Journal of Machine Engineering, Vol. 10, No. 2, 2010

advanced aerospace structure,
machine tool selection, software, service

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MODERN MACHINE TOOLS IN APPLICATION TO ADVANCED AEROSPACE COMPONENTS MANUFACTURING

The article describes general characteristics of components produced by WSK "PZL-Rzeszow" S.A. (WSK) and their influence on machine tool's technical requirements and special accessories defined during the procurement process of new machining center or lathe. It shortly presents the investment process in new machine tool and a new product implementation path. A point on CAD/CAM and CNC systems existing in WSK and some specific aspects concerning such software is also mentioned. Maintenance challenges have also been pointed to based on WSK's experience.

1. INTRODUCTION

Advanced aerospace engine components and transmission production is characterized by:

- high-quality requirements;
- small number of part in batch;
- high variability of production (production line lay-out in accordance with product family e.g. gas generator line, centrifugal compressor housing line etc.),
- wide range of machined material (stainless steels, aluminum, magnesium, titanium and nickel alloys),
- different workability/stiffness of machined engine components and transmissions.

All these features have an effect on technological solutions, equipment and machines used in WSK.

Production in WSK includes turbine engine components and static structures (Fig. 1), gears and transmissions (Fig. 2).

If we talk about the type and material features or structure flexibility of material used in production, this two groups of products are completely different.

Moreover, component complexity, presented in Fig. 1 and 2, and their critical accuracy requirements, have essential influence on technology, machines and tooling selection.

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Most of static structure elements in a turbine engine are made of stainless steel, nickel and titanium alloys. Stainless steel doesn't cause difficulties in machining as titanium alloys and especially nickel alloys do. Due to their low machinability, they demand applying special machine construction and equipment.

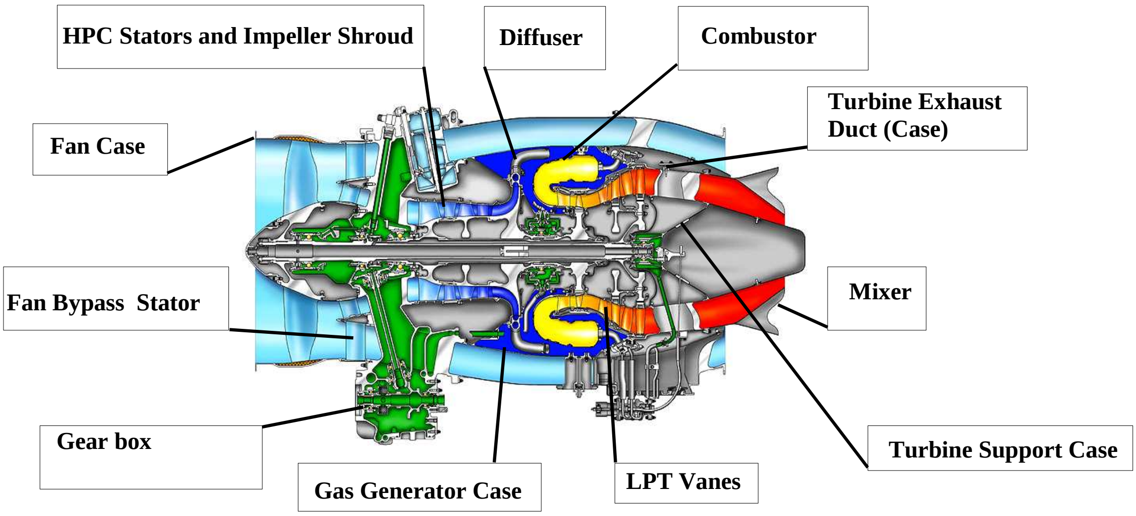

Fig. 1. Turbine engine elements processed in WSK

Fig. 2. Example transmissions produced in WSK

The transmission housing is mainly aluminum and magnesium alloys machining. Both of them belong to the group of light and easy to machine materials, however due to their large thermal expansion and applied machining methods (high speed machining - HSM) and tendency to ignition, they also prefer special solutions.

