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perspective technologies,
manufacturing, simulation,
High Speed Machining

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HIGH PERFORMANCE MANUFACTURING DEVELOPMENT STRATEGIES IN AVIATION INDUSTRY

Foresight as modern planning tool. „Clean Sky" project will effect in creating new technologies, which usage in aviation will improve fast progress of technique. The paper indicates the newest technologies or technologies which will develop in about 25 years. Aircraft industry future technologies for Polish conditions have been discussed. List of perspective technologies for aviation and engineering industry has been described. These technologies may be developed in Poland to increase economy competitiveness. New revolutionary materials for aviation industry have been presented. Machine tool technologies, especially Computer Numerical Control (CNC), High Speed Machining (HSM) have emerged as effective mechanisms in the aerospace, automotive, and die and mould industries. These new technologies are attractive for competitive manufacturing because of their technical advantages, i.e. a significant reduction in lead-time, high product accuracy, and good surface finish. However, HSM not only stimulates advancements in cutting tools and materials, it also demands increasingly sophisticated CAD/CAM software, and powerful CNC controllers that require more supportive technologies. This paper describes the computational requirement and cutting parameters of HSM, look ahead programming and simulation.

1 INTRODUCTION

Foresight method was introduced in 1970 in Japan and then at the turn of the 20th and 21st centuries successfully applied in following countries: USA, Netherlands, Germany, Great Britain, New Zealand, Sweden, Hungary and Czech Republic. It can be explained as looking into the future, not only forecasting the events but also the ability of having influence on their course. The main *Foresight* aim is to estimate future needs, opportunities and risk associated with economic and social development and to prepare suitable foresight performance in the field of science and technology.

Foresight as modern planning method indicates the most socially accepted economy sectors and actions, where national financial aid should concentrate on. Besides, *foresight* results allow to define law regulations in compliance with functioning conditions of enterprises together with state economy profits.

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2. TECHNOLOGY FORESIGHT FOR AIRCRAFT INDUSTRY

It is estimated that one of the most important strategic directions of scientific research in the field of aviation in Poland should be mathematical modeling, simulation and new materials development. The requirements for aircraft industry concerning reduction of carbon dioxide and nitrogen oxides emission, external noise, also production costs and new designs life cycle force the aviation industry to replace expensive experimental research with more and more advanced mathematical models for flow simulations, combustion, heat exchange, aeroacoustics, vibrations and construction dynamics. The suggestions mentioned above apply to many industrial sectors, not only to aviation. It is difficult to itemize all branches of industry, but computers virtual operations are being used in all of them.

„Clean Sky” initiative is held within the framework of 7PR specific programme. The initiative has received *Advisory Council for Aeronautics Research in Europe* (ACARE) positive opinion. According to it, the implementation of *„Clean Sky”* initiative will lead to new technologies development, and using them in aviation transport will result in fast technical progress. The main argument for implementing *„Clean Sky”* initiative in Poland is the possibility of using technology potential of national aircraft industry with research backup together with existing relations of R&D and industry institutions, especially in materials technology field.

Last 2-3 years showed increasing cooperation between science and industry and introduction of new innovative technology solutions. Polish aviation companies participate actively in European organizations gathering manufacturers of aviation equipment and associations focusing on R&D program for this industry sector.

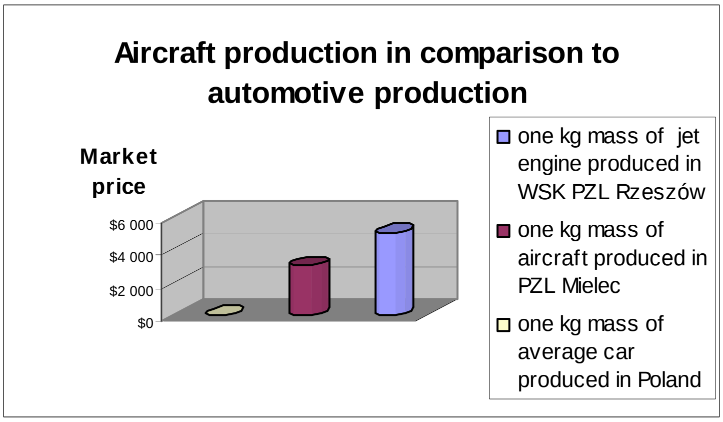


Fig. 1. Aircraft production in comparison to automotive production

Presently Poland tries to implement research and technological development challenges under the Lisbon Strategy and EU initiative concerning development of European Technology Platforms (*Aerospace Technology Platform*, *Polish Technology Platform on Hydrogen, Polish Space Technology Platform, etc.).* It serves Poland’s interests to care for strategic technological goals, defined by the Platform, as new “green” technologies and new materials and technologies for aerospace being developed within the framework of *„Clean Sky”* initiative environmentally friendly objectives Tab.1.

Table 1. List of preference technologies for aircraft and machine industry

	Sector prospective technologies	**Possible date of first application on market**
1	Development of heat-resisting, anti-erosion and diffusion coatings	
2	Nanocrystal sheatings NCOP	2015
3	Monocrystal technologies	2009
4	Precise die-casting - SD, GR, EQ and others	2009
5	Profile inductive hardening	
6	Surface strengthening technologies	
7	Plastic deformations of thin-walled structures	2010
8	Parts production with HSM (High Speed Machining) and HPM (High Performance Machining) methods	2008
9	Rapid Prototyping, Manufacturing and Tooling Technologies	2010
10	Superplastic Forming (SPF) and combining SPF with DG (Direct Gluing)	2011
11	Precise matrix forging	
12	Machining using concentrated thermal flux	2008
13	Fluid Jet Machining – FJM, Water jet	2010
14	Electrochemical machining (ECM)	
15	Advanced technologies of joining structural elements	2012
16	Manufacturing and machining technologies of composite materials (including GLARE)	2012
17	Improving die-casting processes and technology	2012
18	Eliminating contamination from manufacturing processes	2010
19	Simulation of technical and technological processes and conditions	2010
20	Improving methods of non-destructive testing	2010
21	Manufacturing technology of thin-walled casts	2012
22	Development of advanced systems for avionic (on board and terrestial)	2015
23	Automatization of manufacturing, assembly and inspection processes	2012
24	Development of systems for aided design, manufacturing and research processes	2010
25	Refining of materials with heat treatment	

Aerospace industry cluster Aviation Valley – the integral part of the Platform - is located in south-eastern Poland. The region characterizes in strong concentration of Polish aircraft industry (85%), scientific and research centers and well developed educational backup (for example Faculty of Mechanical Engineering and Aeronautics at Rzeszow University of Technology, Institute of Aeronautical Materials in Rzeszow), low work and production costs, over 16 000 of qualified staff and low income tax for legal entities. The main aim of Aviation Valley is to transform south-eastern Poland into one of the European leading aerospace regions, which will provide diversified aviation industry products and services to most demanding clients. Aviation Valley activity will influence positively on dynamical development of the region, increasing number of workplaces and improvement of inhabitants living conditions.

