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High precision machining on high speed machines

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ABSTRACT

Purpose: Modern Machines for precision products for three dimensional machining have by milling over 20.000 rpm. Differences between hard and soft machining have influences on concept of machines. Stiffness and rigidity are characteristics and variables which caused the precision and quality of machined part.
Design/methodology/approach: This paper introduce some of interesting modern machine tools with different concept as DCG (Drive in Centre of Gravity - Mori Seiki), LAF (Look Ahead Function on machine - Sodick), high speed 20.000 – 60.000 rpm, linear drive, etc. The way from idea to machined part will be shown.
Findings: To achieve high precision it is necessary to fill out many request function on machine. Results on machined part depend also from machined material (hardness, structure, size of crystals).
Research limitations/implications: Engineers job is to prepare the optimal CNC (PNC) program on connection of CAD – CAM software's. After all mentioned factor test work piece is machined and measured.
Originality/value: Comparison between results data on plan and measurement shows us the reality and give us decision around high precision product.
Keywords: Manufacturing and processing; Machining; High speed machine tools; Precision machining; Precise products; Soft machining; Hard machining

1. Introduction

Some specifics of modern machine tool are included over modules, as rotation table, precise high RPM spindle, bar magazine, tools magazine, work pieces magazine, laser zero point measurement system, cutting forces dynamometer for diagnostic of process, frequencies sensor, acoustic sensors, etc., [1]. To connect all modules in working action, the machine computer must be excellent. Software's in computer as NN (Neural Network), GA (Genetic Algorithm), GP (Genetic Programming), LAF (Look Ahead Function), are assuring all time in machining process optimal cutting parameters [2], [3]. Many of producers of cutting machine tools all over of the world provide machines in idle level of precision. To achieve precision production we need high level of machine quality. The highest quality caused also high price of machine. Top level ob machine price are 500.000 to 1.000.000 euros for more then three axis machine. 3axis milling machines and turn machines with driven tools are under 400.000 euros.

Classical machining on little older machines - no modern high speed, is also very useful in individual production or in tool making industries. The prices of mentioned machines are under 200.000 euros. They are also mostly not able to achieve HS region. HS region is defined with more of elements, which will be shown in some of next chapter of this paper. 3D gravures polishing is very special job for achieving low surface roughness. Its time consumption technology, mostly handy made. That for it has to be automated with driven polishing tool and minimize with choice of special cutting technology. To ensure it is necessary to choice ball nose cutter, low depth of cut, small feed rate and very high speed. After technology are important maters software and controllers, where is include huge knowledge around complex optimization of cutting condition on base of self-learning controller [4,5]. Automaticaly federate minimization is very usefull before finishing and polishing closing surfaces by 3D dies and moulds.

2. Specifics of modern cutting machine tools

Mentioned modules are also adaptable. Rotation table is more effective in the case of automated clamping device for work piece. Design and workmanship was realized [6]. Figure 1 shows schematically concept to connect hydraulically control on clamping device - above. Below part of figure shows machine cell, powered and control over air and hydraulic medium.

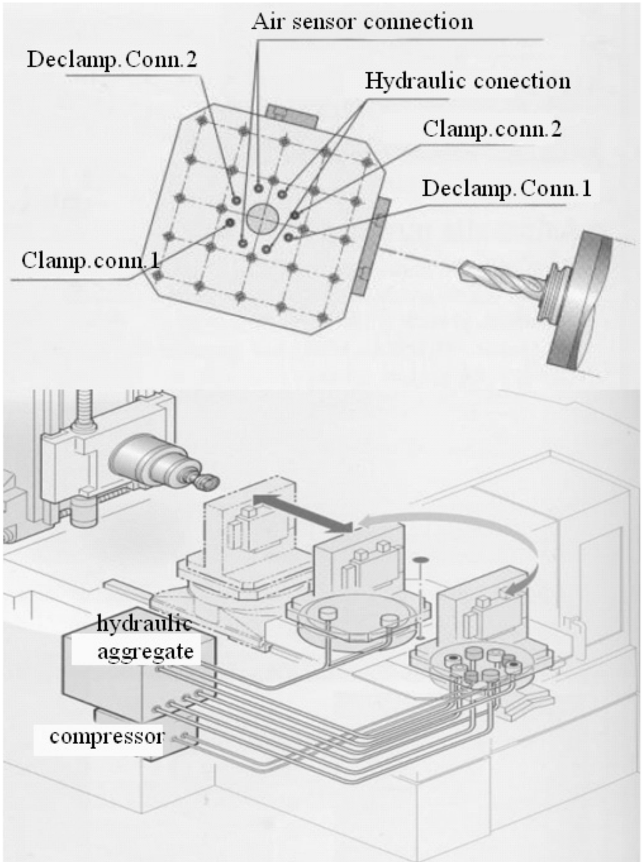

Fig.1. Schematically present of medium flow from source to palette on milling machine

