Summary: In this study the idea of HSM (High Speed Machining) including some different definitions, is presented. The requirements referred to the machine tools, tools and machining data are defined. Some examples of milling cases are described. Some economical advantages of productivity, accuracy in terms of tool and toolholder unbalancing are discussed.

1 Introduction

Machining with high speeds (HSM) is one of the modern technologies, which in comparison with conventional cutting enables to increase efficiency, accuracy and quality of workpieces and at the same time to decrease costs and machining time [9].

Even though High Speed Machining is known for a long time (first tries were made in early twenties of the past century) there are still a lot of questions and less or more complicated definitions of HSM.

The first definition of HSM was proposed by Carl Salomon in 1931. He has assumed that at a certain cutting speed which is 5 –10 times higher then in conventional machining, the chip tool interface temperature will start to decrease (Fig. 1).

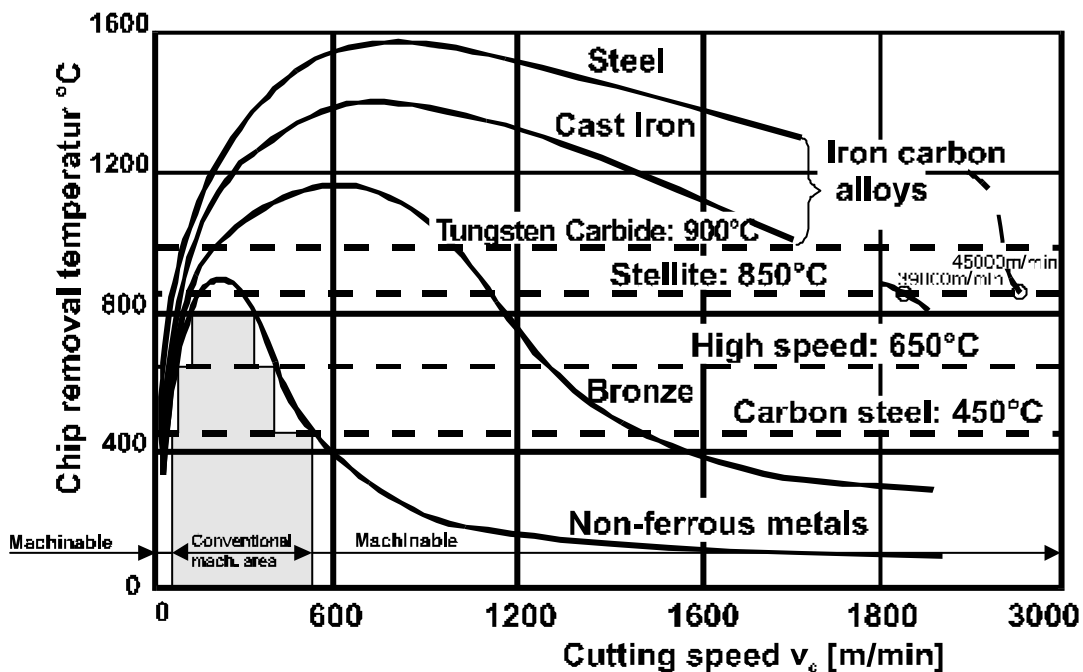


Fig 1. Temperature as a function of cutting speed [2, 9].

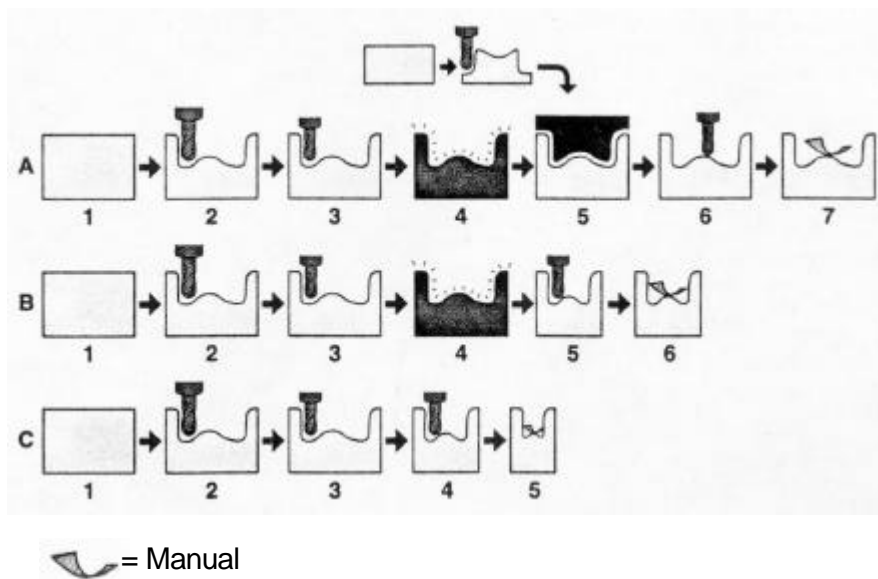
It is not possible to verify this theory to its full extent based on recent experimental results. There is a relative decrease of the temperature at the cutting edge that starts at certain cutting speeds for different materials. Actually there are many different ways to define HSM, upon them HSM is said to be [2]:

- ?? high cutting speed machining (v_c),
- ?? high rotational speed machining (n),
- ?? high feed machining (v_f),
- ?? high speed and feed machining,
- ?? high productive machining.

Practically, it can be noted that HSM is not simply high cutting speed. It should be regarded as a process where the operations are performed with very specific methods and production equipment [2]. HSM is not only machining with high spindle speed because many applications are performed with conventional spindle speeds. HSM is often used in finishing in hardened steels with both high speeds and feeds. HSM can be called rather the High Productive Machining when machining components in roughing to finishing and also in finishing to super-finishing in components of all sizes.

2 Applications of High Speed Machining

The use of HSM allow us to shorten the production time and to increase the accuracy of machined parts. High Speed Machining is being mainly used in three industry sectors due to their specific requirements [1].



- A) Traditional process. Non-hardened (soft) blank (1), roughing (2) and semi-finishing (3). Hardening to the final service condition (4). EDM process – machining of electrodes and EDM of small radii and corners at big depths (5). Finishing of parts of the cavity with good accessibility (6). Manual finishing (7).
- B) Some process as (A) where the EDM-process has been replaced by finish machining of the entire cavity with HSM (5). Reduction of one process step.
- C) The blank is hardened to the final service condition (1), roughing (2), semi-finishing (3) and finishing (4). HSM most often applied in all operations (especially in small sized tools). Reduction of two process steps. Normal time reduction compared with process (A) by approximately 30 – 50%.

Fig. 2. Improvement of production process when using HSM [2].

The first category is industry which deals with machining aluminum to produce automotive components, small computer parts or medical devices [1, 4, 10, 11]. This industry needs fast metal removal, because the technological process involves many machining operations.

The second category which is aircraft industry involves machining of long aluminum parts, often with thin walls [1, 4, 10, 11].

The third industry sector is the die mould industry which requires dealing with finishing of hard materials [2]. In this category it is important to machine with high speed and to keep high accuracy. In this industry HSM is used for machining such parts as [2]:

Die casting dies. This is an area where HSM can be utilized in a productive way as most castings dies are made of demanding tool steels and have a moderate or small size.

Forging dies. Most forging dies are suitable for HSM due to their complex shape. The surface is very hard and often prone to cracks.

Injection moulds and blow moulds are also suitable for HSM, because of their small sizes. Which makes it economical to perform all operations in one set up.

Milling of electrodes in graphite and copper. It is an excellent area for HSM. Graphite can be machined in a productive way with Ti(C,N), or diamond coated solid carbide endmills.

Modelling and prototyping of dies and moulds. is one of the earliest areas for HSM. Easy to machine materials such as non-ferrous, for example aluminum are used. The cutting speeds are often as high as 15 000 – 50 000 [rpm] and the feeds are also very high.

Using of the HSM in the above mentioned regions can cause the reduction of production process when electrode milling ECM and EDM. HSM ensures a dimensional tolerance of 0,02 mm, while the tolerance when using ECM is 0,1 – 0,2 [mm] and EDM 0,01 – 0,02. Replacing ECM with machining causes the durability and tool life of the hardened die or mould is increased considerably.

3 Some recommended parameters for HSM

There are some critical parameters for HSM, as for instance the depth of cut. The cutting tool manufacturers provide recommendations regarding the machining parameters that should be used [7]. Those parameters are usually one of many operating windows [7] (applicable sets of parameters).

