FIVE AXIS MACHINING SUPPORTED BY ULTRASOUND – DMG ULTRASONIC 20 LINEAR

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Abstract

Technology of ultrasonic machining and machining supported by ultrasound enables to machine materials, which are either not possible to machine or very hard to machine by conventional technologies of machining. The article deals with mentioned synopsis, examples of technology exploitation and DMG Ultrasonic 20 Linear machining centre description. Machining centre is a part of Centre of Excellence of 5-axis Machining at Faculty of Materials Science and Technology in Trnava. Machining centre is designed for research on technological possibilities of both five axis and ultrasonic machining. Facts inscribed in this article take into account main parameters of the machine and optional equipments.

Key words

ultrasound, machining, five-axis machining, HSC

Introduction

Ultrasonic machining or more precisely machining supported by ultrasound is considered as a new, perspective technology at nowadays. Technology set-out stretch back to the half of 20th century. As a first is good to clarify basic notions and facts e.g. what is ultrasound. Ultrasound is a mechanical vibration or more scientifically wave motion of the environment. Wave motion is a state of environment when its periodical change is driven by vibration and energy transfer is provided without the material transfer. According to this fact, transfer of ultrasound vibration is possible only in environmental determinants contrary to electromagnetic wave motion which can be transferred also in vacuum. As ultrasonic is wave motion concerned when the frequency value is over 20 kHz. To reach such a high vibration, magnetostrictive and piezoelectric transducers are used.

Original concept of ultrasonic machining so-called USM (Ultrasonic Machining) or USIG (Ultrasonic Impact Grinding) developed in the fifties of last century is based on the principle of removing small particles of material in mechanical base. The tool (material properties suitable for wave motion transfer are necessary) is shaped negatively to the creating hole. Between the tool and a work piece, the suspension consists of liquid, usually water or petroleum and abrasive particles e.g. diamond, siliceous carbide, boride carbide, CNB

or aluminum oxide is to be found. Longitudinal vibration of the tool with frequency value over 20 kHz and amplitude of 5 to 80 μm together with its impression to the work piece provides energy transfer between the tool and abrasive particles in the suspension. The feed rate is about 20 to 50 mm/min. Kinetic energy affords high acceleration to the abrasive particles whom rams the work pieces surface and therefore impact of the particle ejects small amount of material. This process is repeated periodically in selected frequency. Due to particles small size, relatively small material removal is achieved which provides very high accuracy comparative to grinding with surface roughness of 0,2 μm.

Based on USM process, RUM (Rotary Ultrasonic Machining) process was developed in sixties of 20th century. The main difference between each other is that in RUM process the tool beside vibration also rotates along its longitudinal axe however, without a suspension between the tool and a work piece. First machine tools of this type were built on the base of standard lathe construction. The work piece was held in chuck and rotated and the tool moved translational and vibrated with specific frequency. The further development leads to the construction of conventional driller with ultrasonic generator added. This concept allowed machining non-rotational work pieces and increasing accuracy. As a tool the diamond disc (similar to diamond grinding wheel) was used. Compared to USM, RUM process provides higher accuracy, better surface roughness and higher material removal rate.

Technology used on DMG Ultrasonic 20 Linear issues from RUM and USM. Basic principle of RUM is enhanced by five axis machining centre with implemented ultrasonic generator which provides translational axial vibration motions of the tool. The tool consists of a shank and diamond abrasive particles on working length of the tool which preserves material removal. Contrary to USM process, cutting fluid do not have any influence to the material removal, it is used only to cool the process and remove chips as well as in conventional machining. Rotating tool vibrates axially on frequency of 25 kHz and material removal is achieved by its feed to the work piece. The main progress of technology used in DMG Ultrasonic machine in comparison to other ultrasonic technologies is that of use five axis milling machine. It allows to machine freeform surfaces with ultrasonic machining technology. The technology conception is still in research and the first machines are more like prototypes than current machining tools. Therefore research in this field of technology renders large amount of possibilities and perspectives.