High productive are turn machines, which are shared in modern classical system on 60 support bed degree as horizontal and new concept of vertical turn machine, Figure 2. With driven tools equipped and both side spindle turn machine is high productive. With added axis as Z1, Z2 and C1, C2 is production 5-7x higher as on conventional lathe [7].

Vertical turn machine is also new concept of intensive machining, where the chips have better flow away versus horizontal principle. On Figure 2 is concept with below the spindle with work piece. It is possible also opposite; to be spindle above and the cutting tools are moving over revolver and cascade tool clamping system. Machine like this is more rigid, more precise and high productive.

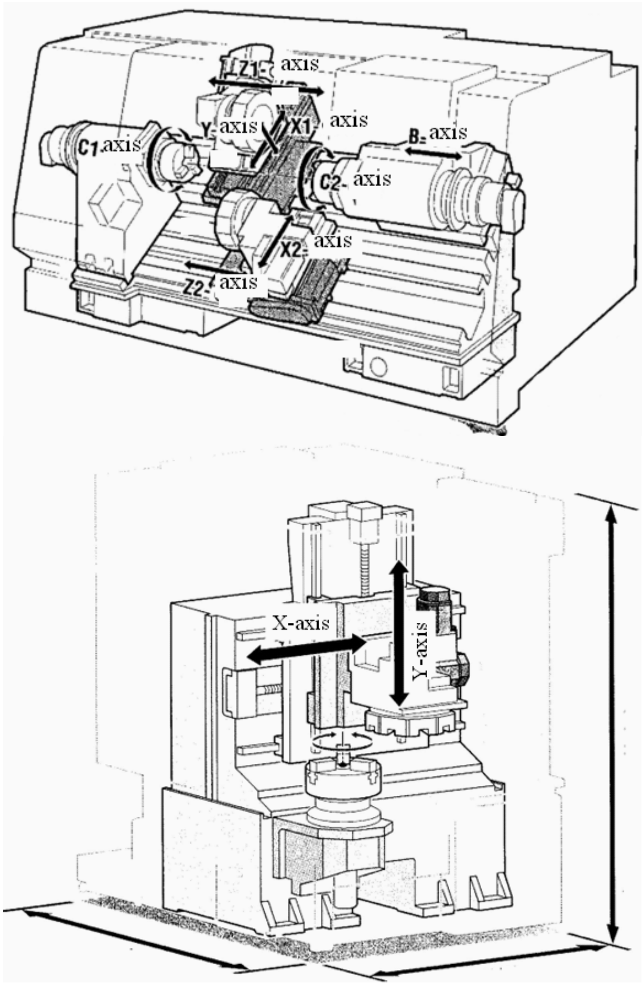

Fig. 2. Horizontal turn machine tool with two revolvers, auxiliary spindle and Y axis and vertical turn machine tool

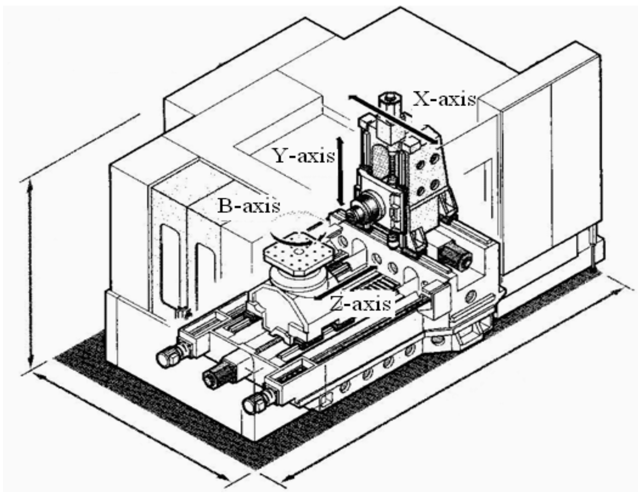

Fig. 3. Robust horizontal machining centre

Robust horizontal machining centre, Figure 3 shows rough concept of modules and structure more axis machine. B axis is so called axis nr.4. It gives possibility of complex shapes of 3D work piece. Machine is also more exacting and it is necessary to prepare effective programming engineer of machining. Simple managing from low educated worker gives not optimal machining time and also higher production costs.
The latest turn machine bed is under angle 60 degrees. Angle like this on Figure 4, Figure 5 gives optimal solution for assumption of cutting force components [8]. The vibrations are limited and chips flow is regulated as well. Schematically introduce below shows two spindles, two revolvers and driven cutters. With opposite side machining in same time make forces compensations.