An increase of cutting speed to HSM values give several benefits such as enlarging of the removal rate and improving of the final surface (Fig. 3).

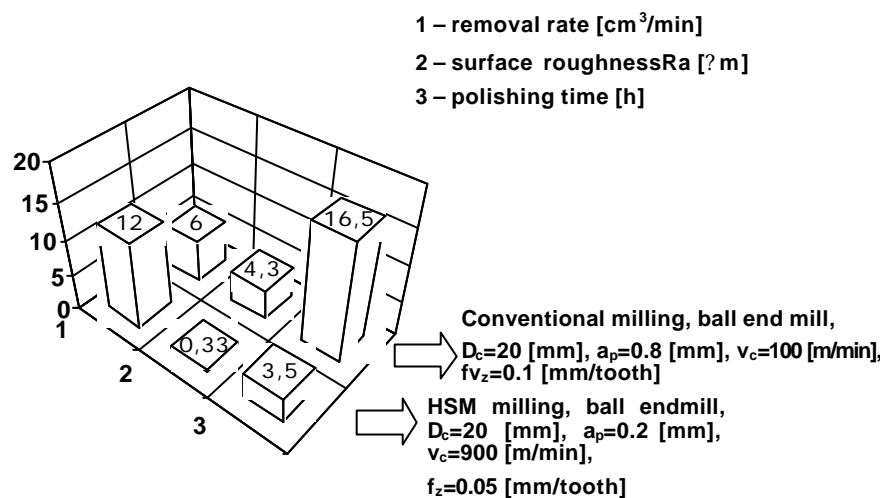


Fig. 3. Comparison of production indexes during machining of a punch [3, 6, 8].

Below there is a comparison of speeds used during machining some selected materials using conventional and HSM methods (Tab. 1).

Table 1. Conventional vs. High Speed Machining [1].

Work material		Solid Tools (end mills, drills) <i>WC, coated WC, PCD, ceramic</i>		Indexable Tools (shell mills, face mills) <i>WC, ceramic, sialon, CBN, PCD</i>	
		Typical cutting speed [m/min]	High cutting speed [m/min]	Typical cutting speed [m/min]	High cutting speed [m/min]
aluminum		>305 (<i>WC, PCD</i>)	>3050 (<i>WC, PCD</i>)	>610	>3658 (<i>WC, PCD</i>)
cast iron	soft	152	366	366	1219 (<i>sialon, ceramic</i>)
	ductile	107	244	244	914 (<i>ceramic</i>)
steel	free mach. steel	107	366	366	610
	alloy	76	244	213	366
	stainless	107	152	152	274
	hardness HRC65	24	122	30 (<i>WC</i>) 91 (<i>CBN, ceramic</i>)	46 (<i>WC</i>) 183 (<i>CBN, ceramic</i>)
titanium		38	61	46	91
superalloy		46	76	84 (<i>WC</i>) 213 (<i>sialon</i>)	366 (<i>sialon, ceramic</i>)

As it was pointed out before HSM is mainly used in die mold industry. Below some typical cutting data for machining of die are selected in Tables 2 and 3.

Table 2. Typical cutting data for solid carbide end mills with Ti(C,N) or TiAlN – coating in hardened steel: (HRC 54 – 58) [2].

Type of processing	v_c [m/min]	a_p [%] *	a_e [%]*	f_z [mm/tooth]
Roughing	100	6 – 8	35 – 40	0,05 – 0,1
Semi – finishing	150 – 200	3 – 4	20 – 40	0,05 – 0,15
Finishing and Super-finishing	200 – 250	0,1 – 0,2**	0,1 – 0,2**	0,02 – 0,2

* % of the cutter diameter, ** [mm]

Table 3. HSM cutting data by experience (R – roughing, F – finishing) [2].

Material*	Hardness	v_c [m/min]		
		Conv.	HSM – R	HSM – F
Steel 01.2	150 HB	<300	>400	<900
Steel 02.1/2	330 HB	<200	>250	<600
Steel 03.11	300 HB	<100	>200	<400
Steel 03.11	39 – 48 HRC	<80	>150	<350
Steel 04	48 – 58 HRC	<40	>100	<250
GCI 08.1	180 HB	<300	>500	<3000
Aluminum	60 – 75 HB	<1000	>2000	<5000
Non-ferr.	100 HB	<300	>1000	<2000

* according to Coromant Material Classification (CMC)

During dry milling with those machining parameters compressed air or oil mist under high pressure is recommended.