2. MACHNINE TOOL SELECTION

Most often the following situations have influence on the decision about purchase of a new machine tool:

- order increase of parts already in production,
- new part production implementation,
- old process modernization,

or a combination of the above mentioned situations,

At present WSK, as a company applying the newest technology and production organization solutions, invests in high automated machining centers, equipped with different kind of systems, permitting the increase in process quality and efficiency, e.g.:

– measurement system – character of aircraft engine components production and parts drawing requirements, induce the application of renown measurement systems. Measurement solutions can help in process control improvement and reduce set up. Producers offer solutions in tool setting, tool breakage detection (Fig. 3a), fixture and part setting, in-cycle part measurement with automatic offset correction, first article inspection with automatic offset update (Fig. 3b).

a) b)

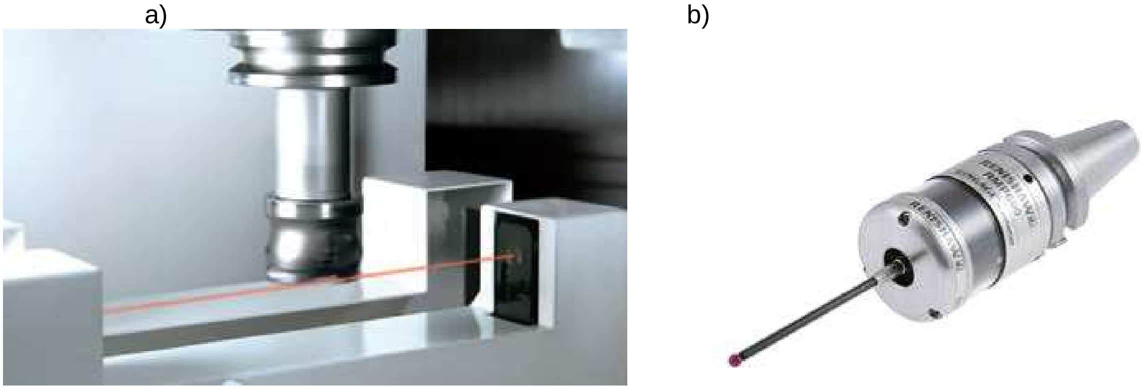

Fig. 3. Measurement probes a) probe for tool setting, b) RMP600 high accuracy touch probe

quick machine set-up including tools, fixtures and parts,

- pallet systems - installed on machining centre pallet changer and transport system (Fig. 4), both of them logically synchronized, making possible to maximize productivity in 24-hour operation system,
- quick change work holding systems – quick and repeatable fixture fixing (Fig. 5),

– coolant systems – depending on needs, machine can be equipped in different, combined, coolant systems:

- coolant through spindle system for tools with internal passage, preferred discharge pressure: minimum 70 bar,

- external system - discharge coolant from nozzles on the milling spindle
- Niagara coolant system – large volume of coolant is discharged from nozzles mounted on the machine top cover to flush chips from the pallet and workpiece. It prevents part on the pallet from warming-up (distortion) during heavy machining with large accuracy requirements,
- oil coolant system for special types of machining e.g. deep hole drilling
- bed flushing system,
- oil shot system
- coolant temperature control system,

Fig. 4. Transport system examples

Fig. 5. Quick change work holding systems

– chips conveying system – for effective chips conveying and removal from the coolant, the following are applied: hinged-chain conveyor, spiral-type chips conveyor, brushing conveyor. All these types of chips conveyors allow an effective removal even of small chips, which with normal systems often bring many problems and shutdowns due to manual chip removal.

– tool magazine – depending on machining parts quantity, character and process complexity, magazine can have from 30 to 220 tool slots, securing tools for all machining operations and parts with a single load. An important factor is the maximum tool size which can be put to a magazine.

Additionally, during investment in a new machine, engineers define numerous requirements, which new machine should fulfill, e.g.:

– pallet size, load capacity of a table, max. workpiece size which all depend on parts overall dimensions and fixture size,

- number of control axis – depending on part design complexity and the character of operations performed, a new machine centre should have from 3 to 5 controlled axis (Fig. 6).
- movement in XYZ-axis - also depends on machining parts overall dimensions,
- spindle type – depending on material type which the part is made of, machining parameters and power rating required for machining, the following has to be defined: type of taper, max. spindle speed, power of drive, max. torque and max. tool weight with holder (Fig. 7). High spindle stiffness, power rating and torque margin are required, especially in machining nickel and titanium alloys.

a)

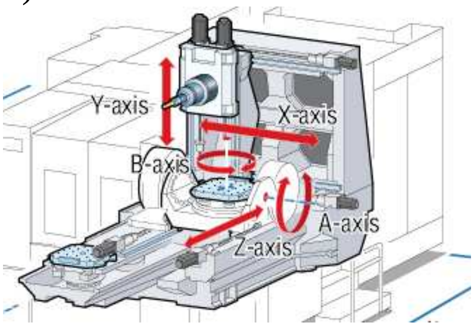

Fig. 6. Number of control axis

b)

