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Original scientific paper

BENCHMARKING FOR IMPROVEMENT OF BUSINESS PROCESSES

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A b s t r a c t: The article describes the methodology of Benchmarking as a base for improvement of the business processes. Predefined types of the Benchmarking process are dependent on the business nature and the company. The phases of the Benchmarking processes such as planning, analysis and improvement are described in the article. The article also practically shows the readiness of a company from the production area for implementing the Benchmarking project. To determine whether your business or organization is ready for Benchmarking, complete the questionnaire in Table 2 based on the American Productivity and Quality Center (APQC) material.

Key words: Benchmarking; business processes

1. INTRODUCTION

The Benchmarking process is defined as "finding and implementing the best practices that lead to superior performance". This deceptively simple definition may cause management to underestimate the effort required to successfully complete a study. Consider that the Benchmarking study first requires that you know and document the current methods by which you perform the work targeted for improvement [8].

Product, service and process improvements can take place only in relation to established standards with the improvements. Benchmarking, one of the most transferable aspects of approach to total quality management, and thought to have originated in Japan, measures an organization's operations, products and services against those of its competitors. These are the means by which targets, priorities and operations that will lead to a competitive advantage can be established [1].

The Benchmarking process is a structured approach of comparison and learning. It involves comparing the operation and performing of a process with the equivalent process in other organizations and organization units. The aim is to learn from the comparison and introduce improvements into your way of doing things.

2. BENCHMARKING PROCESS

Benchmarking is a process of comparing with and learning from other opponents about the manner of doing things and how well they are done with the aim of clarifing improvements. Benchmarking focuses on how to improve any given business process by exploiting the "best practices" rather than merely measuring the best performance. The best practices are the cause of the best performance. Studying the best practices provides the greatest opportunity for gaining a strategic, operational and financial advantage [2, 3].

Benchmarking is a relatively advanced improvement technique which is best applied as an improvement process starting to mature. The most appropriate time to undertake a structured Benchmarking activity is when the following applies:

- a new idea exists and needs to accelerate improvement of the process in order to effective comparisons;
- new ideals are thought to be needed to accelerate improvement;
- the organization wants to learn from others, adapting the best practice and the best processes.

2.1. Types of Benchmarking

The choice of type of Benchmarking is to some extent determined by the nature of the process – some that lend themselves to easy internal Benchmarking, while some technically complex processes are best looked at within the industry (Fig. 1). Where there are options, the choice is normally determined by a balancing risk and reward-internal Benchmarking which is the easiest and therefore usually the least expensive to do, but it often yields only modest benefit. On the other hand, generic Benchmarking is the most complex and potentially expensive, but it can produce a real breakthrough improvement.

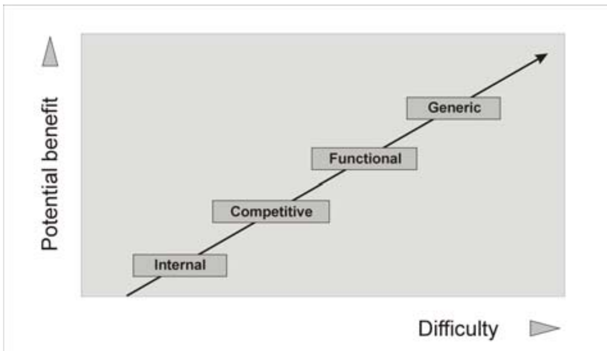

Fig. 1. Potential benefits depend on Benchmarking types [4]

Internal Benchmarking

Internal Benchmarking is applicable when we compare the performance of similar or identical processes that operate throughout in the organization (e.g. across different departments). Internal best practices may be found in a number of processes, and the result is a new standardized process that incorporates a number of these practices and thus raises the performance of the process in all areas.

Competitive Benchmarking

Competitive Benchmarking gives a direct comparison with your competitors. This type of Benchmarking is most often done remotely, rather than by a visit. Research has to be bassed on material that is freely available and published.

Functional Benchmarking

This is where the function of the process has many parallel examples in many other organizations. Often these processes are those that nearly every organization needs to carry out to perform effectively and they are usually the supporting processes within the organization.

Generic Benchmarking

This is the most abstract form, and it involves comparison of processes with similar features, but which on the surface can seem very different.

2.2. Phases of a Benchmarking process

Benchmarking was used in the development of the leadership through quality strategy, and extended far beyond competitive analysis to include the identification and study of the best in the class for all areas of process management relevant to the business.

A Benchmarking process has three phases (Fig. 2): *planning, analysis and improvement***.**