4 Toolholder and tool – unbalancing problem

The elements of the machine – tool subsystem that determine efficiency of high speed machining are: spindles, axes, motor drivers, toolholders and cutting tools. The spindle is probably the most critical element [1], so to maintain maximum productivity and accuracy it is important to ensure the run-out as small as possible. The smaller the run-out is, the shorter is the time between changing inserts in a milling cutter.

Especially in HSM applications the size of run-out is crucial for accuracy [1, 5]. The Total Indicator Readout (TIR) should be maximum 10 microns at the cutting edge [2]. Every 10 microns in added run-out gives 50% reduction of tool life. Even if the tool, toolholder, and spindle are precisely balanced, there still can be several sources of instability. One of the sources of instability is the fit between toolholder and spindle interface. There is often a measurable clearance in this grip. Moreover, it also may be a chip or dirt inside the taper.

In practice, an endmill run at 20 000 rpm may not need to be balance to any better than 20 gmm, and 5 gmm is generally appropriate for much higher speeds. The Fig. 5 refers to unbalance force relating to the tool and adapter weight of 1.2 kg. [2]

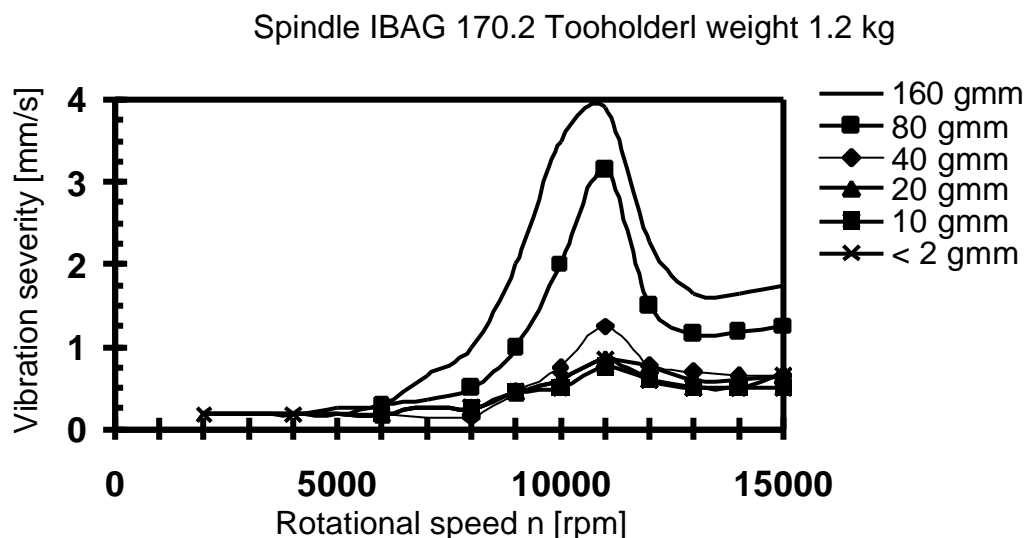


Fig. 4. Unbalance vs. vibration severity at bearing [2].

It is very difficult to balance the tool perfectly, so for the optimal balance is usually accepted the point beyond which further improvements in tool balance do not improve the accuracy or surface finish of the workpiece.

The tool unbalance acceptable for the process is determined by the cutting forces in the cut, the balance condition of the machine, and the range in which these two aspects of process affect each other.

5 Machine tools for HSM – requirements

Even though high speed spindle options for conventional machining centers has been available for some time, it is only recently that machine tool designers and engineers have been developing the machines for HSM. As it was noted previously, HSM requires fitting of many parameters specified in Table 4, which are connected with the machine tools. Below are some typical demands on the machine tool and the data transfer in HSM (ISO/BT40 or comparable size, 3 – axis).

Table 4. Demands on the machine tool and the data transfer [2].