Following numbers are worth presenting:

- *market price of one kg mass of jet engine produced in WSK PZL Rzeszow is ~5000 $*
- *market price of one kg mass of aircraft produced in PZL Mielec is ~3000 $*
- *market price of one kg mass of average car produced in Poland is ~15 $*

The “one kilogram mass” consists of efforts of many scientists, engineers, technicians and technologists. It is obvious which branches of industry in Poland should be supported.

Rzeszow University of Technology has held the research project: Priority technologies for sustainable development of Podkarpackie Province. The objective of the project was to define the most important perspective technologies, which will have positive impact on sustainable development of Podkarpackie Province in next 20-25 years.

Special attention was paid to technologies which are the most modern or will be in the future up to 25 years from now. Technologies of the future in aerospace industry have been indicated for Polish conditions. Of course, the choice of „tomorrow’s” leading technologies relates to the world’s standards, as for example monocrystals production.

Table 1 presents list of prospective technologies for aircraft and machining industry which will or may be developed in Poland to increase general economy competitiveness according to idea of prospective technologies sustainable development.

Following technologies in aerospace and machining industry have the strongest influence on sustainable development of Podkarpackie Province (ratings: 66-67 points):

- monocrystals technology,
- Superplastic Forming (SPF) and combining SPF with DG (Direct Gluing),
- Manufacturing and machining technologies of composite materials (including GLARE),
- parts production with HSM (*High Speed Machining*) and HPM (*High Performance Machining*) methods.

Below there are technologies with ratings over 60-65 presented:

- Development of heat-resisting, anti-erosion and diffusion coatings,
- Precise die-casting - SD, GR, EQ and others,
- Plastic deformations of thin-walled structures,
- Rapid Prototyping, Manufacturing and Tooling Technologies,
- Machining using concentrated thermal flux ,
- Advanced technologies of joining structural elements,
- Simulation of technical and technological processes and conditions,
- Improving methods of non-destructive testing,

2 Manufacturing technology of thin-walled casts.

Analyses have been conducted and the points granted for each technology with following 3 criteria: practicability, attractiveness and influence on sustainable development. Basing on points summary 12 most important technologies have been indicated (ratings: 99-102) – Tab. 2.

Table 2. Areas of application of the most crucial technologies

	Sector prospective technologies
1	Parts production with HSM (High Speed Machining) and HPM (High Performance Machining) methods
2	Improving die-casting processes and technology
3	Monocrystal technology
4	Manufacturing and machining technologies of composite materials (including GLARE),
5	Plastic deformations of thin-walled structures
6	Superplastic Forming (SPF) and combining SPF with DG (Direct Gluing)
7	Improving methods of non-destructive testing
8	Development of heat-resisting, anti-erosion and diffusion coatings
9	Rapid Prototyping, Manufacturing and Tooling Technologies
10	Precise die-casting - SD, GR, EQ and others
11	Advanced technologies of joining structural elements
12	Simulation of technical and technological processes and conditions

3. NEW MATERIALS IN AVIATION INDUSTRY

Boeing (787 Dreamliner model) and Airbus (A380 model) take a large step forward in airframe design by using variety of attractive engineering materials. The next generation of aircrafts will replace a large amount of traditionally aluminum parts with carbon-fiber composite materials and modern high tech metal alloys. In June 2006 Boeing started the assembly of the new advanced commercial twin-engined jet liner - 787 Dreamliner – which will realize a 20% fuel savings in comparison to today's similarly sized airplanes. New light materials of high strength to weight ratio have been used to design aircraft. More than 50% of its construction, including fuselage and wings, is made with composite materials. Moreover 15% key parts are made of titanium, which is twice the number of titanium parts being used in previous generation aircrafts. Titanium is better than aluminium (in some applications), because it is more compatible with composite materials and reduces problem of corrosion, which occurs on traditional steel surfaces.

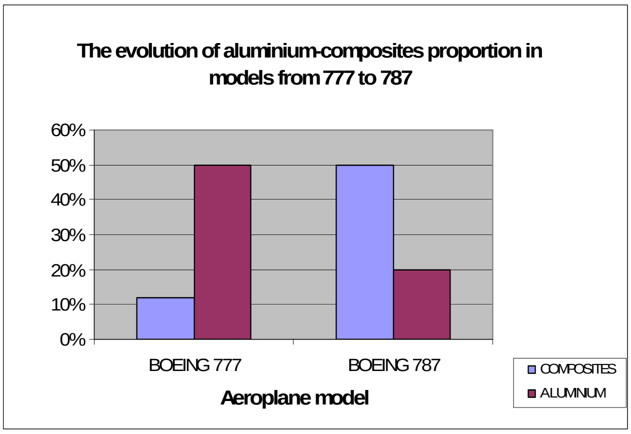


Fig. 2. The evolution of aluminium-composites proportion in models from 777 to 787

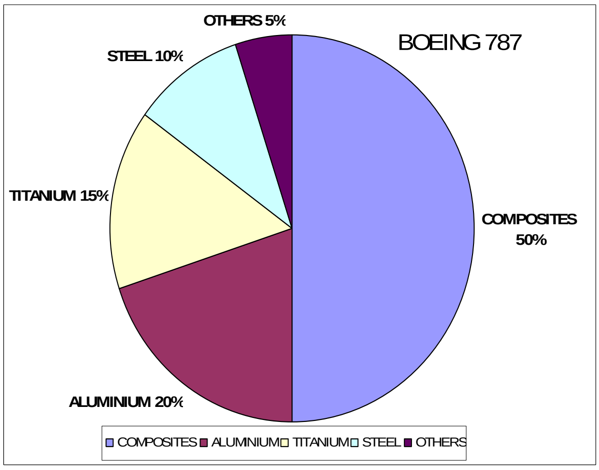


Fig. 3. BOEING 787 materials composition

Titanium is an attractive material for structural engineering applications in aircraft production industry. It is a light weight metal with high strength, stiffness, high elevated temperature properties and fatigue resistance. In the new generation aircrafts the percentage of titanium application increases together with using high strength complex, integral parts joined by composite profiles. These parts are located in highly loaded landing gear elements and function in high temperature (for example in the engine). Engineering market forecasts estimate that the manufacturing industry will need more machining capacity for titanium than there are now in the world. This is why there is strong need of improving titanium machining productivity.