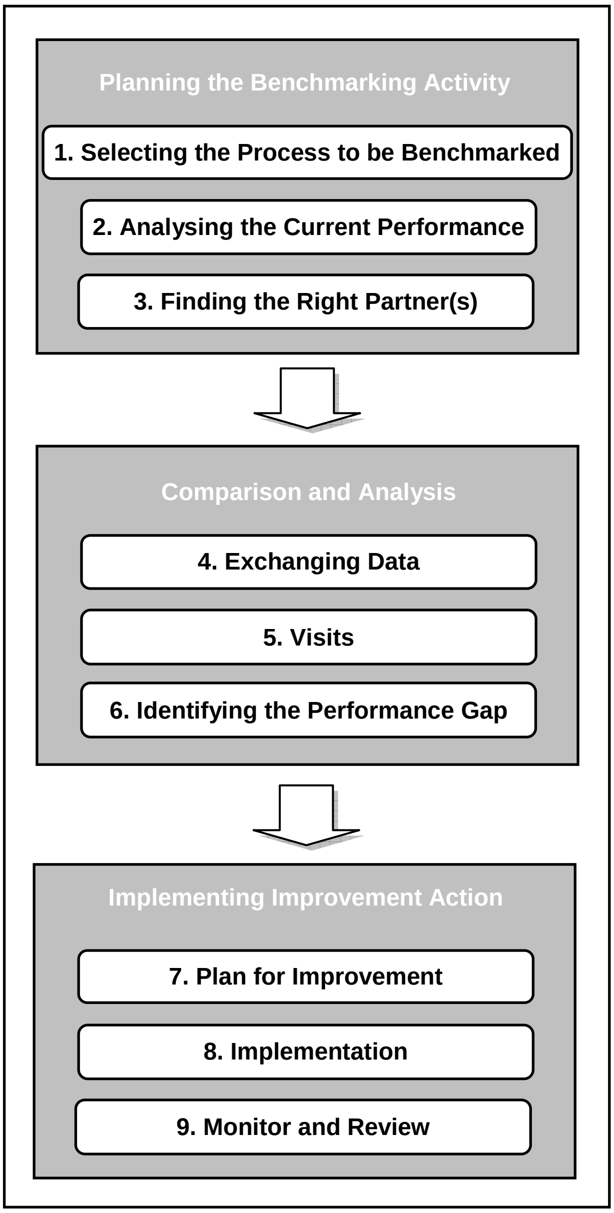

Fig. 2. The phases flowchart of the Benchmarking process according to literature data [4]

Planning

Like most good quality practices, the secret of successful Benchmarking lies in the quality of the planning undertaken. Choosing the most appropriate process to benchmark is vital. Ensuring that the organization thoroughly understands the performance of its own process before looking for comparisons is the next step in this phase. Once management had done this, then it is ready to research the performance of other organization and identify the best potential ones which to benchmark.

Analysis

Having established suitable Benchmarking partners, you are then ready to exchange information about your respective processes – either through remote data exchange, a face-to-face visit or quite often, a combination of both. This enables you to establish the size of the performance gap and helps you identify the most interesting opportunities for improvement.

Improvement

Option for improvement can then be identified and prioritized, and once the desired improvement options are agreed, the planning for implementation can take place. Successful implementation of the new process is obviously the most critical part of the project so it is important to monitor measure and review performance in order to ensure that the desired improvement has indeed been achieved.

2.2.1. Planning the Benchmarking activities

- *Selecting the process*

Structured benchmarking projects need resource and often involve expenditure in terms of travel and other associated costs. Done well, they are therefore a significant investment for the organization, unless you are simply Benchmarking internally. It is therefore important to choose the subject of Benchmarking wisely.

Very often the processes chosen for Benchmarking are those that would appear the greatest scope for improvement.

- *Analysing the current performance*

A fundamental requirement of successful benchmarking is the need to thoroughly understand your own process before seeking Benchmarking partners. The flowchart is essential not only to help you understand the effectiveness of your process, but also your Benchmarking partner may be in demend to see the flowchart. The high level process can easily be seen and understood, but operational details are also available when needed.

Once flowcharted, the key characteristics of the process are measured. The measures used may relate to customer satisfaction, the outputs of the process or the internal process performance.

- *Finding the right partner(s)*

If the desire is to become "the best of the best", then this is a critical stage in the Benchmarking process. Identifying the most appropriate type of organizations to partner with, finding the best performers, and then making contact and getting access is key to success. The steps involved cover the following:

– confirming the appropriate type of Benchmarking;

– researching possible partners;

– identifying and selecting best-in-class performers;

– developing preliminary questionnaires for potential partners;

– identifying what you have to offer potential partners is return;

– making initial contact.

Effective research is the key. The purpose of preliminary questionnaires is both to gather information to narrow down the partner choice and to avoid wasting both your own time and resources and those of your potential partners.

The questionnaires should be designed to provide information that you have not been able to establish from desk research. The required information is usually related to the performance of the process, and is used to help choose the most effective partners.

2.2.2. Comparison and analysis

The second phase of the Benchmarking process involves comparison of processes, performance and the analysis of the results in order to answer the questions:

– *What results have been achieved, and how have they been achieved?*

– *What is the difference in performance, and what can we learn from it?*

The main activities are:

- *Exchanging data*

The contact had been made and the agreement got in principle, you should establish the terms of agreement for working with the partner. For instance, they may have their own conventions as to how much and what type of information is needed before a visit can be arranged. Whenever reasonable, you should always try to meet the partner's requirements. In many cases, after a thorough analysis of your own activities and exhaustive research, you will want to visit your chosen partner to verify what is being achieved (using valid and truly comparable measures) and how it is actually being achieved (the processes, procedures and work practices). Remember though that a visit is not always necessary. With appropriate documentation, including flowcharts, if available, it may be possible to conduct an effective Benchmarking interchange electronically or by telephone. This is often necessary when benchmarking partners are in far-flung places (attractive though the thought of a visit might be).

- *Visits*

If it is decided that a visit is appropriate, you owe it to your partner (and of course to yourselves), to prepare well for the visit in order to make the best use of your respective organizations' resources. Having prepared a plan, your partner will expect some information from you about your requirements from the visit. Be prepared to share your checklists, interview plans etc. so that the partner organization is in the best position to optimize your visit. Also, don't forget to communicate within your own organization about plans for the visit. The need for this will obviously vary according to the nature of the project and the organization to be visited.

Planning and organizating of the visit include:
– who should go on the visit;
– how to organize the visit;
– developing check list and interview;
– recording and analyzing the findings.