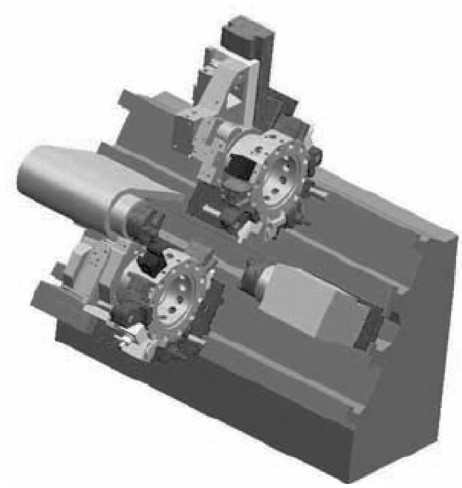

Fig. 4. Basic structure of horizontal lathe with two revolvers and auxiliary spindle

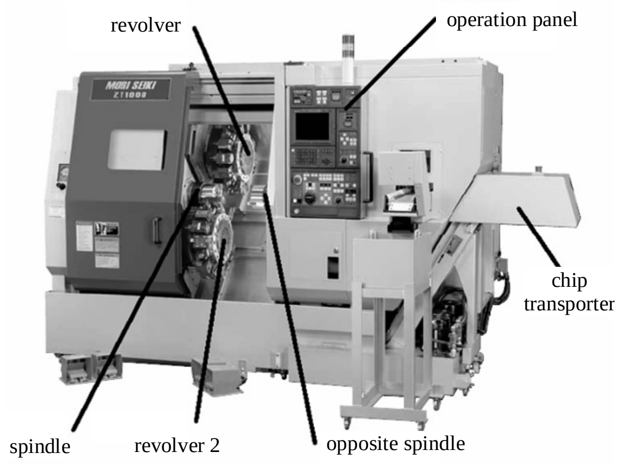

Fig. 5. Basic structure of horizontal lathe with two revolvers and opposite spindle

Step more and the last model is multi axes machine. It is basically turn machine with all possible modules and axis. With right and left side of spindle is possible to finish the product on the same machine without logistics, double positioning and clamping. Milling spindle produce the shapes in complexity versus classical production on 7 different machines.

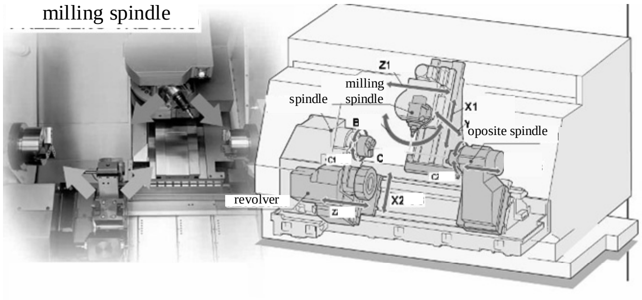

Fig. 6. Multi axis turn- machining centre

Working principles and controller of modern machine collect modules as shows Figure 7. Classical control was NC, after then CNC, but new one is CPU unit. All segments are connected with fast internet bus connection. High power electro motors are AC concept, digital servo motors.

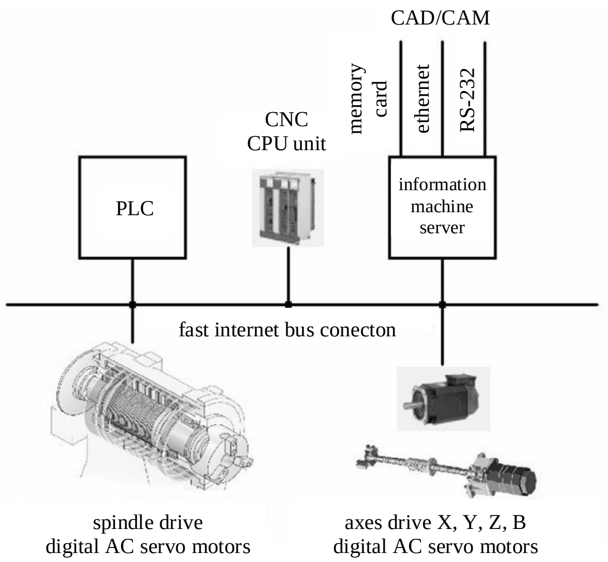

Fig. 7. Working principle of modern machine tool with CNC control with CPU technology