Whereas Ti-6A1-4V alloy was the engineering standard, Ti-5AI-5V-5Mo-3Cr alloy will be used in most key parts. Ti-5AI-5V-5Mo-3Cr titanium alloy is similar to beta-alloy and has great hardenability characteristics and great strength combined with high cracking resistance and also very high fatigue resistance in comparison to Ti-6A1-4V alloy. The above mentioned properties are the reason why Ti-5AI-5V-5Mo-3Cr alloy forgings will be used in highly loaded parts such as flap guides or brackets and landing gear elements.

4. HIGH SPEED MACHINING

How the expression High Speed Machining (HSM) should be explained? There are plenty of different definitions suggested, for example:

1 High Cutting Speed (*Vc*) Machining
2 High Feedrate (*Vf*) Machining
3 High Spindle Speed Machining
4 High Speed and Feedrate Machining
5 High Performance Machining

HSM (High Speed Machining) usually refers to process of machining with high speed and high feed rates. For example, milling so-called „pocket" in aluminium frame of aircraft with very high values of volumetric material removal rate. Different definitions of HSM are based on Salomon research results "Process for the machining of metals (...) " [9], which were patented in 1931. For machine-part-tool system, HSM occurs when the increasing machining speed reduces machining forces (Fig. 4).

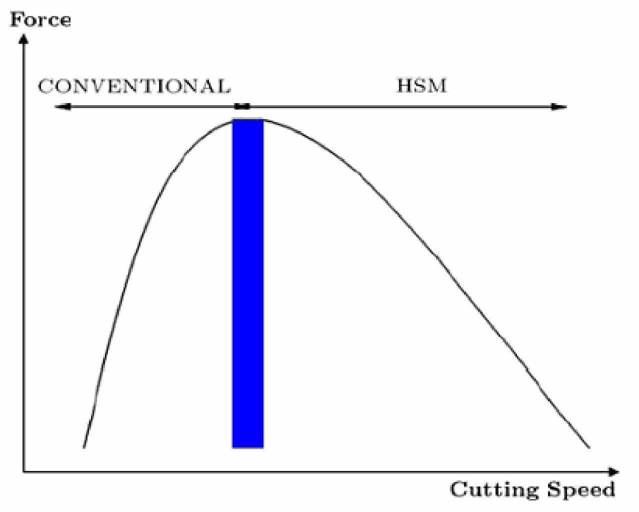


Fig. 4. Machining forces in relation to machining velocity [11]

HSM: $$\frac{\partial F}{\partial V_c} < 0 \quad (1)$$

CONVENTIONAL: $$\frac{\partial F}{\partial V_c} > 0 \quad (2)$$

Dynamical stability is very important when using HSM methods. Mativenga and Hon [12] have found the relation between vibrations arising from cutting forces and velocity changes. Five components have been indicated as significant for HSM:

1 Frequency of spindle

$$f_s = N/60 \text{ [Hz]} \quad (3)$$

2 Frequency of tooth passing

$$f_{tp} = z^* f_s \text{ [Hz]} \quad (4)$$

3 Frequency of beam resonant

$$f_b = 3{,}1560 * \sqrt{\frac{E*I}{m*l^4}} \text{ [Hz]} \tag{5}$$

4 Frequency of longitude rod resonant

$$f_r = \frac{\pi}{2*l}\sqrt{\frac{E}{\rho}} \quad \text{[Hz]} \tag{6}$$

5 Frequency of chip creation

$$f_c = \frac{v_c * n_s}{60} \quad \text{[Hz]} \tag{7}$$

where:

N – rotational speed *[rpm]*,
z – flute number,
E- elasticity modulus *[N/m^2]*,
I –inertia moment *[kgm^2]*,
m - mass per unit length *[kg/m]*,
l – beam length *[m]*,
ρ – density *[kg/m^3]*,
v_c – chip velocity *[m/min]*,
n_s – number of serrations per unit chip length (1meter).

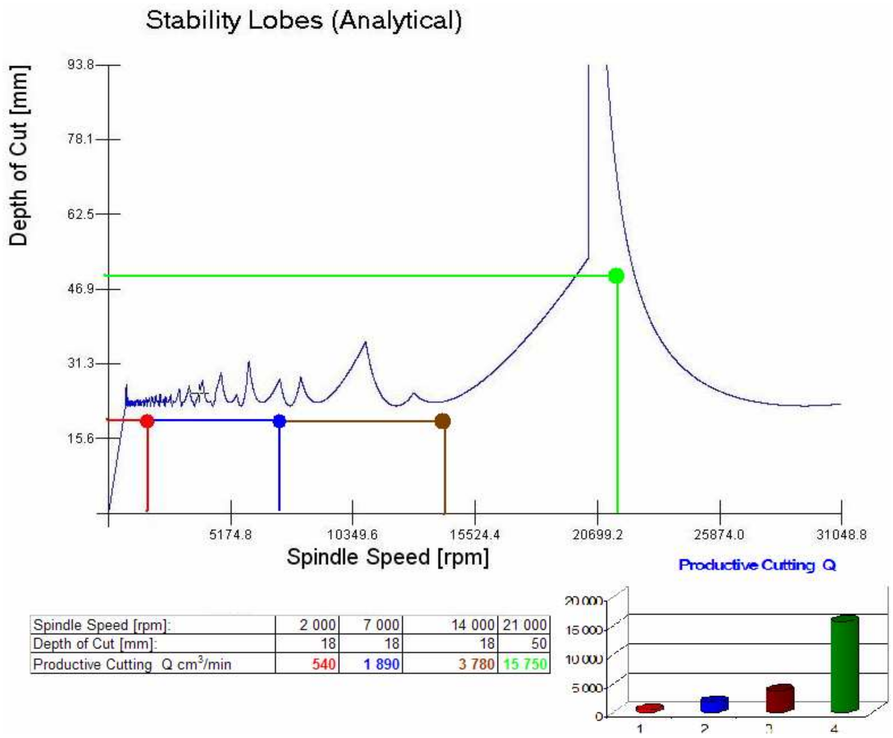
4.2. DEFINING MACHINING EFFICIENCY

What is very important and typical for HSM is the fact that depth of cut a_e and a_p, together with average chip thickness h_m remain on significantly lower level than for conventional machining. However, volumetric material removal rate Q is much higher than for traditional machining. It is caused by much higher feed speed $V_{f.}$.
Formulas for feed speed and material removal rate are listed below:

$$V_f = f_z * n * z_n [mm/\min] \tag{8}$$

$$Q = \frac{a_p * a_e * v_f}{1000} [cm^3/\min] \tag{9}$$

Analysis of stability lobes (Fig. 5) [7] shows that stable machining zone can be found below the stability lobes.



