TENDENCIES IN THE DEVELOPMENT OF PRODUCTION ENGINEERING

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1. Introduction

One of the basic elements of technological developments is the rapid development of production engineering. The article presents the trends in this field from the view of past, present and future.

2. Development of Production Engineering

In the past 30 years production engineering, especially machining, developed substantially. According to a German survey the norm time for one generally chosen product that was produced in 1960 decreased to 1/5 [1] in 1990. Considering [1] the tendencies to be expected until 2000 are drawn according to Figure 1.

The main factors of the development are as follows (according to Figure 1):


- In respect of tool material, the main steps of the development are: coated carbides -> single-layer coatings (TiC, TiN, and TiAlN) -> multi-layer coatings -> diamond and ceramic inserts.

- Changeable-insert technique, contraction of multiple-tool operation element, implanted insert tools with complex geometry.

- Model and knowledge based manufacturing processes, control and regulation -> monitoring sensors -> machine intimate and adaptive controls -> environment friendly machining, minimal lubrication technique -> high speed machining -> integration and combination of process methods.
For conventional machine groups only 11% of the real working time was machining time. In production with today's modern monitoring systems this time can be increased up to 65% (see Fig. 2).

This short summary will be explained in detail in the following.
1. without monitoring, 2. theoretical working time, 3. there is no 3rd shift, 4. Saturday, Sunday, holiday, 5. there is no 2nd shift, 6. set up time, organisational problems, maintenance, 7. technical breakdown, stops due to human causes, 8. 75% of this can be avoided, 9. real working time without monitoring system, 10. with monitoring system, 11. the 1st shift with monitoring, 12. the 2nd shift with monitoring, 13. the 3rd shift with monitoring, 14. automated operation at Saturdays, Sundays and holidays with monitoring, 15. real working time with monitoring system (for 3rd shift)

Figure 2. Properties of machine utilisation [1]
3. Connections between production engineering and other fields of science

It has to be taken into consideration that production engineering is in close connection with a lot of other fields of sciences. Some of them are as follows (Fig. 3):

- Physics (e.g. shaping force examinations, process modelling in molecular and atomic dimensions, nanotechnology, etc.)
- Electrotechnics (controlling, regulation)
- Biology (ecology, environmental factors)
- Mathematics (information science, quality assurance, process simulation)
- Chemistry (fuels, lubricants)
- Economics of works operation (economics, management)
- Materials science (examination of materials, material development in micro- and macro-structures)
- Production planning (configuring the manufacturing process, assignment of machine tools and manufacturing devices, planning of support and auxiliary manufacturing elements, design of manufacturing systems)

Figure 3. Connection between production engineering and other fields of science
4. The development directions are surveyed in the following structure.

Main development directions in production engineering:
1. Main development directions of machine tools
2. Development tendencies in production engineering
   2.1. General development tendencies in production engineering
       2.1.1. Micro-system technique
       2.1.2. Rapid-prototyping process
       2.1.3. Near-net-shape-technology
       2.1.4. Technical development with ‘new’ structural materials and ‘high’ accuracy (Fig. 4)
           2.1.4.1. High performance ceramics
           2.1.4.2. Ultraprecision technology
               2.1.4.2.1. Ultraprecision machining of ductile materials
               2.1.4.2.2. Ultraprecision machining of rigid materials
       2.1.5. Laser technology
       2.1.6. Environment friendly technology
   2.2. Development directions in cutting
       2.2.1. Development of production engineering
       2.2.2. Increasing the intensity with the use of computers
3. Fields of development in the workpiece-tool relation
4. Effects of new factors on production and the development of manufacturing systems
5. Quality assurance

As an example it can be mentioned that the Department developed and manufactured the production geometry of conical gear hobbing and spiroid worm gearing. The results suggest that in ‘clearance-less’ drives (by simple axial displacement of the worm) spiroid drives can be employed.
ad. 1. Main development directions of machine tools

Results having overriding importance:

- Conventional machine tool constructions have undergone a morphological transformation mainly for achieving better movements for the purpose of control:
  - the lathe centre, in addition to the properties typical of a lathe, can operate as a boring-and-milling manufacturing centre with a circular table (the functions of the circular table are realised with the chuck, which can position it, or if it is rotated, can be controlled simultaneously with the axial movements of the working rotating tool -> 4-D machining with lathe centre);
  - the spindle head of a boring-and-milling manufacturing centre can be tilted independently or coordinated with other movements into vertical/horizontal or other positions -> the horizontal or vertical nature of machine tools disappear, and 5-D machining can be achieved.
- measurements, status and process monitoring (with or without a tracer) carried out on machine tools become common,
- in addition to basic machines, manufacturers offer complete configurations to facilitate the building of a system (MAP interface, tool house, workpiece or palette storing-changing unit, measuring option on machine tools, status and process monitoring, serving with robots, etc.),
- new machining methods on machine tools (laser machining, water jet machining, laser heat treatment) can be realised on machine tools with CNC control mechanism,
- machining centres:
  - the speed of moving the drilling unit is increased,
  - the further goal is to decrease cutting time (e.g. applying new microcrystalline ceramic aluminium tool materials),
- there seem to be increasing tendencies in the application of digital connection between the driving and the NC control mechanism, with a speed of 32 Megabit/sec and a synchronising tolerance of 0.5 microsecond,
- the latest developments in 3-D applications are the bender and the 5-axes laser,
- 1 micron adjusting precision between robots with the Hexapod system,
- machines of the forming technologies also appear in cell-like configurations,
- there is a great number of serving modules (e.g. workpiece and tool ‘chargers’).

Effects of the development of complex automation

Complex automation is characterised first of all by the solutions of multi-location machinability and the use of computers.
The following are of overriding importance here:

- CNC boring-and-turning machine centres which are able to machine 5 sides, and CNC lathe centres and their tool systems able to do the complete machining with their 8-9 controlled axes,
- the interfaces, modules and additional elements of system integration, and
- the computer-aided process planning (CAPP).

These resulted in a 5-10 times higher machine utilisation.
There is a further speciality that can be distinguished within the framework of complex automation, namely task-oriented automation, i.e., assembling the flexible single-purpose machine construction from its elements.

ad. 2. Development tendencies in production engineering

2.1. General development tendencies in production engineering

2.1.1 Microsystems technology has developed at a quick pace towards the miniaturisation of product structures (e.g. complete epicycloidal gear with a diameter of 2.8 mm for medical vein examination). Microsystems technology is used for the production of complicated, miniature, micromechanical parts in most cases with a non-mechanical (e.g. lithographic process) production process [2] (Fig. 5).

Figure 5. The miniaturised epicycloidal gear can examine blood vessels (Production of components by the process ‘Liga’)

Japaner zielen mit Mikrostrukturtechnik auf einen Zukunftsmarkt
2.1.2 The rapid-prototyping process is used for the direct production of prototypes with complex geometrical structures and for the reduction of product developing time. The shortening of the process time can be 30-70% depending on the structure of the product (Figs. 6-7).

Figure 6. LOM manufacturing method

Figure 7. Rapid-prototyping procedures
From the 2D image of the tomograph the 3D model can be built-up, and on the basis of this the prosthesis can be produced easily and rapidly.
2.1.3 Near-net-shape technology. This new technology can facilitate rationalisation and increase of performance. Near-net-shape technology means the finishing of workpieces which differ only slightly from the final contour after the primary and plastic shaping, i.e., small allowances have to be removed as far as possible in one grip and with one advance. The development of erosive technique assists this to a great extent.

2.1.4 Technical development with ‘new’ structural materials and ‘high’ precision. High-strength industrial ceramics (e.g. sliding-ring seals of all-ceramic internal combustion engines) and reinforced-fibre plastics (e.g. used in car manufacturing, etc.) belong to the new materials nowadays.

2.1.4.1 High-performance ceramics. The main fields of application include e.g. ceramic ball bearings.

2.1.4.2 Ultraprecision techniques are developed together with new materials in the directions of tolerance, surface requirements and extreme ranges. In manufacturing and measurement techniques the increasing use of laser requires a great number of reflective optics for directing the laser beam. These surfaces can be manufactured by conventional grinding, lapping, and polishing only time-consumingly and non-economically. Obtaining the submicrometre (nanometre) range of tolerance requirements, which is close to the atomic radius, creates special requirements (Fig. 8).

![Ultra precision lathe at the Department of Production Engineering of the University of Miskolc](image)

2.1.4.2.1 Ultraprecision machining of ductile materials. Ultraprecision machining of these materials can be performed by turning, and milling with monocrystalline natural diamond tools. With these tools a radius of 0.01 micrometre can be obtained. Naturally, this process permits the machining only of metals and metalloids that have a low affinity for carbon as well as some types of plastics.
2.1.4.2 Ultraprecision machining of brittle materials. With the ultraprecision grinding of brittle materials a nanometre range of workpiece roughness can be obtained if an appropriate technology, a high-speed grinding wheel and grinding machine are used.