- *Identifying the performance gap*

The first step in the analysis is to quantify the performance differences between your process and the partner's ones. You need to understand, quantitatively, their practices and approaches. Any of the early steps is the effort to understand the current performance. This can then be used as a benchmark against other organizations that have a similar process where the difference is a simple gap analysis. Some Benchmarking has very structure statistical gap analysis and other use a more qualitative gap analysis of the data collected. It is important that effective Benchmarking rarely results in simple coping of another organization's process. The mayor gains are usually to be found in learning from the other process and adapting aspects of it to fit best your own circumstances and culture.

2.2.3. Implementing improvement action

This is an essential phase of the Benchmarking process. The phase of improvement is an efficient way to promote effective change by learning from the successful experiences of the other one and putting that learning to good effect. Many of the aspects of the phase however, are common to many improvement projects, and should apply the principles of sound change management.

Improvement in the quality of products, services, and processes can often be obtained without major capital investment, if an organization marshals its resources, through an understanding and breakdown of its processes in this way.

The driving force for this will be the need for better internal and external customer satisfaction levels, which will lead to the continual improvement question "Could we do the job better?"

An important aspect of action for improvement of Benchmarking is maturity of the process and the achievements of the superior performance.

Many of the aspects, and you should apply the principles of sound change management.

The broad process you should follow has three phases:

- *Plan for improvement*

The major steps involved here are:

– making recommendations for improvement, with quantitative targets and qualitative practices;

– developing the implementation plan, with activities, responsibilities and resources clearly identified;

– gaining acceptance of the recommendations and plans.

- *Implementation*

Once the organization is ready for implementation of the improved process:

– hand over responsibility to those involved in implementation;

– implement according to the plans;

– monitor the results and progress against plan;

– ensure implementation is integrated into "normal" practice.

- *Monitor and review*

The final step is to review the project for continuous improvement. Then, you:

– review the Benchmarking project and lessons learned;

– identify further opportunities for benchmarking;

– maintain an ongoing relationship with Benchmarking partners.

3. CRITICAL SUCCESS FACTORS AND BENEFIT OF BENCHMARKING

Like any other improvement technique, Benchmarking requires certain prerequisites for success. Many of these factors will be common to improvement projects, such as process improvement teams.

The critical success factors for Benchmarking are:

- *Management commitment and involvement*

This is the most quoted factor. If the cost and effort of benchmarking projects is not to be wasted, management must visibly commit to process Benchmarking practices in order to ensure real and lasting improvement results.

- *Understanding and measurement*

Benchmarking is dependent on understanding processes in detail. Existing systems and procedures must be understood and, where possible, clearly documented and flowcharted.

If you do not know how to measure your own performance, it will be impossible to compare it with other organizations. This is especially true in the case of process Benchmarking where there may be adequate data on the output of processes but few, if any, "in process" measures available.

Management must organize measuring its own performance as a base for comparing to other organizations.

- *Appropriate partners*

Benchmarking will be of most benefit if appropriate partners are identified. Often management may be tempted to benchmark with certain organizations just because they exist as customers or suppliers. According to such approaches, contacts may prove to be more difficult in the initial stage, but the rewards will be greater in the long run.

- *Action*

Benchmarking can only provide information and data upon which to make decisions. The true benefits come from making those decisions about changes and implementing the changes. The action steps are the most critical; you mustn't condemn the good work of Benchmarking teams to the bookshelf of "useful and interesting" reports that are of no action.

- *Integration*

Benchmarking will be most effective when a truly integrated way of doing business and commonly accepted at all levels of the organization. This will be demonstrated by incorporation of external Benchmarking targets and Benchmarking projects into the business planning process and the resultant cascade into team and individual objectives and performance appraisal.

There are many reasons why organizations undertake Benchmarking. When carried out effectively, the process Benchmarking can provide a way to learn from what the others have already achieved, enable learning about the performance levels of other organizations (i.e. benchmarks) and provide a basis for setting improvement targets, provide motivation for people in the organization by seeing just what it is possible to archive [6].

The benefit of Benchmarking can be numerous and it includes creating a better understanding of the current position, heightening sensitivity to changing customer needs, encouraging innovation, developing stretch goals, and establishing realistic action plans.

The idea and opportunities for improvement from Benchmarking are presented on the Figure 3.

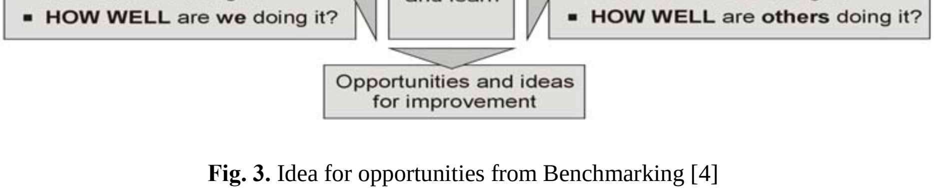

Fig. 3. Idea for opportunities from Benchmarking [4]

4. PRACTICE OF BENCHMARKING

The evolution of Benchmarking in an organization is likely to progress through four focuses. Initially attention may be concentrated on competitive products or services including, for example, decision, development and operational features. This should develop into a focus on the industry best practice and may include, for example, aspects of distribution or service. The real breakthroughs are when organizations focus on all aspects of the total business performance, across all functions and aspect, and address current and projected performance gaps. This should lead to the focus on processes and true continuous improvement [7].