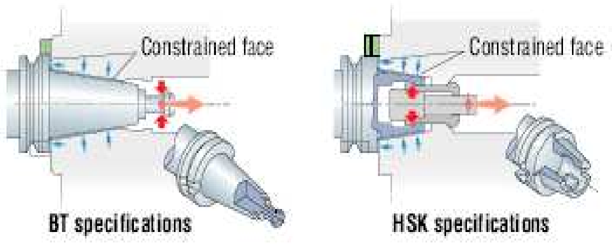

Fig. 7. Spindle type

- 5-axis indexing milling, on intermediate angles, with head or table clamping,
- operational requirements e.g. high construction stiffness, temperature stability (no air conditioned room),
- position and dislocation measuring systems supported by precise linear scale feedback system and digital rotary encoders,
- elevated accuracy packets including temperature compensation systems, screws and drive cooling systems, etc.
- high failure-free
- Expanded and configurable CNC system with additional single-purpose software – parts and operations variety, demands individual approach to software,
- capability to operate with special tooling e.g. angle head – aircraft engine components of complex design, frequently demand tools and devices, which will enable machining in difficult to reach zones. Angular heads make possible to machine with different angles, in one or two surfaces, independent of spindle orientation. Application of this type of holder with drive, demands special spindle adaptation by installing “stop-block”, which positions the head and unlocks (through fuse in head arm) the drive transfer from spindle to tool which is mounted in angular head spindle,
- easily accessible machining space due to the need for applying large quantity of gauges,
- quick and competent service.

Figures 8 and 9 shows 4-axis machining centre spindle with fixed angle head and example of application.

The investments in machine tools and equipment of leading manufacturers are dependant of the design complexity of aerospace engine components and the accuracy requirements. Figure 10 shows intersection of a turbine engine compressor case fragment with indicated essential dimensional and geometrical characteristics. It presents the requirements level which machines and machining process should fulfill. Fundamental for engine non-failure operation dimensions and geometrical tolerances are often difficult to reach even with the application of high quality machines.

After being accepted by WSK's customer, production process is prepared to be started. The process engineers use technological conditions contained in technical specification to define the requirements the machines need to meet. For this purpose a preliminary outline of technological process is created. At this stage suppliers mentioned above, who offer modern machines, may play an important role in the preparation of the process. They may choose one of two possible ways of implementing a machine and new process into production.

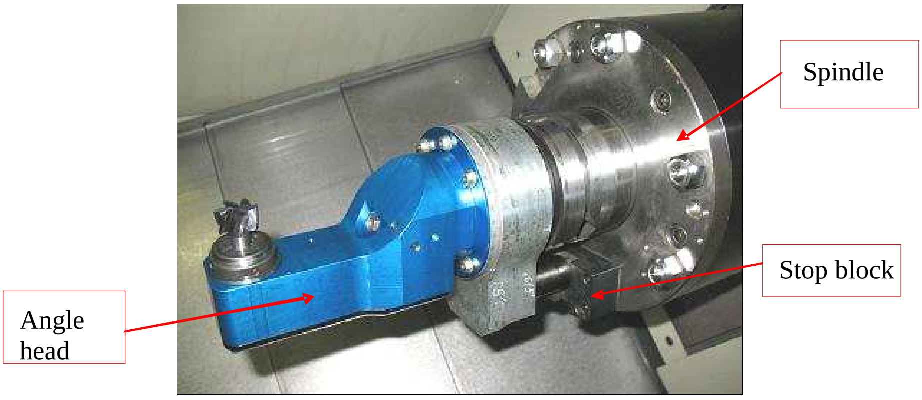

Fig. 8. 4-axis milling center spindle with „Stop block" and angle head

1. The delivery of the machine and the process is done through close cooperation in developing the process. Centers of excellence of machines' producers are used in this process. Process engineers of both parties define machines together with all the equipment, systems of automatic operation, technological set, devices, cutting tools etc. When the agreed quantity of consistent parts are produced by the machine's producer and after their quality reception, the machine and the implemented process are delivered to WSK. Depending on the complexity of the process and the requirements of the new machine, the period of time from the beginning of cooperation with a selected machines producer to delivery of the ready-made technological solution could last even up to 12 months.
2. The delivery of the machine by strictly specified requirements. When this way is chosen, the process engineers from WSK play main role in the process. Together with creating the technological process of a particular part, the process engineer defines technical

requirements that must be met by new machine in order to carry out its assignment. Those requirements are enclosed to the enquiry to the producers of the tooling machines.