2.1.5 Laser technology

2.1.6 Environment-friendly technology (Figs. 9-10)

Figure 9. Universities co-operating in the environmentally friendly EU project EUROPEAN COMMUNITY PROJECT (STD-2 EC, ERB CIPACT 930167) Clean Manufacturing Technology – Decrease and Substitution of Coolants and Lubricants

Figure 10. Development of environment friendly cooling-lubricating tool holder
2.2 Development tendencies in cutting

2.2.1 Development of Production Engineering:

2.2.1.1 New technologies and modifications:

- Combination of processes:
  - turning-milling/milling-broaching,
  - laser technology,
- Technological development through using new, high performance control mechanisms of machine tools

2.2.1.2 Performance increase through the development of cutting material:

- cutting materials used in practice,
- rationalisation potentials
- optimisation of the composition of alloys,
- fine-grained cutting materials;

2.2.1.3 Performance increase through the development of tools:

- technical fields of application of changeable tips,
- fields of monolith tool types;

2.2.1.4 Performance increase through the enhancement of elasticity:

- flexible processes,
- laser and water jet processes,
- optimisation of production process;

2.2.1.5 Performance increase through the development of auxiliary materials:

- importance, tasks, classification,
- minimal-lubricating technique;

2.2.2 Intensity increase through the use of computers:

2.2.2.1 Strategies of computer aided production planning:

- Model and knowledge-based production optimisation and production development,
- Examination of further improvement and process modelling,
  - computer aided external optimisation,
  - computer aided internal optimisation,
  - AC regulated and controlled processes,
  - self-optimising process;

2.2.2.2 Performance increase through the monitoring of processes:

- Sensors and devices of tool monitoring:
  - monitoring tool break,
  - detection of force and fluctuation (of the current in the engine),
  - tool wear and edge life monitoring,
  - perspective sensor development.

ad. 3. Fields of development in the workpiece-tool relation

- results of developments of the workpiece and the tool material,
- possibilities of formations of face and flank surfaces of a tool (e.g. in tools with complex geometry),
• possibilities of the improvement of machinability (cutting property) (e.g. application techniques of coolants and lubricants).

**Overall tendencies of tool development**

- oxide ceramics, silicon nitrides, cermets and use of coatings,
- spread of new tip geometries,
- designing of modern - in their cross-section - milling tools (e.g. Coronite, Fig. 11),
- application of medium hot and hot cutting,
- IT5/IT6 machining by turning, milling,
- development of fine-grained, ultra fine-grained carbides,
- developments in the field of single-point edge tools,
- systems design of assembled tool solutions,
- application techniques of multiple-tool machining with changeable tips: for combining several operation elements in one tool (program tool), and for tool circulation based on tool pallettes in manufacturing cells (and/or systems),
- development of environment-friendly technology.

![Figure 11. Development tendencies of tool materials](image)
From the analysis of the results the following conclusions can be drawn:

- Oxide ceramics and silicon nitrides have also become suitable for industrial applications, the use of cermets and coatings is well established.
- New tip-geometries have been created and have become suitable for industrial applications with technological solutions ensuring modern production geometry.
- Development of new tools for applying environment-friendly technologies.
- Modern tool material solutions (according to stress) have been developed, mainly for milling tools.
- Medium hot and hot cutting with the appropriate tooling is gaining ground nowadays.
- IT5/IT6 quality surfaces produced e.g. by turning, milling, etc. are more and more common.
- The use of fine-grained and ultra fine-grained carbides shows great development results.
- In multi-point tools a similarly great development can be seen as in single-point tools (e.g. in grinding wheels, manufacturing tools with fine surface). On the other hand, it must be mentioned that, in order to increase operation concentration, the replacement of multi-point tools is the main direction of developments.
- The systems of assembled tools solutions approached monopoly position, and methodical planning has resulted in a tool system that can be used for both moving and rotating tool systems.
- Flexible tool fixing systems have started to develop – with modern marketing methods applied – for the purpose of adjusting tool supply to user-centred manufacturing.

In the creation of the face and flank surfaces which are determinant in the working of the tool important development stages can be distinguished. Here, first of all tools with complex edge geometry used for toothing can be mentioned; they represent one of the research fields of the Department of Production Engineering of the University of Miskolc [3].