Spindle Speed [rpm]:	2 000	7 000	14 000	21 000
Depth of Cut [mm]:	18	18	18	50
Productive Cutting Q cm^3/min	540	1 890	3 780	15 750

Fig. 5. Optimal parameters for different machine-tool combinations

Above the curve there is unstable region, where chatters occur. Chatter means phenomenon that causes the tool or machined part to jerk or jump when being fed. Stable system is *chatter*-free depending on spindle rotates and depth of cut combination, what is shown on the stability lobes diagram above. Four examples had been analyzed (Fig. 5) machined with mill of ϕ=20 mm, 5 flutes and machining width=20mm, feed per tooth=0,15 mm. With following values: rotational speed of 2000 rpm and depth of cut of 18mm the material removal rate Q = 540 cm^3 is obtained. For speed of 21 000 rpm with 50 mm depth of cut system still remains in stable zone. The received material removal rate is 15 750 cm^3, so it is over 30 times larger (faster production). The formula for the depth of limiting cut layer (undeformed chip) - below the stability lobes - is as follows:

$$a_{pg\gamma} = \frac{2 \cdot k \cdot \zeta}{K_c \cdot \frac{a_e}{D} \cdot \frac{z}{2}} \tag{10}$$

where:

K_c specific resistance of cutting force,
z – number of teeth,
k – stiffness coefficient,
ζ- damping coefficient,
D –tool diameter,
a_e –axial approaching feed.

Stability results are shown in Tab. 3 [7].

Table 3. This chart summarizes the test results for one combination of tool, toolholder and spindle. Running this test took about half an hour. The green region indicates stable cutting

Rotational speed (rpm)		6500	7000	7500	8000	8500	9000	9500	10000	10500	11000	11500	12000
Feed rate (mm/min)		840	900	960	1 020	1 080	1 140	1 200	1 260	1 320	1 380	1 440	1 500
Chip load (mm/tooth)		0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075
Depth of cut (mm)		4	4	4	4	4	4	4	4	4	4	4	4
Side step over (mm)	**0,5**	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	1	🟧	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧
	1,5	🟧	🟧	🟩	🟩	🟧	🟧	🟩	🟩	🟩	🟧	🟥	🟥
	2	🟧	🟧	🟩	🟩	🟧	🟧	🟩	🟩	🟧	🟧	🟥	🟥
	2,5	🟧	🟧	🟩	🟧	🟧	🟧	🟧	🟩	🟧	🟧	🟥	🟥
	3	🟥	🟧	🟩	🟧	🟧	🟧	🟧	🟩	🟥	🟥	🟥	🟥
	3,5	🟥	🟥	🟩	🟧	🟧	🟧	🟧	🟩	🟥	🟥	🟥	🟥

In aviation industry HSM makes it possible to manufacture large complex thin-walled parts from integral blocks (Fig. 6, 7). High cutting speed allows to remove material with lower cutting forces, what does not result in part deformations during machining process. The next HSM merit is the possibility of manufacturing an aerodynamic brake for F-15 fighter as single part instead of assembly including about 500 parts. Machining time of aerodynamic brake assembly was about three months. Using High Speed Machining *lead time* was measured in days.

Fig. 6. Main undercarriage flap of C-17 transporter

Fig. 7. F-15 fighter aerodynamic brake

Main landing gear flap of C-17 air freighter had been produced as an assembly of parts manufactured from profiles and sheets. Using HSM technology the flap has been manufactured as single part on CNC machine with machining time of about 12 hours.

Machining a frame from single element reduced significantly its weight. Previous solution was an assembly of 20 parts. The frame integral version has allowed to reduce 80% of the weight comparing to the assembly weight. The frame is a part of aircraft fuselage.

4.2. WHY SIKORSKY COMPANY USES HIGH SPEED MACHINING TECHNOLOGY?

HSM spindles are high loaded what results mainly from high rotational speed and working in unstable chatter areas. It has a negative influence on construction elements of CNC machine and lowers quality parameters of machined surfaces. Monitoring the spindle state from the date of its purchase allows to define CNC machine's characteristics of performance and analyse its changes in time. Regular measurements (for example once a three months) define spindle state and changes of its dynamical stiffness when operating. Renishaw QC10 ballbar diagnostic system in PZL Mielec allows to conduct an automatic test for checking CNC machine's geometry and faults of guide movements. Measuring results are presented as diagrams. Systematic measurements result in specifying needs of machine overhauls and planning them in the most convenient time. Monitoring technical state of CNC machines helps to find quickly the components needing service or repair. High dynamic stiffness of CNC machine does not ensure stable work (without chatters) with any machining parameter.

The Tab. 4 shows the results.

Table 4. HSM Benefit

Machining parameters	**Theoretical values**	**Assumed values**
Feed (per minute)	1000 ft/min (305m/min)	2500 ft/min (760m/min)
Spindle rotations	7 640 rpm	18 500 rpm
Feed per tooth	0,001" (,0025mm)	0,005" (0,13mm)
Depth of cut	0,25 (6,5mm)	0,15" (4mm)
Material removal rate	1,9 cubic inches/min (31cm^3/min)	6 cubic inches/min (98 cm^3/min)
Machining time	**90** hours	**30** hours

Purchasing high quality CNC machine will not ensure high machining accuracy until adjusting optimal machining parameters.

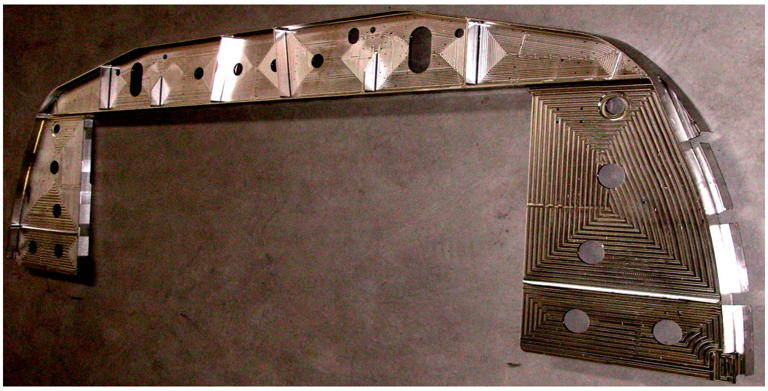


Fig. 8. The example of. Machining with Φ 12mm cutter.
Semi-finished product dimensions = 120mm x 752mm x 2400mm

Cutting tool producers suggest to use several tools with different length and diameter to deep pockets or small radius machining. This methodology allows the users to adjust tools and holders to specific production tasks and speed the machining up even a few times.