3. Precision machining; theory and principles

Fine machining can be done on more ways, as classical fine cutting, smooth machining, rolling and finishing. Classical way was cutting with sharp cutting edge and small feed rate. Smooth machining is modern way of cutting with big radius R on cutting edge. Fed rate is huge and remove rate is 8 x bigger. It is very important from view of machining time for achieve required surface roughness, Figure 8.

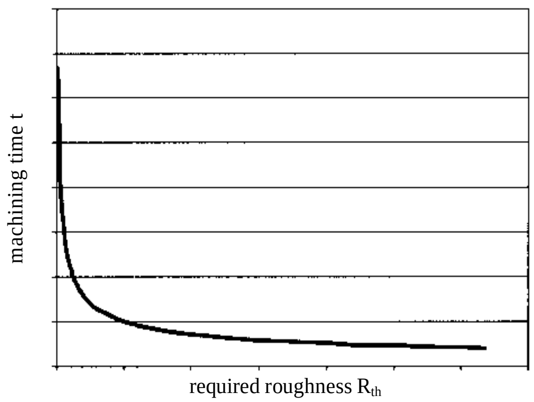

Fig. 8. Surface roughness quality versus machining time

Cutting tool material has important influence on work piece surface roughness. Especially type of coating as TiN, TiCN, TiAlN caused lower toll wear, Figure 9. As result of minimal toll wear is toll life to achieve criteria of cutting edge changing. Movic as soft cutting caused good sliding phenomena, better tribology contact and better surface roughness. Ra achieved with mentioned tolls is significant lower as by inserts of tungsten carbides.

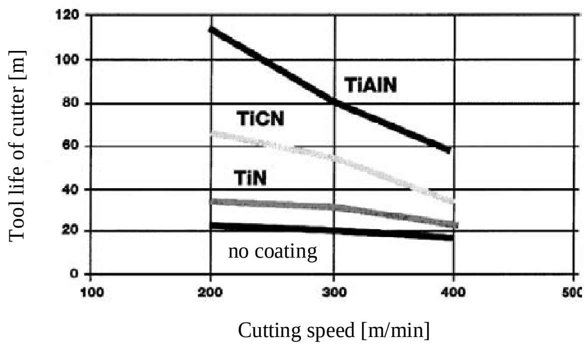

Fig. 9. Tool life of milling cutter carbide cutting tool material with different coatings

Ball nose milling cutter is ideal cutting tool for fine machining. Phenomena of that pencil milling tools is possibility to cut work piece hardness to 62 HRc. Producers of cutting tools are able to produce diameter of cuter 0.5 mm with two flutes. Every cutting edge is very sharp and has very precise cutting angles. After machining time the cutting edges are weared, Figure 10. Normal, theoretical wear is on flutes, but middle part of cutter, it means central part can has also some breakages [9]. The reason is in smaller cutting speed, where BUE is assist able [10].

Tool wear and tool life depends of used cutting tool materials and Nr. of passes of tool over the machined surface. Tool wear W or VB is the best by coating TiAlN/TiN [11], Figure 11.