As the simplest, the competitive Benchmarking, the most common form, requires every department to examine itself against the counterpart in the best competing companies. This includes a scrutiny of all aspects of their activities. Benchmarks which may be important for ***customer satisfaction*** for example, might include

- product or service consistency;
- correct and on-time delivery;
- speed of response or new product development;
- correct billing.

Benchmarking is very important for the administration areas, since it continuously measures services and practices against the equivalent operation in the toughest direct competitors or organizations renowned as leaders in the areas, even if they are in the same organization. An example of quantitative benchmarks in an organization for absenteeism is given in Table 1.

Table 1

Quantitative Benchmarking in absenteeism

Organization's absence level (%)	Production opportunity
Under 3	This level matches an aggressive benchmark that has been achieved in "Excellent" organizations.
3–4	This level may be viewed within the organization as a good performance representing a moderate productivity opportunity improvement.
5–8	This level is tolerated by many organizations and represents a mayor improvement opportunity.
9–10	This level indicates that a serious absenteeism problem exists.
Over 10	This level of absenteeism is extremely high and requires immediate senior management attention.

Technologies and conditions vary between different industries and markets, but the basic concepts of measurement and benchmarking are of general validity. The objective should be to produce products and services that conform to the requirements of the customer in a never-ending improvement environment. The way to accomplish this is to use a continuous improvement cycle in all the operating departments – nobody should be exempt.

The purpose of Benchmarking then is predominantly to:

- change the perspectives of executives and managers;
- compare business practices with those of the world class organizations;
- challenge current practices and processes;
- create improved goals and practices for the organization.

As a management process for change, Benchmarking uses a disciplined structured approach to identify ***what*** needs to be changed, ***how*** it can be changed, and the ***benefit*** of the change. It also creates the desire for change in the first place. Any process or practice that can be defined can be benchmarked but the focus should be on those which impact on customer's satisfaction and/or business results – financial or non – financial.

For organizations which have not carried out Benchmarking before, it may be useful to initially carry out a simple self-assessment of their readiness in term of:

- how well processes are understood;
- how much customers are listened to;
- how committed the senior team is.

An American Productivity and Quality Centre shows the readiness of an organization for Benchmarking (Tab. 2). A score between 32–48 means that the organization is ready for Benchmarking, the score 16–31 means that the organization needs some more preparations, and 0–15 that the organization needs some help.

Table 2

Practically provides a simple pro forma for this purpose: is the organization ready for Benchmarking?

Statements about the organization	most	some	few	none
The process has been documented with measures to understand performance	✓			
Employees understand the processes that are related to their own work	✓			
Direct customer interaction, feedback, or studies about customer influence the decisions about products and services		✓		
Problem solving is a teamwork		✓		
Employees demonstrate by words and deed that they understand the organization's mission, vision and values		✓		
The organisation demonstrates by words and by deeds that the continuous improvement is part of the culture	✓			
Commitment to change is articulated in the organization's strategic plan			✓	
Add the columns	3	3	1	0
Multiply by the factor	×6	×4	×2	0
Obtain the grand total	32			

5. CONCLUSION

The process Benchmarking is a structured approach of comparison and learning. Benchmarking measures an organization's products, services and processes to establish targets, priorities and improvements, leading to competitive advantage and/or cost reductions.

The purpose of Benchmarking is predominantly to change perspective, compare business practices, challenge current practices and processes, and to create improved goals and practices, with the focus on the customer's satisfaction and business results.

Benefits of Benchmarking can be numerous and include creating a better understanding of the current position, heightening sensitivity to change customer's needs, encouraging innovation, developing stretch goals, and establishing realistic action plans.

Presented practically, a simple scoring pro forma may help an organization to assess whether it is ready for benchmarking, if it has not been engaged in it before. Help may be required to establish right platforms if low scores are obtained.

Many reasons for benefits of Benchmarking processes exist: to provide a way to learn from what others have already achieved; to enable learning about the performance level of other organizations and to provide a basis for setting improvement targets and to provide the motivation for people in the organization by seeing just what it is possible to achieve.

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Р е з и м е

BENCHMARKING ЗА ПОДОБРУВАЊЕ НА БИЗНИС-ПРОЦЕСИТЕ

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Клучни зборови: Benchmarking; бизнис-процес

Во трудот е прикажана методологијата на Benchmarking-от како основа за подобрување на бизнис-процесите. Прикажани се типовите на процесите на Benchmarking преку кои се дефинирани потенцијалните придобивки во организацијата. Опишани се фазите на процесите на Benchamrking: планирање, споредба и анализа и подобрување. Во трудот исто така се прикажани резултатите од подготвеноста за Benchmarking-от на една организација од подрачјето на производство.

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OPERATIONS IMPROVEMENT THROUGH SERVICE QUALITY

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A b s t r a c t: The problem of ISDN service in the national telecom provider, has existed for several years. Utilization of the service is very low. Low sales of the service arise from the poor quality of the service delivering.

The application of the Pareto analysis of failures in the service delivery shows that the main problem is poor quality of equipment and unqualified technicians for provisioning of the service. By reducing the number of suppliers, replacement of all terminals from vendors that count 80% of total faults on terminals and establishing of the long-term partnership commitment with the best vendors will increase the quality of the service. Well educated, empowered and rewarded employees will also deliver improved quality.

The justification of the proposed solution shows that in the period of one year the company will have financial benefit. Continual measure, review and improved customer service, based on customers' perception of how well the service is, not on how the company thinks it is, is crucial factor for improving quality to obtain business growth.

Key words: quality; service delivery; suppliers; operations

1. DESCRIPTION OF CURRENT SITUATION

"Makedonski Telekomunikacii AD" (MakTel) is a dominant provider of telecommunication services in the Republic of Macedonia.