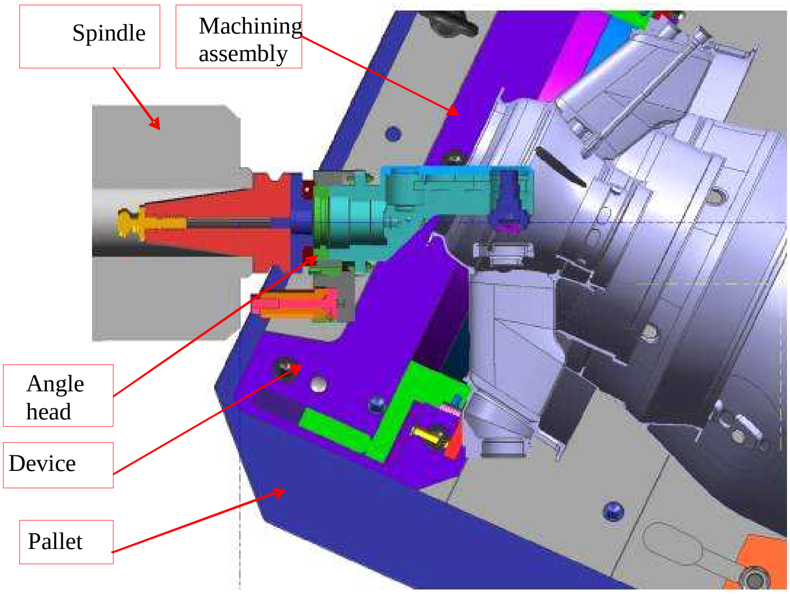

Fig. 9. Angle head in application to bearing mounting machining

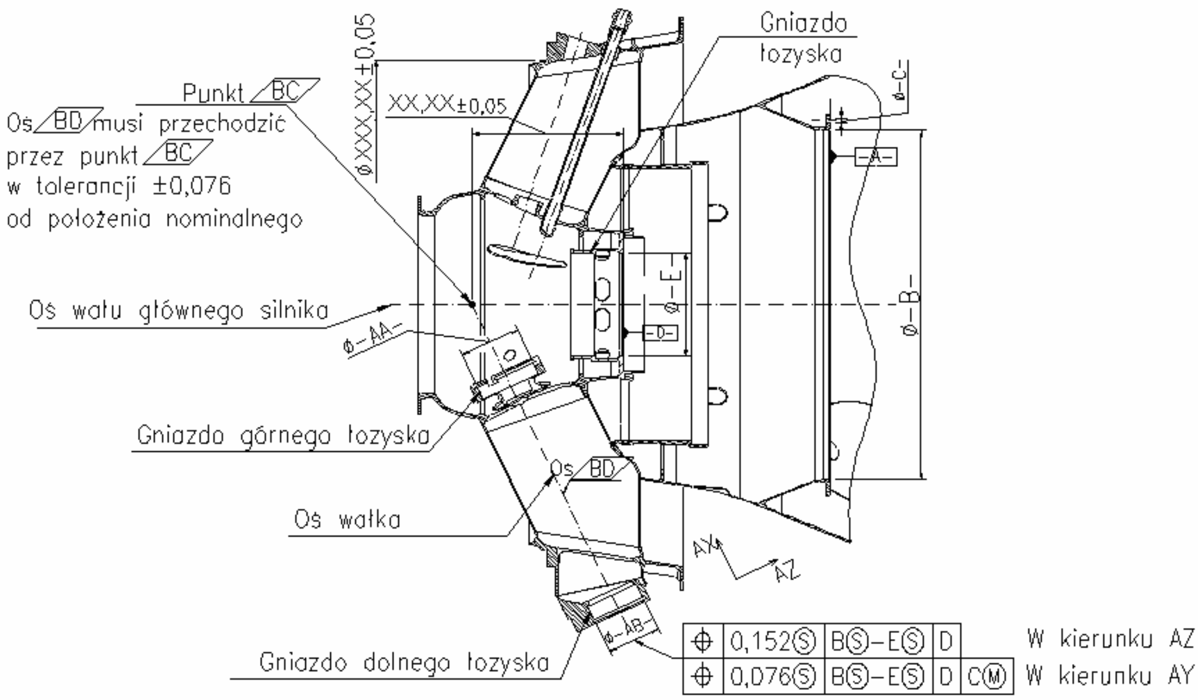

Fig. 10. Intersection of turbine engine compressor case assay with main dimensional and geometrical characteristics