Technology application

Usage of technology of machining supported by ultrasound results from its technology conditions. As a first it is important to notify that wave motion diffusion is possible only in environmental determinants and depends on its properties. Energy transfer of oscillating particles is better in solids than in fluids or gases due to its molecular structure. Values of solidity, elastic modulus and absorption are different in dependency of material structure and causes absorption of ultrasonic wave motion. Soft and tough materials have higher coefficient of absorption than hard and brittle ones. According to that, machining with ultrasonic wave motion is effective to utilize in hard and brittle materials machining. In general it can be said that usage of ultrasonic machining is valid for machining materials with hardness more than 40 HRC [2]. There are materials such as nonmetallic materials like glass, porcelain, graphite, carbon-fibers, fiberglass, ceramics (Al_2O_3, SiO_2, ZrO_2, Si_3N_4, SiC, SiN, MnO), quartz, ruby, sapphire as well as tool steel or titanium [1, 2].

Ultrasonic machining is suitable for all kinds of industry in which above mentioned materials are used. In automotive industry it can be used in production of body and frame made of carbon fiber composites, electronic components made of ceramics, hybrid bearings

made of Si_3N_4, mats for heated seats made of silicon and ceramics, cylinder head gaskets and high-pressure pumps made of zirconium oxide, fiberglass cables for the central lighting supply, mould tools made of magnesium-stabilized zirconium oxide, gearwheels made of compound ceramics, etc [1]. Huge spread out and utilization of ultrasonic technology it can be found in an optical industry. It is used to produce highly precise laser rods for YAG-lasers, mirror mounts with narrow ligaments made of zerodur, rod lenses made of glass, corundum or silicon for scanner systems and endoscopes as well as for classical geometries such as concave or convex lenses. In semiconductor industry the technology can be used for machine materials such as silicon carbide, silica glass and ceramics for its ability to achieve high surface qualities (Ra=0,2 μm) and making of miniature bores of diameter of 0,5 mm. At least but not last usage of ultrasonic technology can be found in production of medical equipments e.g. components for magnetic resonance, endoscopes, ceramic adjustment ring for use in X-ray devices furthermore in production of hip-joint ball made of compound ceramics, dental bridge made of zirconium oxide, etc. [1]. With rising utilization of hard to machine materials it can be assumed that technology of ultrasonic machining usage will rise and will conquest other fields of industry.

DMG Ultrasonic 20 Linear

Fig. 1. *DMG Ultrasonic 20 Linear machining centre [2]*

Machining centre DMG 20 Ultrasonic Linear is based on five axis machining centre structure by Gildemeister p.l.c., DMG (Deckel Maho Gildemeister). Ultrasonic generator and technology of ultrasonic machining was developed by Sauer Ltd. as well as tools for ultrasonic assisted machining. Sauer Company became a member of Gildemeister group in 2002. Machine's philosophy issues from standard 3-axis milling machine tool where 4th and 5th axes are added by rotating table. Moves along axes X, Z, Y are realized by spindle and moves along A and C axes, which are rotational, provide the table. Feeds are driven by linear magnetic engines. Usage of this type of engines guarantees very high accuracy of positioning and continuousness of movements in comparison to conventional engines. To avoid vibration transfer between machine and its environment the machine is placed on concrete stands which preserve absorption of vibration. DMG Ultrasonic 20 Linear is equipped with high speed spindle USB 40. The spindle's maximum rotational speed value is 42000 min^{-1}. Maximum feed rates are up to 40 m/min. According to stated values High Speed Machining (HSC) is possible. For ultrasonic milling maximum rotational speed are in range

of 8-10000 min^{-1}. The limitation of speed is due to different clamping system for HSC and ultrasonic machining. Spindle is equipped with HSK 32 E/S tool clamping system with both internal and outer cooling. Internal cooling is provided by IKZ system, which contains of a tube in the tool holder. Air cooling is not allowed for ultrasonic machining due to small particles of removed material, which can broke the spindle, drivers or some critical parts of engines. Standalone coolant device WK 331/3 with power of 3kW is used for the spindle. Ultrasonic generator works in range of 17,5 to 48 kHz with amplitude of 5- 80 μm in dependence of the tool and work piece's material used. Mentioned frequency range allows selecting optimal cutting parameters for each tool and material. Control of the generator is fully integrated into the control system. Basic technical parameters of DMG Ultrasonic 20 Linear are shown in Tab. 1.