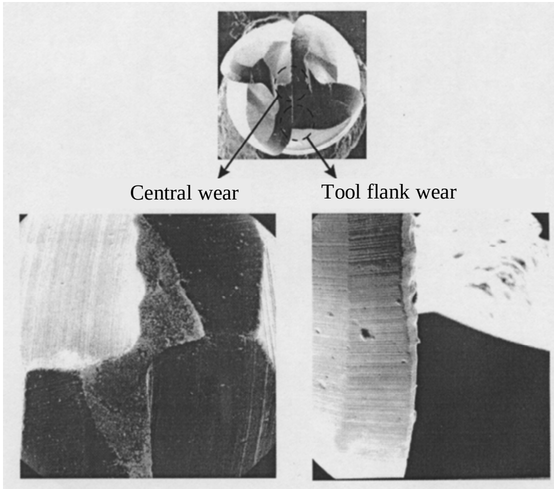

Fig. 10. Different wear shapes on the pencil milling ball end nose

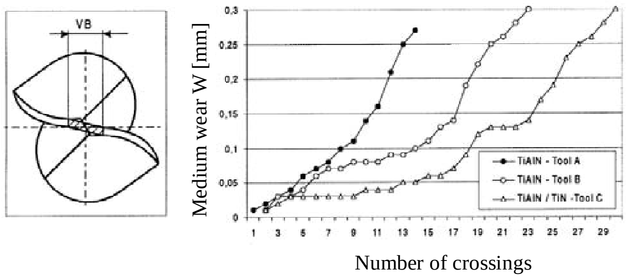

Fig. 11. Toll wear diagram based on middle of cutter

After more experiments we carried out optimal solution for precise machining: It is multilayer coatings with last layer of TiN [12], which has very low tribological coefficient. Toll wear is minimal, as shows Figure 12. Normally the parameters of cutting must be defined as a= 0.1mm, f=0.05mm and cutting speed v = 150 - 200 m/ min. By small cutter diameter it is possible to achieve only on HS machine, which has 20.000 to 40.000rpm [13].

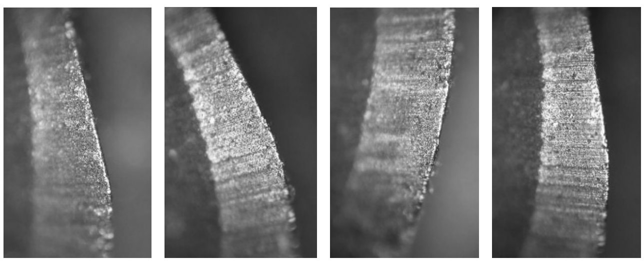

Fig. 12. Tool wears on cutting edge

Figure 13 shows toll wear of the free surface on the rounded tip of the milling tool which is quite big. The break down of the cutting edge is visible on the rounded tip of the milling tool. It is the case of wrong decision of machining parameters. Feed rate in this case was too high. To achieve bigger material remove is not feed rate right solution. It must stay small. Only with higher cutting speed we achieve bigger removal chip volume.

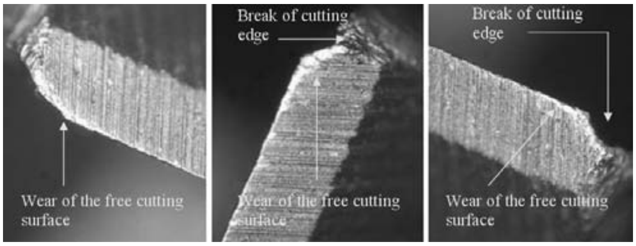

Fig. 13.Toll wear on cutting edge by pencil cutter – bed case

4. Polishing

Last step by finishing of machined surface is polishing. It is useful only in the case, when geometry shape is not request to be in tolerances over 2 µm. Polishing is very time consumption and using driven hand polishing tools is request. On this way polishing time is shorter, because vibrant power on polishing segment helped as well. Figure 14 shows last fine machining on closing surface by mould tool. With combination of precise milling, the polishing time was shorted from 16 hours to 3 hours.

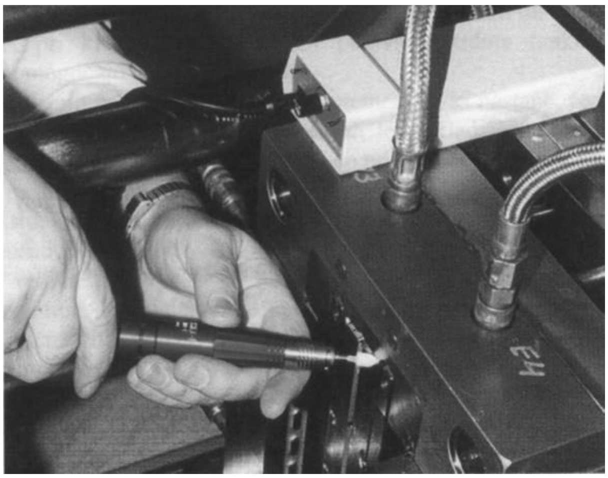

Fig. 14. Hand polishing of work piece with driving tool

Using different diamante polishing gel help also to shorter the polishing time. Different gels are using for different materials. Hardness of polished surface and Ra request different size of diamante cons. Gel fluid and his viscosity is influencing on intensively/time of polishing, Figure 15.