In 1997, the company was separated from its predecessor "PTT Makedonija" as a telecom provider. In 1998, the Company was registered as Shareholding Company owned by the Government of RM, in order to prepare for the future privatization. In 2001, the Consortium led by the Hungarian telecommunication operator MATAV bought 51% of the shares of MakTel, thus becoming a dominant owner of the Company. Today the Company is publicly held with majority shares owned by Magyar Telekom.

The Company's portfolio consists of a variety of products and services, starting with telephony services in national, long-distance, and international traffic, including ISDN services, value-added services, public payphones, up to Internet services and complex business solutions. At the end of 2006, the total number of subscribers was 480,000, out of which only 9,200 are ISDN customers, which represent only 1,9% of the total customers.

Since the beginning of 2005 the competition exists in all segments of offering voice services. The competition in the Internet exists from the very beginning of Internet era in the country.

In many households, there is a demand for several phone lines: one for business, one for normal family use, one for Internet, a different one for teenage children etc.

In most cases, ISDN is the solution because it offers multiple subscribers numbering, making it possible for as many as 10 numbers to be allocated per line.

ISDN (Integrated Services Digital Network) is a service offered by telecom providers. ISDN offered affordable high-speed last mile connectivity. The biggest ISDN applications are voice, Internet access, and videoconferencing and according to Heather [1], "… few people had an obvious need for the depth of communications service that these lines provide"(p.53).

The company introduces the ISDN service in 1997. From the 18,000 parts installed in the digital switches, only 9,200 are sold until the end of 2006. Nine years after implementing the service in the network, and having in the company product portfolio, the number of customers using the ISDN service is less than 2% from the total number of customers. Although the company introduces the service almost at the same time as other telecom operators in Europe, the number of users in others countries is significantly higher (28% in Slovenia, 12% in Hungary, 32% in Germany). Disproportion is evident. Selling ISDN in the company is a problem.

Ron [2] in his article stated: "Since ISDN is a digital service and capable of high rates of speed over the same pair of copper wires that service the POTS infrastructure, combining voice and data over a common medium, it results in improved service capacity and higher quality" (p. 70). Even ISDN is a digital service and should result in higher quality, customer's perception as the poor service quality is one of the biggest problems for increasing the sales volume.

According to the faults statistics for 2006, the existing ISDN subscribers were reported more than 3400 faults. In the previous years, the ratio between number of subscribers and reported faults was similar.

The detail analysis of reported faults shows that the majority of faults occurred on the network terminals and physical telephone lines. The network terminal is equiped for service delivery throughout transformation of analogue network into digital connection.

Over the period of nine years, the company changes several times the suppliers of network terminals (at least six times). Because of different type and quality of the equipment, difficulties with maintenance exist. The maintenance and fault clearance of different type of terminals is difficult for technicians and usually they need additional help from engineers in an expertise. Therefore, faults are not cleared promptly. The average time in faults for ISDN customers is bigger than for the ordinary phone line. Concerning the fact that the main users are SOHO (Small Office Home Office) users, their business depends on reliable Internet and phone connections. Not having consistent and conformance service delivery forces them to use the alternative type of telephone connections. According to Slack [3] "Quality is consistent conformance to customers' expectations" (p. 555). Obviously, there is no consistency in the quality of offered service and customer's view of quality, so the problem of sales arises from the quality issue.

2. POSSIBLE SOLUTIONS

The ISDN service is inseparable from the company as a service provider. Employees, who install the terminal equipment and activate services, are also part of the ISDN services. In addition, the key for successful service delivery is reliable customer-contact people. Technicians who install the terminal equipment at customer premises are not well trained and educated. The service quality depends on their performance. Therefore, employee's behavior directly affected the ISDN service. Major characteristics of services, their quality, can vary greatly depending on who provides them, when and how.

Because employees are part of the service, the quality of the service will depend on the quality of the delivered service by employees. According to Heskett [4] "…customer satisfaction and the resulting sales volume to the satisfaction derived by the person serving the customer. Naturally, the more motivated the employee, the better the service is**."** A careful selection and development of employees is important to succeed in the business. It is necessary to obtain customers who focus education for technician, and additional technical education for technicians who install terminals. Finally, the implementation of incentive system for all employees involved in the process of service delivering will enhance the quality.

According to Levitt [5] "No matter how well trained or motivated they might be, people make mistakes, forget, commit indiscretions, and at times are uncongenial-hence the search for alternatives to dependence on people" (p. 99). Therefore, relying on quality based only on people is a threat for the company.

Reducing number of suppliers and replacement of all terminals from vendors on which faults frequently occurred is the next possible solution for improving the service quality of ISDN. In addition, the company should offer long-term relationships to suppliers, asking from them to provide exact standardized quality, and to fit the company business policy.

3. DESCRIPTION OF THE PROPOSED TECHNIQUE OR CHANGE PLANNED

The Pareto analysis will be used to identify the vital few problems or causes of problems that have the greatest impact. A Pareto diagram represents the data in the form of a ranked bar chart that shows the frequency of occurrence of items in descending order. The Pareto diagrams usually reveal that 80% of the effect is attributed to 20% of the causes; hence, it is sometimes known as the 80/20 rule. The purpose of the Pareto analysis is to distinguish “vital few” from “trivial many”.

Kiesow [6] while discussing the usage of the Pareto chart as a tool for continuous improvement gives three steps for using the chart

- identify the most significant aspects of the problem,
- generate theories and test them,
- use chart to show the impact of each theory.