Other benefits of HSM machining are:

- Simplified fixing (lower cutting forces),
- More clean mill edges => lower deformations during machining process,
- smoother surfaces => shorter finishing machining,
- lower consumption of cutting tools.

4.3. EXAMPLES OF USING HSM IN PZL MIELEC

Fig. 9 presents complete measuring system. Vibrations are measured when knocking tool with small hammer (Fig. 10).

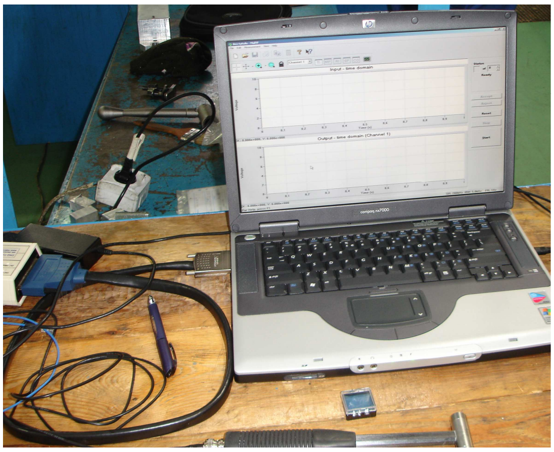


Fig. 9. Vibration measuring system

Fig. 10. Knocking tool with small hammer

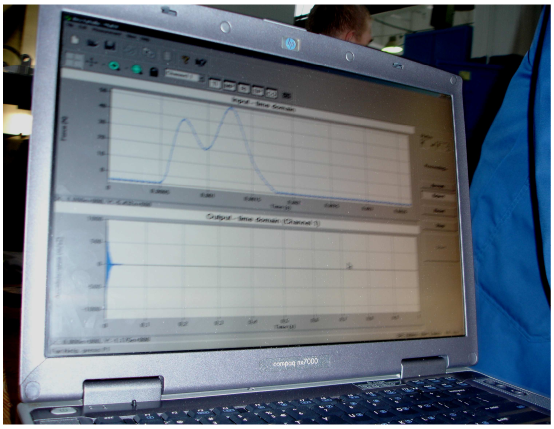


Fig. 11. Vibration measuring

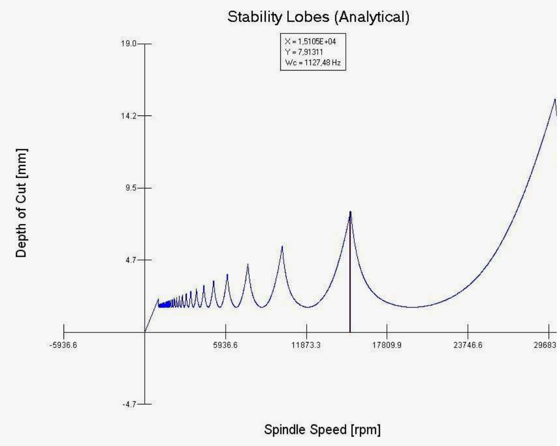


Fig. 12. Received stability lobes

Fig. 13. Stage-of-the-art passenger plane part

Measuring results are shown on laptop screen (Fig. 11) and stability lobes are generated for given machined material and tool parameters (Fig. 12).

The measuring results were applied to part presented on Fig. 13. Machining time of one operation in this case has been reduced from 32h to 8h, i.e. over 4 times.

5. LOOK-AHEAD FUNCTION

Introducing CNC machines into the industry has rapidly changed it. Problems with manufacturing of very complex surfaces no longer exist. Look-ahead function, used in CNC machines, allows to foresee the event before it happens (for example mill damage) and prevent it effectively. There are also various systems for aiding CNC machining as for example OMATIVE Adapting System and monitoring spindle load during milling process. Monitoring spindle load during CNC machining process with OMATIVE System reduces machining time significantly. The following examples show reduction of labour consumption in numbers: 29,7% for aluminium alloy stringer machined in Boeing or 24,4%

for stainless steel parts machined in Aerospatiale-EADS, Toulouse, France.

In extreme conditions, if the tool is damaged because of:

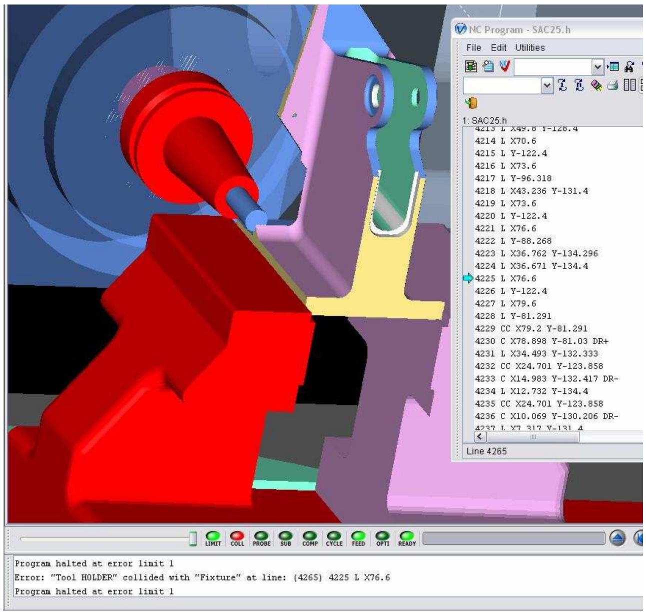
- tool hitting material,
- hard inclusions in material,
- excessive tool wear,
- cooling break,
- excessive depth of cut,

then OMATIVE ACM System automatically reduces feed rate to maximum safe value protecting the tool against the damage or turns the machine off and signals alarm. Next example is the active control function, which rapidly reduces tool path errors during so-called "work with jerks". It is especially beneficial for higher values of feed rate with ensuring required surface roughness and dimensional accuracy.