When the best offer is chosen, further consultations are undertaken in order to determine the final shape of the machine. The preliminary reception of the machine takes place at the producer's place. It's done in the presence of WSK's process engineers with the instrumentation and a semi-finished product chosen by him or her. If the process engineer decides that the machine meets the technical requirements specified in the purchase contract, the machine is delivered to WSK. The new machine is equipped with previously defined instrumentation and tools and the implementation of new technological process can be started. A technologist, a programmer and an operator take part in the implementation process. They all have to decide that the machine meets all the requirements, the technical conditions defined in the contract and then the reception protocol of the machine can be signed. The whole process of choosing and purchasing a new machine (from formulating technical tasks do signing reception protocol of the machine) is supervised by special commissions, that study the influence of the machine on the environment, human health and industrial safety. The period of time between the decision about starting the production of a new product to manufacturing a consistent part on the machine is similar to the one described in the first point and comes to about 12 months.

The time required to start a new production is much shorter when the part is to be manufactured on a machine, which already is a property of the company. Including time needed to prepare technological documentation, design documentation of the instrumentation and tests, creating the instrumentation and tests and implementing the production, we can assume that the production process will be implemented in approximately 6 to 7 months.

When the purchase of a new machine is forced by the increase in the number of manufactured parts, the waiting time depends mainly on time required to conduct procedures connected with the enquiry, the analysis and consultation of the offer, which takes 1 to 2 months and on time necessary to deliver a new machine and implement it into production – 6 to 12 months, depending on the machine producer's production capacity.

The procedure described above contains numerous 'if the machine meets specified requirements' expressions. The experience shows that during both, preliminary reception at the producer's and the final reception at the production unit, there may be many objections, which make it hard or even impossible to implement the production fast. Those objections may be:

- lack of machine design changes determined previously
- special equipment which is inconsistent with the specification or doesn't work properly
- mistakes in the configuration of the CNC's controller parameters, which appear in particular situations, eg. functions of correction and radius of a tool
- the necessity of purchasing extra functions of control system, which weren't taken into consideration in the offer
- extended technical reception caused by the negative results of static and dynamic measurements (standards, lasers) and tests according to contractual settings (eg. work test on the tool)

- delays in the implementation of post-processes for CAM system, particularly when they are produced by outside companies; often the necessity of correcting NC program manually
- despite taking part in trainings, the operators' experience with the new machine is limited
- long waiting time for the service support with non-typical problems, especially concerning 5-axis tooling and configuration of control system's parameters; the necessity of waiting for the information directly from the factory or central service

Furthermore, even if the inaccuracies are removed and the first series of parts is manufactured perfectly with good results, there might be situations (which has already taken place in WSK) that another series has some dimensional deviations. They were still tolerable but the following series were inconsistent with the drawing requirements.

3. MANUFACTURING PROCESS SOFTWARE

Due to the diverse production profile and the task type machines, WSK applies machines from many producers, which minimize offer for NC systems. In that situation, full unification of NC systems was impossible.

The main NC systems applied in WSK include products from many of the major CNC control suppliers and their variables. If we multiply that by all versions and varieties resulting from different configurations of formally the same control systems which cooperate with different machines, we get a large variety of solutions.

This situation is disadvantageous and increases the requirements of CNC programmers, CNC operators and process engineers who are responsible for the implementation of the new processes and production processes.

Fig. 11. Typical modern CNC controls

All NC systems mentioned above are programmed in EIA/ISO code, which is a standard in WSK. It partially compensates the lack of unification and allows, after necessary modifications (e.g. M-codes' changes), to run program on machines with different NC system.

At the stage of the RFQ process, the CNC programmer and the process engineer define detailed options of the control system as well as additional software and equipment.