Fig. 15. Diamante polishing gel

As mentioned above, vibrations powered polishing tools are very effective. Figure 16 shows polishing device with ultrasound powering frequency. It means from 14 to 21 KHz. Movements as this one can be danger for surface in case, when worker is not really concentrated on his obligation. Force on device has to be very gently in another case the surface can be damage over preheating, what caused recrystalization of surface layer.

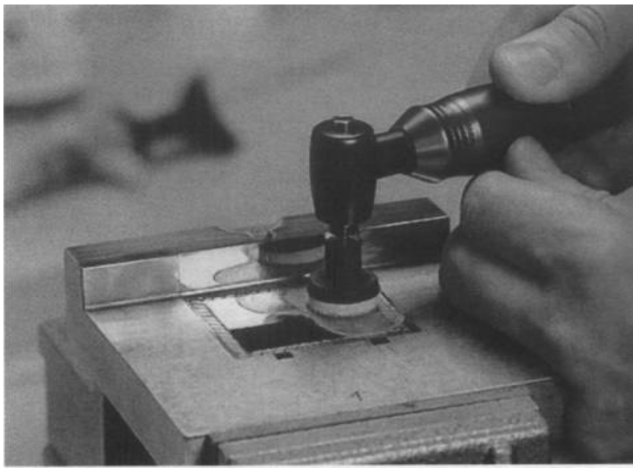

Fig. 16. Hand/driven/polishing of work piece with ultrasound device

5. Case study of precise and ability of machine Sodick

Machining case study was carried out over the mould work piece product. Figure 17 shows schematically actions, which are necessary to achieve requested shape of product. As first was done design over one of CAD program. Input of design is new or old part with some changes. In that case RE Reverse Engineering is right way for quick preparing of CNC program. After CAD is CNC program created over CAM software. Missing is still jet post processing, where is for every machine tool controller a little bit another.

Case of modern turn machine with integration of many modern modules shows Figure 18. Work pieces magazine is on left and strong control system is on right side of machine centre. Very right is toll magazine.

Fig. 17. Flow chard of CAD- CAM strategy [14]

Fig. 18. HSC machining centre Sodick MC430L

As we mentioned before many modern modules are include in SODICK machine centre. To explain one of them could be interesting, especially, because for soft machining is very important high feed rate speed. These characteristics ensure linear drive motor. The base is AC (Asynchrony) electromotor principle; develop from rotation on linear shape. Permanent magnets are located as linear »rotor« in the shape as magnet plate. Housing part of electromotor is connected to electricity power and control system. On this way is possible positioning very precise and very fast in every point of moving area. All three axes have separate linear drive systems. Table is driven on Y axis, X and Z axis is feed rate system for spindle

Next test was done on machining of request part. Some significant shapes, dimensions and tolerances were prepared on design map over CAD. Figure 19 shows also interesting surface raster, which is more and more modern as especial surface design on product. 3D design shows different shapes of medical tablets. Many similar shapes on machined product are requested. That for cutting technology must be optimizing. The program on machine makes quick change of tools. As case we will describe on cutting operation. Tool changer choice ball cutter for tablet holes design. Main spindle is moving with fast feed rate velocity between tool magazine, zero point measuring system and machining work piece. Technological parameter of cutting request on spindle 28.000 rpm to achieve over the diameter of cutter optimal cutting speed. Machining feed rate is 800 mm/min - 2300 mm/min, depend of request of fine or precise machining. Some of specifics on machined surface show Figure 20 and 21. Pocked shapes shown on Figure 21 are excellent precise machining, in this case is hand polishing no more interesting, because Ra = 0.2 µm.

After machining polishing must be applied to achieve better surface roughness quality. With different cutting parameters and use no worn tool is possible to get surface Ra = 0.5 µm. Normally after this hand polishing is not necessary.

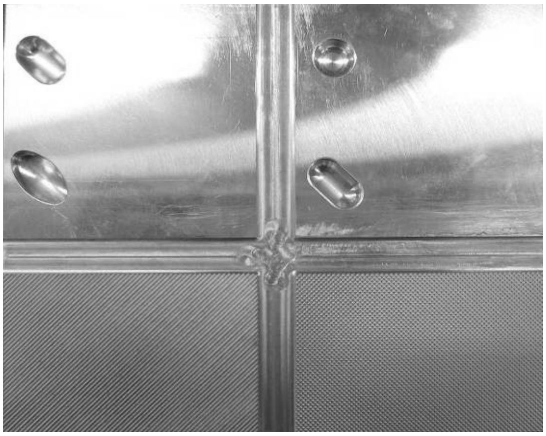

Fig. 20. Specifics on machined surface

To generate raster is interesting for pharmacy. Al moulds are designed for tablets packing.