TECHNICAL PARAMETERS OF DMG ULTRASONIC 20 LINEAR Table 1

Parameter	**Unit**	**Value**
Traverse paths		
X axis	mm	200
Y axis	mm	200
Z axis	mm	280
A axis	°	-10 – 130
C axis	°	360
Drives		
Spindle	type	USB 40
Rotational speeds ultrasonic up to	min^{-1}	10000
Rotational speeds conventional up to	min^{-1}	42000
Torque	Nm	6
Power (42000 min^{-1})	kW	15
Positioning accuracy	μm	±2,5
Feed range up to	mm/min	Max. 40000
Rapid traverse (X, Y, Z)	m/min	40
Rotational speed of rotary axes (A, C)	min^{-1}	200
Ultrasonic		
Frequency	kHz	17,5 – 48
Ultrasound generator	type	USG2000
Equipment		
Tool clamping system	type	HSK 32 E/S
Tool magazine	pockets	24
Tool measurement	type	BLUM Laser P87
Work piece measurement	type	Renishaw OMP 400
Cooling device	type	Sauer KMA 300
Thermal clamping device	type	Bilz ISG 2200
Tools		
Max. diameter	mm	Ø 40
Max. length	mm	200
Max. weight	kg	1
Work table		
Clamping area	mm	Ø190
Max. work piece weight	kg	10
Control		
DMG ControlPanel		Siemens 840 D

Machining centre equipment and devices

3D touch probe Renishaw OPM 400 is specified to work piece measurement. Data transfer between the probe and the machine is covered by usage of infrared light system consists of a transmitter in the probe and a transceiver in the machine. According to that the probe can move easily with no limitation due to signal cable and manipulation with probe is simpler. Control of the probe and measurement process is fully integrated to the control system of a machine, where the controlling screen is created. Measured data are then transferred to machine directly and for example setting the start point on a work piece is more easily. In fact there is no needs to calculate for the operator, the system sets start point of a coordinate system automatically in that position where the probe currently is with accuracy of 0,001 mm. Technical parameters of a touch probe Renishaw OMP 400 are shown in Tab. 2.

TECHNICAL PARAMETERS OF A TOUCH PROBE RENISHAW OMP 400 Table 2

Parameter	Unit	Value
Weight (with batteries)	g	262
Measurement direction		±X ±Y +Z
Measurement accuracy	µm	0,25
Measurement speed	mm/min	10 – 100
Measurement static force value	N	axe Z: 2,55 plane X,Y: 0,06
Communication system	type	OMI, OMI-2

Laser tool measurement device Blum Laser Control NT P87.0634-030.305 L is installed in the space of tool magazine and it is designed to automatic measurement of tool's parameters such as diameter and length. The measurement of a tool is possible only for tools clamped in spindle. Control of a device is fully integrated to controlling system of a machine and to operate easily there are users cycles. Choice of a cycle depends of the tool and parameters going to measure. Before tool measurement it is necessary to enter informative values of diameter and length of the tool and number of measurement (standard number of measurement is 3). Blum laser control works on laser interferometer principle. Maximum values of tool diameter and length are shown in Tab. 3

TECHNICAL PARAMETERS OF LASER MEASUREMENT DEVICE BLUM LASER CONTROL Table 3

Parameter	Unit	Value
Max. tool diameter	mm	Ø 30
Max. tool length	mm	200

Cooling device Sauer KMA 300 BAF with cutting fluid filtering provides cooling and filtering of the fluid. Device is equipped with a system of pumps and a 300 liters tank. Technical parameters are shown in Tab. 4.