If the theory worked, the largest bars of the Pareto chart will be reduced. In the next step, bars will show another set of significant items.

Using the strategic service vision by Heskett [4], the company should find a link between the service concept and the operating strategies. The company should maximize the difference between the value of the service to customers and the cost of providing it. On the other hand, the company must take care of the customer’s perception of quality of services, because if the customer finds that the quality is not on a satisfactory level, that can jeopardize the current ISDN service.

According to Slack [3] operations seek to satisfy customers throughout developing five performance objectives. Those five performance objectives are quality, speed, dependability, flexibility and cost. The customer has a strong influence on performance objectives, so different competitive factors (defined by customers requirements) imply different performance objectives.

Order qualifying factors for the ISDN service are prices comparable with ordinary phone lines and the possibility for value added services offered by ISDN. Order winners factors are high-speed Internet connectivity, digital quality of voice and possibility up to ten numbers to allocate per line.

According to Parasuraman [7] study, presented in his article, customers define 10 different dimensions of consumers’ expectation about perception of services. In addition, he presents four key discrepancies or gaps on the service provider’s side that affect the customer's perception of the service quality. The existing gaps are related to service quality specification-service delivery gap and expected service-perceived service gap. Taguchi [8] stated that if the product or service fails, the company must replace it or fix it. Losses will be much greater than the cost of manufacture, and there are no expenses that will recoup the loss of reputation. MakTel case of failure of the ISDN service delivery is proved what Taguchi wrote in his article. The bad reputation of MakTel ISDN service, reduces the usage of this service and it is very difficult to be on track again.

In the Table 1 below fault statistics for 2006 for ISDN are presented. According to that data, the Pareto chart is prepared.

Table 1

Fault statistics for ISDN (place of faults)

Telecommunication Operational Center (OC)	Number of active ISDN subscribers	Reported faults in 2006	Place of faults						
			Physical telephone line	Network terminal	In-house installation	Power supply of network terminal	Switching system	Main Distribution Frame	Others
OC Skopje	4240	1630	498	728	152	104	75	29	44
OC Štip	2240	956	304	399	100	27	45	41	40
OC Ohrid	2720	880	286	335	98	54	31	36	40
Total	9200	3466	**1088**	**1462**	**350**	**185**	**151**	**106**	**124**
			31.39%	42.18%	10.10%	5.34%	4.36%	3.06%	3.58%

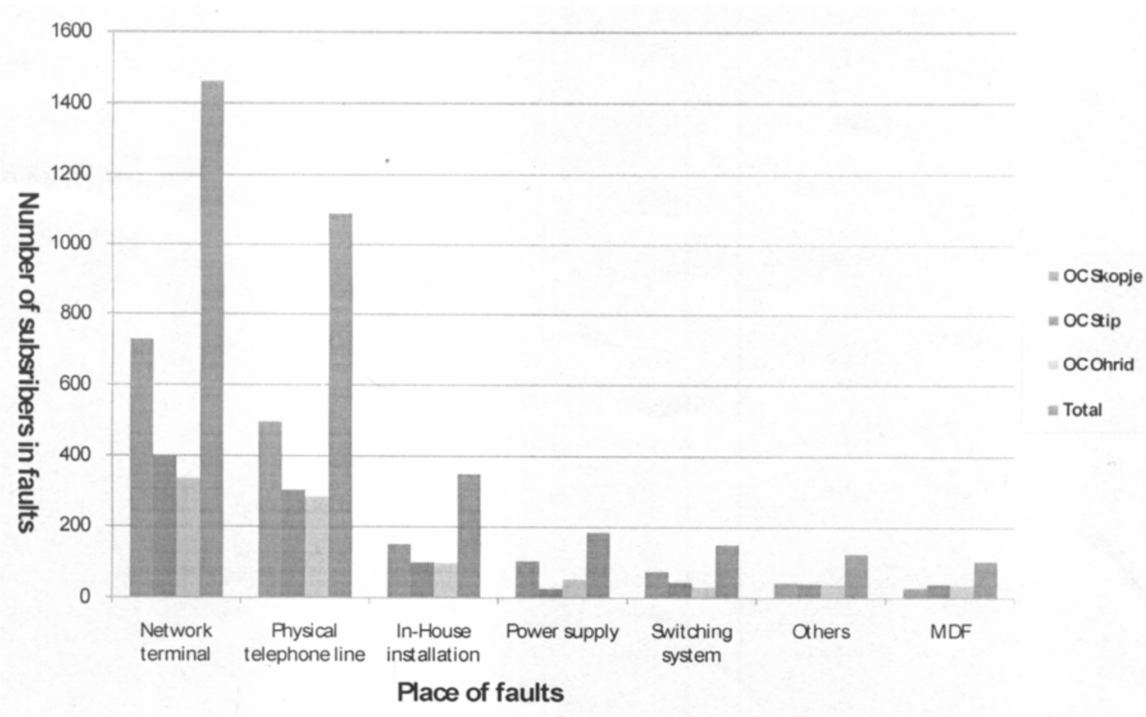

Chart 1. The pareto diagram for causes of faults on ISDN subscribers

Two items cover more than 73% of all faults. Extraction of 'vital few' from 'trivial' many is done. The problem is identified; the next step is to analyze the causes. Problems with faults on the physical telephone line exist due to the configuration of network and designing access networks with aerial copper cables. This problem is well known and it is not a part of this analysis. The focus is how to overcome problems with network terminals.

Detail analysis shows that there are two major problems on terminals. The first one is faulty terminals. The second one is faults on terminals due to bad terminal configuration.