HSM technology together with CNC (*Computer Numerical Control*) system need integration with computer-aided manufacturing (CAM) and designing (CAD) in order to obtain faster, more effective production according to required quality level. Most CAM systems work in 3D environment together with CAD applications. CAD/CAM systems with proper quality eliminate the need of re-modeling the CAD model of machined part for CAM system. At the market there are many CAM systems able to „read" numerical models from CAD systems. Unigraphics, Surfcam, AutoCAD, CATIA or ProEngineer are the examples of such systems popular in industry.

CAM systems not only generate tool path, but are also used to verify and optimise the path to reduce the number of errors even to zero. VERICUT system is example of very good system which is independent from CAD/CAM systems. PZL Mielec uses VERICUT for part machining simulation and optimizing programs for CNC numerically controlled machines. System contains library of most popular numerical models of CNC machines and control systems used in the industry. By simulating machining programs on computer instead of hazardous testing on real CNC machine PZL Mielec has gained significant savings and profits. Shorter lead times have been obtained, CNC machines productivity has increased, machining quality level has improved (reduced number of *rejects*). The risk of program errors during CNC machining has been also reduced, because errors are detected on computer long before real machining process. Today's CNC machines are more complex and precise, so computer simulation of manufactured part for given machine is a necessity. Especially important issues are: function of preventing machining program errors and avoiding tool collision in working area, what results in reduced number of production rejects, avoiding damage of expensive CNC machine and time loss. It is obvious that client does not want to be charged for the above. VERICUT system became the world standard for CNC machining simulation. The system simulates all known CNC machines types and configurations including such names as Mazak, Makino, Matsuura, Hermle, DECKEL MAHO, DIXI, Mori Seiki and Chiron. PZL Mielec has virtual models of all its modern CNC machines with tool holders, tools, vice, jaws and jigs. Virtual testing of machining programs is already a common practice. One more advantage of VERICUT system is "cheaper" education of CNC machine operators with the use of virtual CNC machines instead of real ones. Manufacturing parts on real CNC machines is significantly easier for operators after computer simulation of the machining.

Figures 14 and 15 present examples of part machining simulation with 5-axis machines. Red color on Fig. 14 marks a collision of tool holder and machined vice. Machining program analysis repeated by programmer (*after postprocessor*) allowed to prevent the collision on real CNC machine. Fig. 15 presents another case - spindle override exceeding 900mm limit to the value of 1045.8786 mm. The override range is indicated by red color.



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4213 L X49.8 Y-128.4
4214 L X70.6
4215 L Y-122.4
4216 L X73.6
4217 L Y-96.318
4218 L X43.236 Y-131.4
4219 L X73.6
4220 L Y-122.4
4221 L X76.6
4222 L Y-88.268
4223 L X36.762 Y-134.296
4224 L X36.671 Y-134.4
4225 L X76.6
4226 L Y-122.4
4227 L X79.6
4228 L Y-81.291
4229 CC X79.2 Y-81.291
4230 C X78.898 Y-81.03 DR+
4231 L X34.493 Y-132.333
4232 CC X24.701 Y-123.858
4233 C X14.983 Y-132.417 DR-
4234 L X12.732 Y-134.4
4235 CC X24.701 Y-123.858
4236 C X10.069 Y-130.206 DR-
4237 L X7.317 Y-131.4
```