COOLING DEVICE SAUER KMA 300 BAF TECHNICAL PARAMETERS Table 4

Parameter	Unit	Value
Power	kW	17
Tank capacity	l	300
Min. flow rate	l/min	20
Max. flow rate	l/min	80
Min. pressure	bar	0,5
Max. pressure	bar	40

Oil smog separator is a device used to steam exhausting which is rising from the cutting fluid during machining and cooling. It consists of pumps and a condensing tank, where the steam is condensing to fluid. The fluid is then driven back to the cooling system of a machine.

Thermal tool clamping device Bilz ThermoGrip ISG2200 works on the basis of induction heating of clamping adapter HSK 32/64 E. In dependence of chosen equipment, tools with diameter range between 3-20 mm of the shank are able to clamp. System of thermal clamping allows to machine with high rotational speeds i.e. high speed machining. Some of the important parameters are show in Tab. 5.

BILZ THERMOGRIP ISG2200 TECHNICAL PARAMETERS Table 5

Parameter	Unit	Value	Type designation
Power	kW	8	
Weight	kg	25	
Tool holder	type	HSK 32	T3-W/HSK32
Cooling adapter	mm	Ø 6-9	T3-K/6-9
Measurement adapter	mm	Ø 6	T3-M 0600

Work piece clamping system Erowa ITS 100 P is a special pneumatic system of work piece clamping installed on the milling center's table. The „chuck" is installed on the table and other devices like vice, table, fixative and positioning jigs are then clamped to the chuck with pressure of 5 bar.

Control system Siemens Sinumerik 840D Powerline works on modular platform. Therefore adding new subsystems is able. DMG Ultrasonic 20 Linear is equipped with 5-axis version of control system and ultrasonic generator control. Except that, probe and laser measurement users interface is imported. Control system allows to create an NC code for both 3- and 5-axis machining by using cycles for drilling and milling. Simulation is possible for all tool paths created or imported, view modes for 2D and 3D simulation are included. Simulation is possible to zoom in and zoom out as well as slow-down or speed it up. Interpolation covers huge range of curve types, from circles, spirals, helical or B-splines to NURBS curves. According to that, product's shape is very close to the CAD model.

Control system is based on Windows XP and Linux operation system allowing direct access to LAN and Internet. Automatic system updates, errors diagnostics and fixes are than easy to do without operator intervention. Beside network access, four USB ports are available in the control panel.

DMG Net service represents online service for Gildemeister p.l.c. customers. In case of emergency it is possible to connect to the internet and online technician in co-operation with operator is able to diagnose and solve current problem.

Conclusion

Technology of machining with ultrasound support, in the form of its application on machine DMG Ultrasonic 20 Linear, represents a progressive machining method of brittle and hard to machine materials. Achieved values of accuracy and surface quality ranks the machining with ultrasound support among the top of cutting machining technologies. Resulting from above mentioned parameters, machining with very low tolerances is possible and parameters of surface roughness are similar to parameters achieved by grinding.

In year 2009 on Faculty of Materials Science and Technology of Slovak University of Technology the Centre of Excellence of 5-axis Machining was established with aim of utilize the faculty´s potential and fill the faculty´s bearing with research realization in mentioned field. In the frame of project the faculty obtains two 5-axis milling machines and one lathe with counter spindle, among them machining centre DMG Ultrasonic 20 Linear. Besides possibility of 5-axis machining and high speed machining, the machining centre offers research realization in the field of new, progressive technology of cutting machining: machining with ultrasound support.

Properties, parameters and possibilities of technology and machine briefly summarized in the paper creates broad field of action for research activities. Centre of Excellence of 5-axis Machining on Faculty of Materials Science and Technology of Slovak University of Technology in Trnava represents one of the top workplaces with high perspective in research and development not only in Slovakia and surrounding countries in the field of machining of hard to machine materials, research on possibilities of 5-axis machining and research on high speed machining.

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Technical parameters of the devices were extracted from manuals and user guides. On the basis of that, the tables were created.