For the first problem, detail analysis of all suppliers of NT was made. There are six different suppliers. More than 80% of all faults occurred on the terminals supplied by two vendors.

As Porter [9] stated, "From a strategic point of view, it is desirable to purchase from suppliers who will maintain or improve their competitive position in terms of their products and service". The company should conclude long-term contracts instead of six, with only two suppliers of network terminals. Terminals from two vendors on which faults occurred frequently, should be completely replaced. As a result, there will be fewer faults, easy maintenance, and lower training cost, thus improved quality of the service.

Stanley and Goetsch [10] pointed that "employees need ongoing education and training to continually improve quality, productivity and competitiveness" (p. 178). Additional training for technicians should be obtained. Training should consist of two parts. The first one is the technical part and will be focused on configuration of terminals. The second part will be strictly customer focus oriented training. By that, the company will provide consistency in service delivering.

4. JUSTIFICATION OF PROPOSED SOLUTION WITH COST BASED ANALYSIS

"Companies seek to maximize the difference between the value of the service to customer and the cost of providing it", stated Heskett [4] in his article (p. 119).

The proposed changes and contribution to the company improvement into the operations are analyses in the period of one year. Those changes will bring benefit to the company in the next years, too.

To improve service quality, the company should ensure additional training for technicians. The course duration will be two days and will cover configuration, installation and maintenance of NT. Additional training should be obtained for the same employees to improve customer relations contact.

According to the analysis, 60% of faults are on the terminals out of which 80% belong to two vendors. Hence, for replacement will be 3466×0.6×0.8 = 1664 network terminals.

Marketing cost will be generating to inform all ISDN customers about new strategy for improving quality of services and to inform all other potential new ISDN customers.

Improving quality of services will reduce time in faults. The first benefit will be increased traffic revenue. The second and the biggest benefit will be increasing of sales volume of ISDN. Revenue will be generating from connection fee, new traffics and monthly subscription fee. The third benefit will be reduced costs for overtime work for maintenance of faulty terminals. Related to the operational improvements, it is expected to have reduced customer complaints that will result in reduced usage of customer care personnel. Having two suppliers will reduce inventory costs also. In addition, the greatest benefit will be increased value of the company brand due to the increased quality of offered service, reduced faults and promptly fault clearance.

By adding all benefits and subtracted from all additional costs will result in a positive effect of 124,760 € in the first year (Tab. 2).

Table 2

Cost based analysis for 5mproving ISDN service

	Cost benefits analysis		€
Cost			
	Additional training for technicians	188 technicians × 2 days × 400 €	150,400
	Customer care training	188 × 2 × 300 €	112,800
	Cost of replacements of NT	90 € × 1664 pcs.	149,760
	Marketing costs		30,000
	Incentive system for ISDN service delivery	Budget, dedicated to quality improvement	25,000
Total			467,960
Benefits			
	Increased traffic revenue for 2%	2% from 20€×12 from 3400 subs.	16,320
	Saving on customer care personnel	Reduce usage of personnel	6,000
	Saving on over-time work for maintenance activities	Reduce over time works up to 50%	4,600
	Increased sales of service for 15%	15% = new 1380 subscribers	
	One time connections fee	50€ × 1380	69,000
	Monthly subscription fee	10€ × 1380 × 12month	165,600
	Traffic generated from new subscribers	20€ × 1380 × 12month	331,200
	Brand/Image improvement	Cannot be quantify	
Total			592,720

5. CONCLUSION AND RECOMMENDATIONS

ISDN as a product offers benefits to the customers. Those benefits are communicated and delivered by product attributes. The main product attribute is quality. Quality is one of the major positioning tools. Quality level supports the position of the product's on the market.

Quality level could be increased if the company offers consistency and conformance in the service elivery.

Reducing suppliers of terminal equipment, improving relationship with them based on commitment on long-term partnerships, and force them to obtain standardize quality of product is one set of improvements of service delivery. As Stanley and Goetsch [10] pointed "The goal is to create loyal, trusting and reliable partners to win, while promoting the continuous improvement of quality, productivity and competitiveness" (p. 171).

The other set is delivering quality through employees. Employees should be encouraged, empowered and rewarded for delivering an excellent customer experience. In addition, developing and training employees is one of the key factors for improving the business and driving quality. People should share good practice and be involved in improvement activities (generate ideas, propose solutions). Establishment of incentive systems for rewarding employees for achievement and performance of excellent quality in the service delivery is also important and useful tool. Delivering on the basics of quality, as British Telecom [11] proposed is the key factor for success.

Continual measure, review and the improve customer service, based on what customers tell us about how well the service is, not on how the company thinks it is. Using diagnostic tools for cost of quality, statistical approaches, business excellence self-assessment, and other techniques, to find possible improvement in business processes and operations and prioritize it.

Finally, justification of changes showed that operational improvement would gain significant benefit even in the period of one year.

Obviously Kotler [12] is right when states that by increasing customer ratings of the service quality, business could grow faster.

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Р е з и м е

ПОДОБРУВАЊЕ НА ОПЕРАЦИИТЕ ПРЕКУ КВАЛИТЕТОТ НА СЕРВИСОТ

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Клучни зборови: квалитет; сервис; испорака; добавувачи; операции

Проблемот со сервисот ISDN во националниот телеком-провајдер постои повеќе години. Искористенодување наста на сервисот е многу мала. Слабата продажба произлегува од лошиот квалитет на испораката на сервисот.