```
Program halted at error limit 1
Error: "Tool HOLDER" collided with "Fixture" at line: (4265) 4225 L X76.6
Program halted at error limit 1
```

Fig. 14. 5-axis machining simulation with collision holder-part (red color)

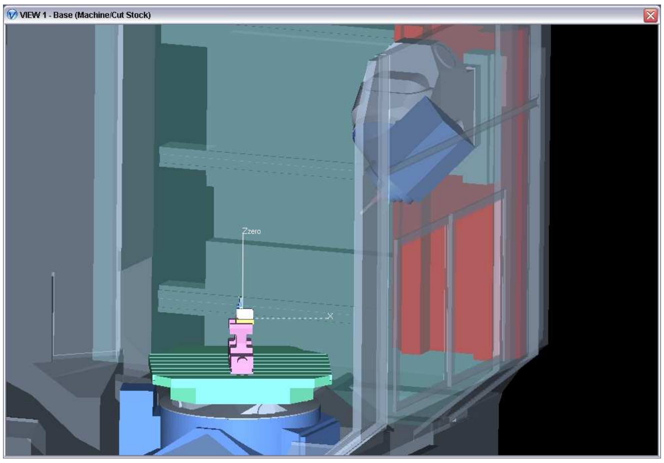

Fig. 15. 5-axis machining simulation. The example of collision – exceeding x-axis range – in red color.

How does the electronic information flow looks like at given manufacturer in practice? How numerical model of a part is transformed during production process into real part.

Part model (Fig. 16) is designed in CATIA system. The model is then transmitted to SURFCAM system by native CATIA-SURFCAM translator. Using SURFCAM the CNC programmer designs the whole machining process of a part, creates tool path and generates given machining program with postprocessor. The program is then “uploaded” into CNC machine to make the part. Numerical model of a part is transmitted by the use of IGES standard package of data exchange to Power Inspect measuring system. Final manufactured part is inspected on CMM measuring machine in comparison to CATIA model uploaded before into CMM database.

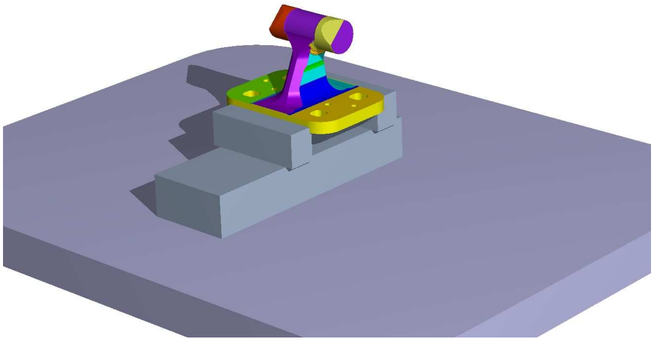

Fig. 16. Model of part machined in handle

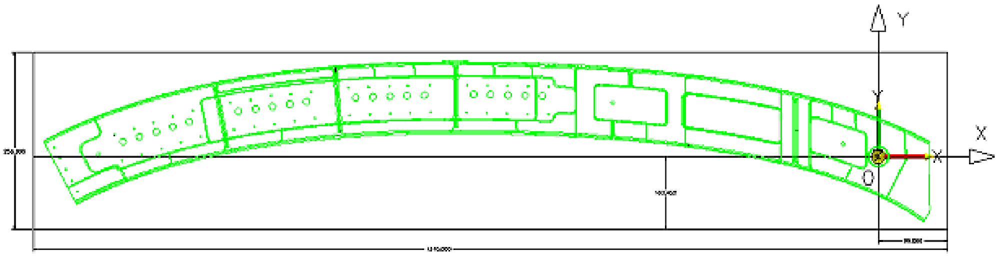

Fig. 17. Before optimisation

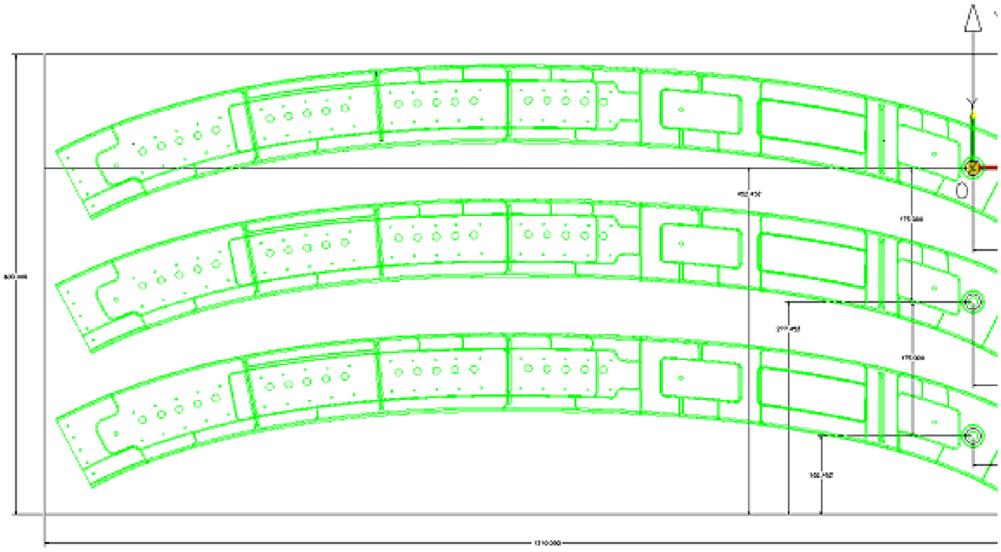

Fig. 18. After optimisation

Fig. 19. Parts just after CNC machining

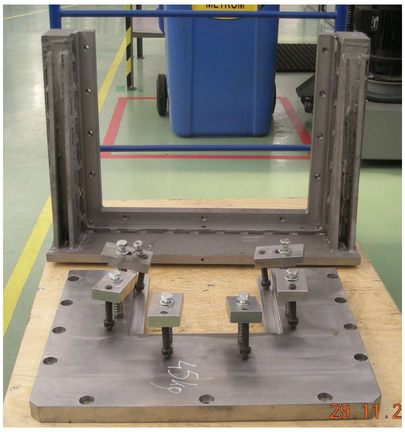

Fig. 20. Frame type tool

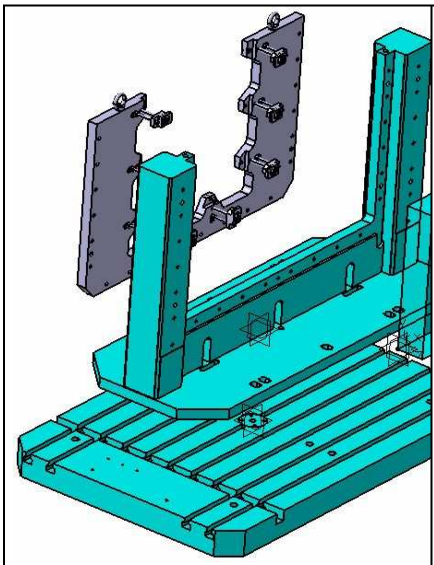

Fig. 21. Frame type tool model

Fig. 22. Using special high handles

Figures 23 [7] and 24 show- in theory and practice -the information flow during a part manufacturing. Numerical model of the part has been created in CATIA system. Next the model has been transmitted to SURFCAM system using direct CATIA-SURFCAM translator. Part machining program has been also generated in SURFCAM and then “uploaded” by fibre optic media to CNC machine. Fixing tool has been manufactured basing on the numerical model designed in CATIA and mounted at CNC machine. Cutting tools have been mounted in tool holder using thermic shrinkable jig. Cutting tools have been measured in computer tool setup before transporting them to CNC machine in special cart. Part numerical model has been sent to Power Inspect measuring system by the use of IGES data exchange standard package. Next the real manufactured part has been inspected by measuring machine (CMM) and measuring results compared to numerical model of the part, generated in CATIA and sent to Power Inspect system. Data, jigs and cutting tools flows on Fig. 26 are indicated by arrows.

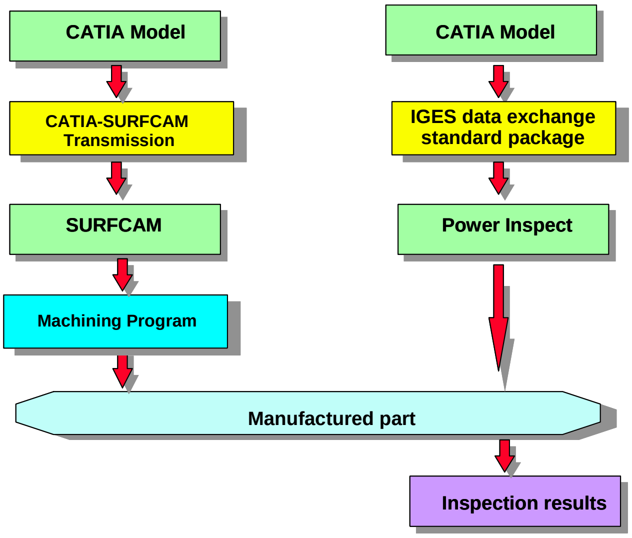

Fig. 23. Information flow and using CAD/CAM models in PZL Mielec in theory

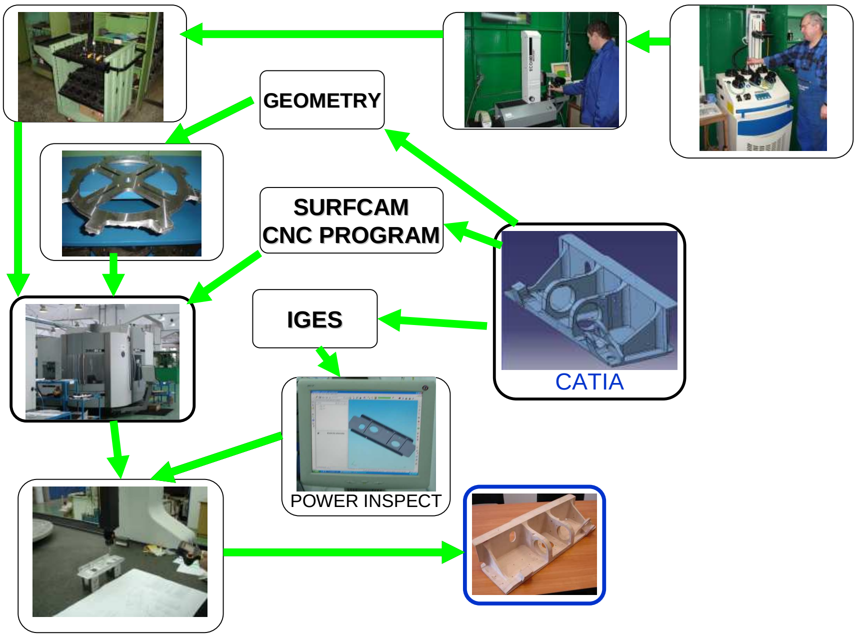

Fig. 24. Information flow and using CAD/CAM models in PZL Mielec in practice

6. ADDITIONAL METHODS OF IMPROVING MACHINING PRODUCTIVITY