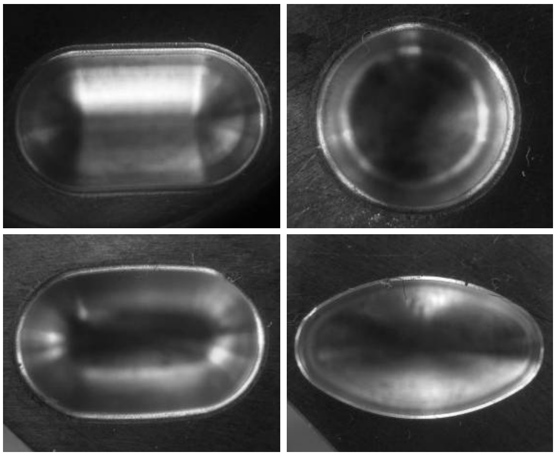

Fig. 21. Specifics on machined surface

Every producer of machine tool gets also characteristics at machine as quality certificate. Precision of dimension is possible to control on all axes. As case we will show measurement rectangularity of spindle, versus milling table. The best and very precise measuring equipment was used by measurement, because micrometers were measured. Producer of machine guarantee is value of 0.007 mm in both axes X, Y. By producer SODICK were measured value in X axis 0.004 mm. In our Laboratory LABOD - Faculty of Mechanical Engineering, University Ljubljana, we got better results; it is 0.002 mm in both axes. Figure 22 shows in diagram all mentioned values.