Range of additional options depends on basic equipment, which is provided by a machine manufacturer and on manufacturing process requirements. Typical additional options are:

- additional coordinate system bases of machining part G54.1P(1÷48),
- stiff threading cycles,
- drilling and boring cycles,
- three-dimensional coordinate system transformation function G68, used on 4-axis machining centers to program and set angular heads,
- special cycles for 5-axis machining centers (TRAORI, dynamical offset, machine geometry dynamical correction, etc),
- extra variables –#XXX macros, necessary to use measuring probes,
- increased number of correctors in tool table compared to storage capacity (in machining program tools often have a few correctors assigned),
- extra M-codes (to enable program annexing of measuring probes or oil mist extract etc.)
- spindle and servomotors charging monitors, with possibility of active control for chosen tools,
- extra software for measuring probes and tool measuring system,
- cooperation with automatic tool setters and identification systems, etc.

In WSK, NC machines are being programmed by indirect method i.e. CAD/CAM systems and dedicated postprocessors.

UG NX4 and diminishing GTJ system are used as CAD/CAM systems. Preparatory work of complex system is ongoing supported by Catia v5, which is used by main bussiness client. Main task of that system is to create and manage technological documentation, including CNC software.

The choice of technological software isn’t accidental. Both CNC software and CAM system has to keep particular conditions:

- compatibility with valid standard (e.g. Renishaw software „Inspection Plus” and „Tool probing”),
- programming rating and facility, programming automation,
- flexible configuration,
- advanced machining strategies (residue treatment, plunge, streamline, 5-axis simultaneous machining with the tool axis control)
- expanded tool library,
- machining parameters library,
- advanced graphic simulation of machining and machine operations,

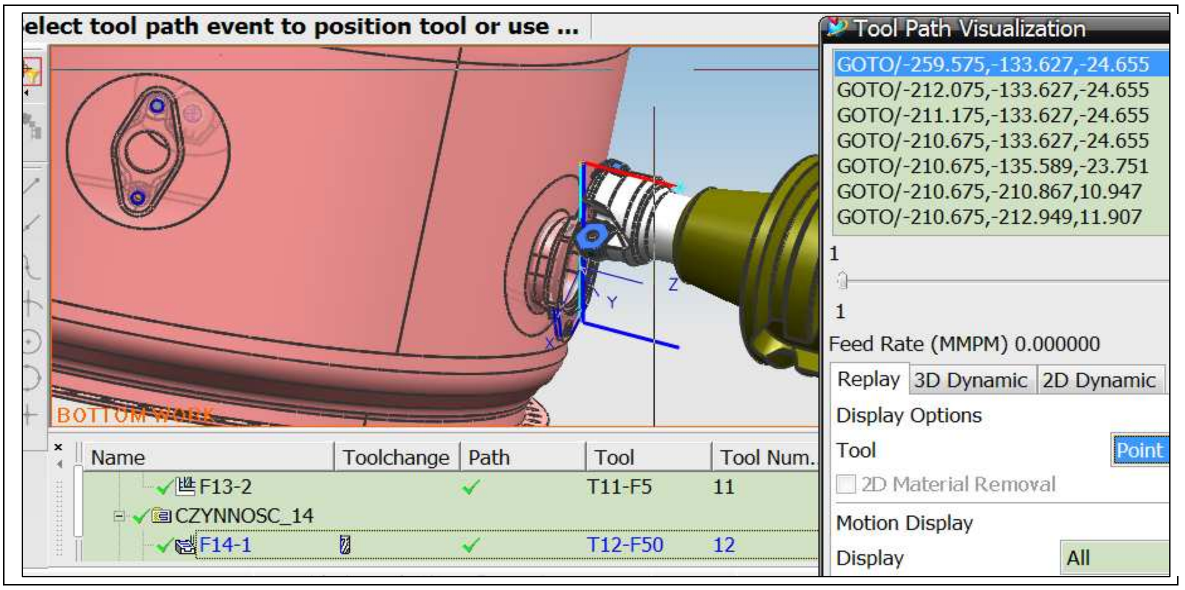

Fig. 12. Tool path analysis in CAM system (UG NX4)