In this field the aims were:

- elaboration and generalisation of geometrically correct finishing of helical surfaces taking into consideration earlier and recent results in kinematic geometry and toothing theory [4];
- determination of the proper profile of the wheel for the grinding of a given profile, development of devices for creating the required profile;
- production geometrical analysis of single-point tools for machining;
- mathematical formulation of the required geometrical and contact conditions;
- elaboration of the measuring and qualifying processes;
- general systematisation of production geometry on the basis of characteristic data of different types of helical surfaces;
- developing special devices for production in modern manufacturing systems [5];
In this topic during the development of the tools we dealt with:
• tools for cylindrical and spiroid worm-gear drives;
• gear-hobbing and profile cutters, profile-grinding wheels [6];
• different threaded tools, etc. [7].

Recommended development and research guidelines:
• it is essential to re-organise high-level cutting tool supply based on domestic manufacturing bases,
• breakthrough is possible only with ‘high quality’ cutting tools,
• accordingly, the activities in domestic research, development and cutting experiments have to be intensified.

Arguments for the use of dry machining:
• dry machining is environment-friendly, and health-supportive,
• it decreases the costs of chip clearing, there are no coolant costs,
• there are no coolant clearing costs, which decreases production costs [8].

Arguments against dry machining:
• decreases the edge life of tools,
• increases machining time,
• decreases productivity.

ad. 4. Effects of new factors on production and the development of manufacturing systems
The results which can be distinguished in this field – for the purpose of the optimisation of value adding – are applications related to manufacturing with more effective co-operating small units instead of manufacturing with production units. This means the correct division of the technological process as well as the implementation of a system that prescribes the issues of quality assurance and creates the conditions for co-operation. The correct division of the technological process helps the efficiency of the supply system. This makes it possible to satisfy the needs coming from below, and to co-ordinate the methods based on high-performance ‘mass production’ coming from above with the market demands. In conventional production methods the steps of the technological process and the supply process follow each other in turn, essentially for the purpose of achieving the production plans coming from above. Nowadays the modern production method takes into consideration, in order to satisfy the market demands, that the ‘production chain’ has to be divided (product variations have to be created!). The section boundaries that are required for this have to be determined carefully on the basis of the possibilities created by the design and the restrictions considered in consequence of the chosen technology.

ad. 5. Quality assurance
The development of systems controlling quality assurance can be analysed on the basis of Figure 12. Nowadays the DIN ISO 9000 series are exclusively dominant and this system assists in the success of the elements formulated in the last section.
5. Conclusions

5.1 Drawing conclusions from tendencies
The Hungarian university Departments of Production Engineering have always kept in touch with the developments in production engineering. This is demonstrated by the evolution of the following areas included in the academic and research work of the departments:

- flexible automation,
- process modelling, optimising and monitoring,
- Computer Aided Design (CAD),
- application of artificial intelligence,
- precision and ultra-precision production,
- new, non-conventional procedures,
- robotics,
- up-to-date controlling systems,
- resources planning and production programming,
- quality assurance,
- rapid prototyping, etc.

5.2 Development trends in production-informatics
Intelligent manufacturing
The main trends of integrated planning and controlling systems can be summarised as following:

- besides mass and series production: tailored production, mass customisation of products,
• further integration within CIM (Figs. 13-14),
• time factor (concurrent engineering, rapid and virtual prototyping, simulation, virtual manufacturing),
• quality (monitoring, diagnostics, ultra precision machining, quality management),
• symbiosis of technical and business decisions (business process re-engineering, enterprise integration, management decision support systems),
• globalisation (world-wide distribution, co-operative production, production networks, logistics),
• sustainable development (green production, life-cycle engineering, assembly-disassembly, recycling),
• instead of unmanned factory: the importance of human factors (education, new organisation paradigms)
• miniaturisation (submicron- and nano-technologies, manufacturing, assembly),
• application of artificial intelligence techniques (intelligent manufacturing processes and systems).

Naturally, the trends mentioned above occur not one-by-one, but parallel to each other. The restrictions appear, generally, in the paradigms of Intelligent Manufacturing Systems. Currently, the Department of Production Engineering of the University of Miskolc is involved in the trends presented above through the fields of environment-friendly technologies, rapid-prototyping, modern gearing systems in CIM systems and tooling.

Figure 13. A grinding wheel truing and measuring system in operation
(Patent registration number: 207967) Inventor: Illés Dudás
Figure 14. Production of helicoidal surfaces in a CIM system
(University of Miskolc, Department of Production Engineering)
References

3. TU Miskolc, Lehrstuhl für Maschinenbautechnologie, April/Mai 1994. (Gastprofessur)