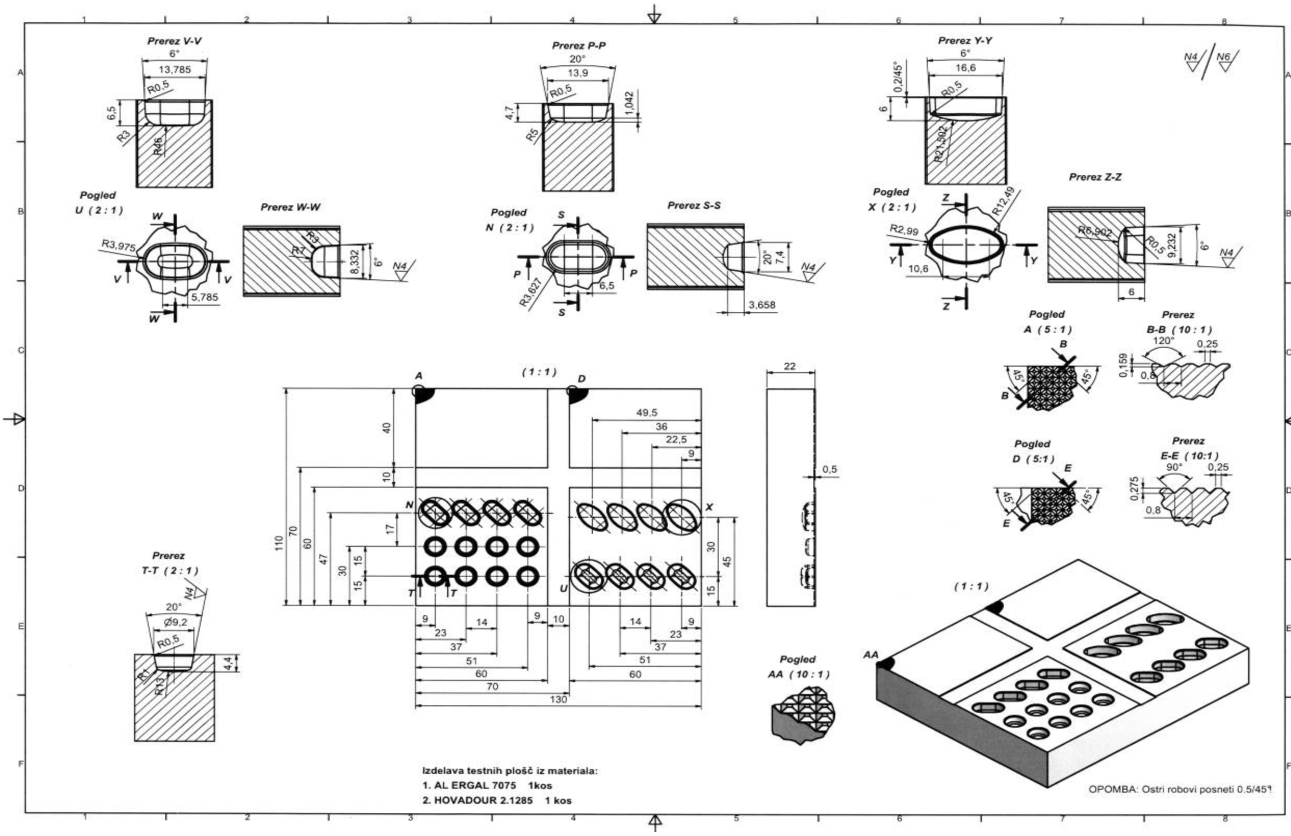

Fig. 19. Design of test product-case study

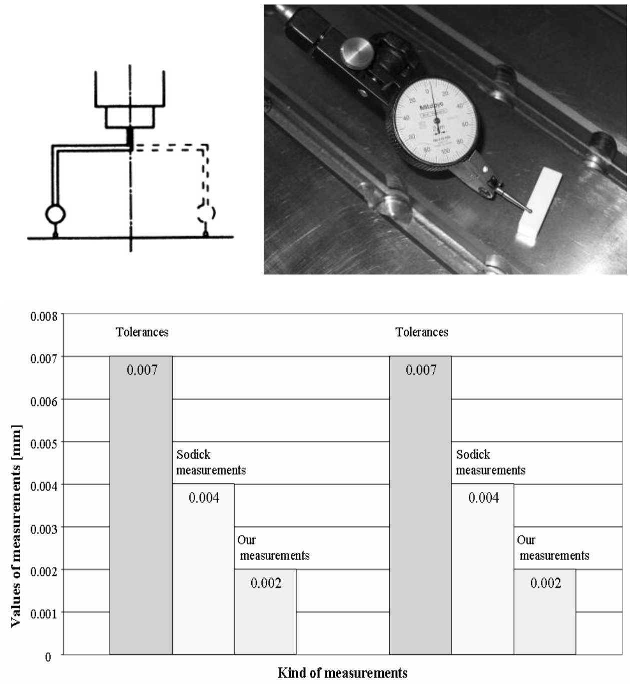

Fig. 22. Rectangularity between spindle and table of milling machine

6. Conclusions

Modern hybride production based on systematically self optimization of technological cutting parameters. First of all are precise high speed machine tools, which is on the top level of strategy pyramid.

The reduction of machining time, necessary in die and mould tool finishing has been achieved by modern high-speed milling with elements of fine machining and polishing. Time of adjusting the closing die surface is approximately reduced by 15% in comparison with classical finishing approach. For correction value of 0.05 mm the software calculates a little too big correction of the cutter. In this it is better to include in action a 5-axes machine tool. Very narrow tolerances of closing surface and fast production (short cycle time of Al-alloys injection molding) dictate additional die function, which is to vacuum close the engrave. Using experiments and measurement of deflection, we will additional extend the technological data bank. With more and better data it will be possible to use CAM programming for much shorter hand finishing for adjusting closing die surfaces.

In Automotive industry, part materials are chosen or developed to able to operate at specific mechanical and thermal conditions encountered in service and at the same time maintain their machinability characteristic to ensure economical aspects of used material. Machining of test materials generates high temperatures at the cutting edge, which impair the performance of cutting tool materials. Commercially available cutting tool materials can only be used at moderate speed conditions. Superior tool material such as CBN is capable of producing high quality components at higher cutting speed. Like all tool materials their tool life is limited by extreme temperature and/or pressure generated at the cutting interface. Since all tool materials lose their hardness at higher cutting conditions, there is a genuine need to harness technologies tailored specifically to minimising the temperature generated at the tool-work piece and tool–chip interfaces. In machining technology optimization, machined parts customer requirements must be taken into account. In machining of automotive parts, surface quality, tolerances and productivity are the most specified customer requirements, where major indication of surface quality on machined parts are surface roughness and burr appearance.

Improving performance of available cutting tools, not only very hard and expensive CBN tools but also coated carbide inserts with TiAlN + TiN have significant influence on effective cutting technology [15], [16]. In future machining of soft and hard materials at higher speed conditions can therefore be improved by a combination of appropriate tool material, machining technique and the choice of suitable cutting tool geometry.

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