If possible it is suggested to machine two (Fig. 17) or more parts from one billet (symmetrical/mirror image). Using the same setup time, billet is provided from store-room directly to work stand. Benefits from such solution are: material savings, reducing billet preparing time even to zero and the part is more stable during machining process. Fig. 16 shows the example of material savings of 18%. Next examples are parts machined with the same fixing in vice with higher vice jaws (Fig. 22).

Another improvement examples are jigs machined as frames (windows) (Fig. 20, 21, 25, 26).

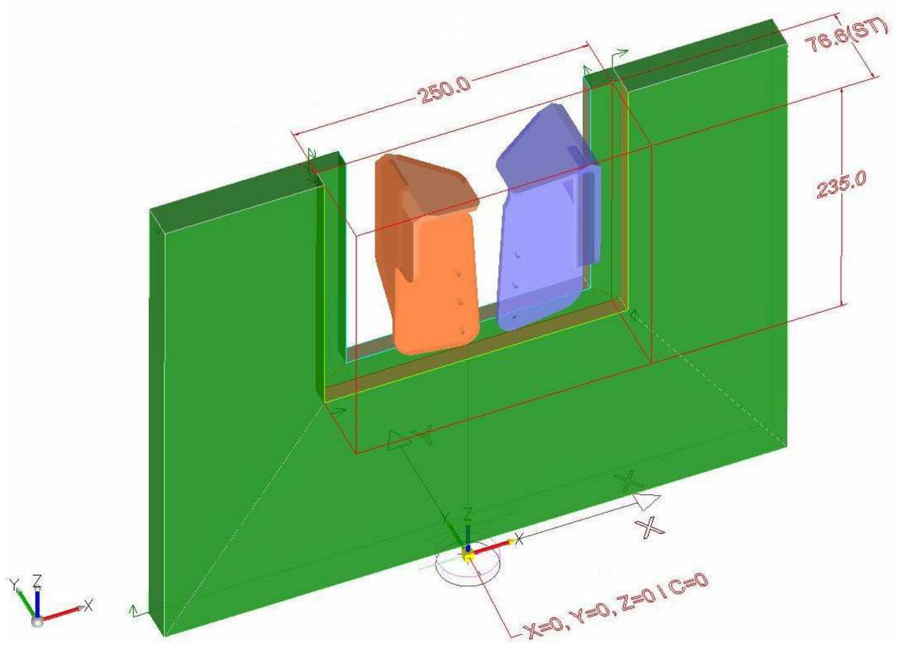

Fig. 25. The way of parts holding in a frame type device

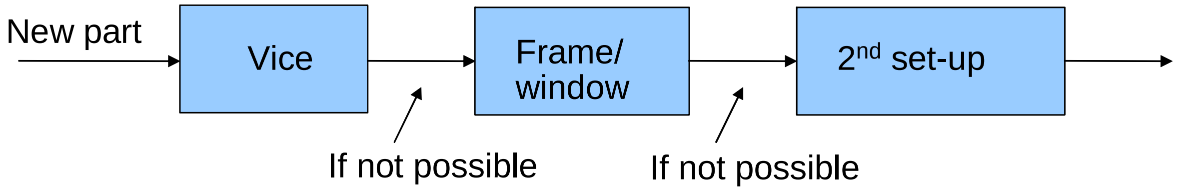

Fig. 26. Fixing device choice strategy

Benefits of such solution are listed below:

- universal jig for defined group of parts (even up to 20 different parts),
- universal jig for parts with small dimensional differences (up to about three times difference),
- jig for manufacturing parts with the same fixing (two-sided machining with rotating table).

Using the above mentioned solutions for machining parts the following results have been obtained to reduce labour consumption:

- Setup time reduction (two pallets system, billet dimensions reduction, reducing number of settings),
- Introduction of the principle of fixing solution: first vice, then frame/window, eventually jig for second setting,

- Increase of machining time for group of parts (more than one part for one billet) gives the CNC machine operator the possibility of preparing next job and finishing previous one,
- Parts are divided into family groups according to specified criteria, for example family group for vice or for frames/windows,
- Implementing new production methodology.

7. SUMMARY

Practical usability of High Speed Machining can be described as following:

- High Speed Machining is not just machining method with high speed values. It is the whole machining process, where operations are performed with specific methodology and production equipment.
- HSM does not require high values of spindle speed. Many HSM operations may be performed with moderate spindle speed and relatively large tool diameters.
- HSM is more important at the final stages of finishing the part.

High Speed Machining advantages:

- Cutting force reduction,
- Small heat flow to workpiece, heat transferred into chips,
- reducing cycle time,
- inreasing the quality of manufactured parts,
- reducing finishing machining,
- operation of cutting in stable zone (avoiding chatters),
- possibility of fine elements manufacturing.

With cutting speed increase the important requirement issues connected with CNC machines for HSM arise:

1 increased static and dynamic stiffness of CNC machines and their high thermal stability,
2 large capacity memory of *computer numerical control*, ensuring precise tool „driving" in working area,
3 increased capacity of tool storage magazines and the shortest time of tool exchange,
4 reduced time for automatic systems of exchanging machined parts (pallets)

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