?? Spindle speed range ≤ 40 000 rpm	?? Circular interpolation via NURBS (no linear increments)
?? Spindle power > 22 kW	?? High thermal stability and rigidity in spindle – higher pretension and cooling of spindle bearings
?? Programmable feed rate 40 – 60 m/min	?? Air blast/coolant through spindle
?? Rapid travels < 90 m/min	?? Rigid machine frame with high vibration absorbing capacity
?? Axis dec./acceleration > 1g (faster w. linear motors)	?? Different error compensations – temperature, quadrant, ball screw are most important
?? Block processing speed 1 – 20 ms	?? Advanced look ahead function in the CNC
?? Data flow via Ethernet 250 kbit/s (1 ms)	
?? Increments (linear) 5 – 20 μm	

6 Machining methods for the die and mould manufacturing

Practically, HSM is used to reduce the costs of workpiece production. Such a case takes place when machining press dies or moulds. As it is known dies consist of cavities in various shapes, with the dimensions and numerous radii sizes of corners. As an example methods for machining of a cavity below are described.

Based on experience, or other production information, the surface machined, can be split up in segments. Each segment can be machined with one set of insert edges. This technique can be used both for roughing and finishing. It gives several benefits, namely [2] :

- better machine tool utilisation – less interruptions, less manual tool changing,
- higher productivity, i.e. easier to optimise cutting data,
- better cost efficiency – optimisation vs. real machine tool cost per hour,
- higher die or mould geometrical accuracy, which means the finishing tools can be changed before getting excessive wear.

6.1. Methods for machining a cavity

There are several methods used for machining the cavity.

One of them is to pre-drill of a starting hole. Corners can be pre-drilled as well. This method is not recommendable, because a special tool is needed. When the cutter breaks through the pre-drilled holes in the corner, the variations in the cutting forces and temperature appear negative from a cutting point of view. When using pre-drilled holes the re-cutting of chips also increases, (Fig. 5).



Fig. 5. Example of machining a cavity with predrill a starting hole [2].



Fig. 6. Example of machining with a ball nose endmill [2].

In the second method a ball nose end mill is applied. Thus it is common to use a peck-drilling cycle to reach full axial depth of the cut and then mill the first layer of the cavity. This is repeated until the cavity is finished as shown in Fig. 6 [2].

One of the best methods is linear ramping in X/Y and Z to reach a full axial depth of the cut [2]. The inclination can start both from in to out or from out to in. It depends on the geometry of the die or mould. The main problem is how to evacuate of the chips in the best way. Down milling should be done with a continuous movement and continuous cutting. It is important to approach with ramping movement or even better with even circular interpolation, during changing to a new radial depth of cut. (Fig. 7)

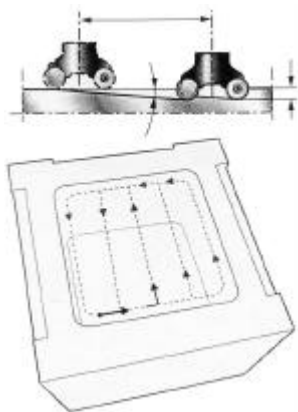


Fig. 7. Example of machining with linear ramping [2].

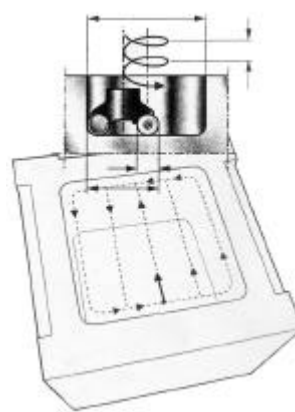


Fig. 8. Example of machining with ramping capacity [2].

The last method is effective when using round insert cutters or end mills with a ramping capacity. The best choice it is to take the first axial depth of cut using circular interpolation in helix the rest of machining goes as in the previous point. (Fig. 8)

7 Conclusion

Hard competition causes rapid development of the machining technology and design of new solutions. High Speed Machining is proposed as an example. HSM ensures high metal removal rates, boost productivity, improve surface finish and eliminates the need of coolant. In spite of high requirements of machining tools, HSM gives numerous benefits. It allows to shorten the production

time and eliminates some treatment (e.g. manual finishing) beside simultaneously retaining the accuracy. These advantages are decisive for the use of HSM for machining the press dies. Even though HSM has been known for a long time, the research are still being developed for further improvement of quality and minimization of costs.

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