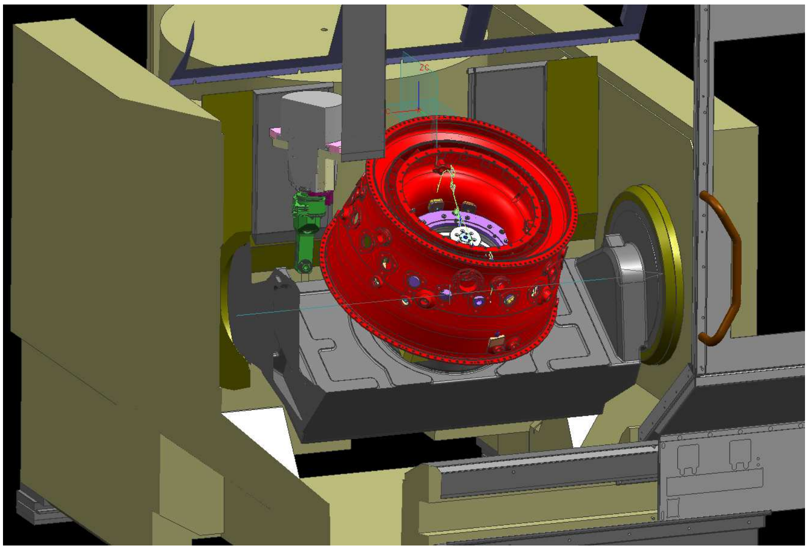

Fig 13. Tool collision analysis using machine model, fixture, tool and machining assy (UG NX4)

Even the best, the most effective, user friendly CAM system with advanced procedures and functions to help projecting machining processes is practically useless, when we don't have postprocessor for a machine centre.

Once, postprocessors were ordered together with machines, however due to the negative experiences in this area (requirements incomprehension by supplier, long period of initiating, large engagement of our workers) it is not longer maintained. At present, this solution is avoided and postprocessors are being created in WSK by programmers.

Nowadays, machining simulation, is limited to CAM system by tool path verification. Configuration of UG NX4 system makes possible to verify machining process propriety to a limited degree. Actually the collision analysis tests with 3D machine models are being conducted. It is applied to machining complicated assemblies in hard to reach places by special tools. 3D machine models are one of the contract requirements for new machine.

The final CNC program implementation takes place on a machine with the use of a machining part model, where the final verification of the program takes place.

It is not an optimal solution, which is why software purchasing and creating machines database is planned. It will make possible to simulate the CNC code on a “virtual machine” with real machine kinematics.

The example of tool application to machining simulation are shown in Fig. 12 and 13.

4. MAINTENANCE CHALLENGES

The important criterion in choosing of a machine producer is service provided by this producer. Specialist’s support and wide experience has a significant influence on high efficiency and the time of machine’s life. Both positive and negative experience in this field inclines that a special attention will be paid to:

- location - is manufacturer’s service situated in the region/country
- time of reaction on notification of problem – in some cases it took one month time from notification, which lowers new machine’s efficiency,
- service's competences and their effectiveness - well known from ongoing cooperation, commendable or discredited
- the costs of service - may be formed depending on negotiated conditions contained in contract of purchase and they are different for individual manufactures,
- the complexity of service - when the machine includes equipment of different companies (the measuring probes, the IT systems, mechanics), in the case of its defect, the manufacturer of machine tool didn't feel responsible for service delivered equipment, in spite of the fact that the contract included it also. The equipment of machine tools with measuring systems is the most general example. Both the manufacturer of machine tool and the manufacturer of measuring probes were convinced that the other side should be responsible for costs of service,
- extra services e.g.: extra, free control of machines at the end of the time of guarantee,
- availability of exchangeable parts in longer period of time - the older tools, despite long life time, can be steel useful. Availability of exchangeable parts for older machines as well as the expert's professional knowledge, can make the time of machine's operation much longer.

In the time of first use and operating new machines, we cannot avoid appearing problems:

- problems with precision - e.g. linear scale damage, lack of dimension repeatability in longer period of time,
- problems with special equipment - e.g. with instrumentation for calibration of measuring and tool probes,
- inappropriate setting of the CNC parameters steering for programming in EIA/ISO,

– pallet exchange system damage
– leakage from cooling system
– damage of door' blockade
– small damages of control system - e.g. automatic break of machining
– insufficient, imprecise or incomprehensible technical documentation

5. SUMMARY

The competitive market of aerospace components manufactures mobilizes WSK to improve the methods and tools of work. Monitoring progress and taking part in different kind of development programs have an effect on manufacturing processes in WSK. These situation causes that requirements for machining centers and equipment as well as for machine's delivers are still changing. The special requirement today is, e.g. monitoring and programming of spindle load and drive feeds, cooling system with minimum quantity of liquid (MQL), cooling system with high pressure through toll (Chip-Blaster), etc. in short time becomes standard in WSK.

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