Применувајќи ја анализа Парето на грешките во испорака на сервисот, се покажува дека главен проблем е лошиот квалитет на опремата и не квалификациите на техничарите кои го испорачуваат сервисот. Со намалување на бројот на добавувачи и на замена на сите терминали на добавувачите кои прават 80% од вкупните повреди на терминалите, како и со воспоставување на долгорочно партнерство со најдобрите добавувачи ќе се зголеми квалитетот на сервисот. Добро образовани и обучени работници, на кои им се дадени овластувања и кои добро се наградени, ќе испорачуваат подобрен сервис.

Анализа на предложеното решение покажува финансиска добивка за претпријатието во период од една година. Континуирано мерење, следење и подобрување на сервисот и споредување на претплантниците, базирано на перцепцијата на корисниците колку е добар сервисот, а не колку компанијата смета дека е добар, е критичен фактор за подобрување на квалитетот и согласно со тоа обезбедување на деловен растеж.

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MECHANISMS OF DECOHESION IN CUTTING ALUMINIUM MATRIX COMPOSITES

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A b s t r a c t: In this paper properties and applications of aluminium matrix composites are presented with a composite reinforced with saffil fibres selected for topical study. Behavior of matrix and reinforcement during machining with a cutting tool is analyzed. The paper presents an explosive quick-stop device designed to obtain undisturbed machined surface for examination. Mesohardness measurements of deformed structure, resultant chips and built-up-edge were carried out. Scanning micrographs of machined surface are presented with morphology and types of chips analysed. Values of the fibrousness angle ψ and thickening index k_h of chip are evaluated. The research performed has enabled the authors to define mechanisms of decohesion during cutting aluminium matrix composites. The results received for composite material are compared with those pertinent to aluminum alloys.

Key words: metal matrix composites; cutting; decohesion

1. INTRODUCTION

Metal matrix composites (MMC) are increasingly popular as materials of choice for fabricating high-strength parts in such industries as aviation, aerospace and automotive. They can be found in turbines, gas and rocket engines, pistons, heat exchangers, extreme temperature furnaces, airplane supporting structures, optical and electronic devices [1–3]. At present, a large variety of composites are commercially available. Matrix can be metal, polymer or ceramics and reinforcement can be of similar types in the form of fibres, particles or powders. The main advantage offered by composites is their ability of providing different properties by each of the constituents, e.g. high tensile strength of fibres may be combined with high thermal conductivity of matrix. The matrix constituent is responsible for protecting reinforcement, transferring stresses to it and giving final shape to a composite part. The reinforcement in turn is expected to impart strength to the material.

Among metal matrix composites (MMC) the aluminium ones are widely used. They are frequently reinforced with ceramic fibres or particles which impart high stiffness, strength (both static and dynamic) and hardness, at the same time leaving the weight-to-volume ratio at an acceptable level [4–8].

New composite materials can only be utilized fully if there are methods available of transforming them into finished products. Material removal processes are viewed in this respect as a principal category of candidate manufacturing techniques. The difficulties are obvious–completely different fracture mechanisms of the two composite constituents and aggressive abrasive effect of reinforcement on cutting tools. That is why machinability of MMCs is being extensively investigated throughout the world. The present paper is concerned with mechanics of decohesion and mechanics of chip formation in cutting aluminium composite materials. Knowledge of the underlying mechanisms may be helpful in selecting and controlling independent variables of adopted material removal processes.

2. EXPERIMENTAL PROCEDURE AND CONDITIONS

2.1. Material investigated

The investigation was done on aluminium composite materials reinforced with ceramic Al_2O_3 fibres of the saffil type manufactured by ICI SAF-

FIL. Cast AlSi9Mg (AK9) alloy constituted the matrix. Properties and chemical constitution of the two constituents and the finished composite are shown in Tables 1, 2 and 3.

Table 1

Approximate chemical composition and minimum properties of AK9 Al-alloy [10]

	Element weight content, %						Minimum properties			
Alloy designation	Si	Cu	Mg	Mn	Fe	Ti	$YS_{0.2}$, MPa	*UTS*, MPa	A_{50mm}, %	HB
EN AC-AlSi9Mg	9.5	<0.05	0.35	<0.1	<0.18	0.15	190	230	2	75

Table 2

Chemical composition and properties of Al_2O_3 "saffil" fibres

	Chemical composition, %			Properties		
Aluminum oxide "saffil"	Al_2O_3	SiO_2	Fibre dia, μm	ρ, $kg \cdot m^{-3}$	*UTS*, MPa	*E*, GPa
	96	4	3	3300	2000	300

Table 3

Approximate chemical composition and minimum properties of the composite

	Composition, %		Properties	
Composite material	Matrix	Fibres	Hardness, HB	*UTS*, MPa
	90	10	105	250

The presented method of fabricating parts with zonally arranged fibres was worked out at the Institute of Production Engineering & Automatization of Wrocław University of Technology. It consists in preparing first a fluid mixture of saffil fibres and silica cohesive agent. The solution is then filtered off, formed into a desired shape, dried and fired at a high temperature. The saffil brick is then placed at a given place of a mold, poured with a molten metal and squeeze cast [9].

2.2. Experimental details

Orthogonal cutting was selected as well controllable means of inducing deformation in the materials tested. The machining operation could be stopped abruptly to "freeze" the cutting zone. The base of the chip being formed could then be left in the undamaged form so as to obtain reliable microscopic evidence.

In order to remove the tool insert in a clean way at high cutting speeds a custom designed arrangement was used. The inserts could be shot off by projectiles consisting of hard-steel nails ejected by a Hilti DX E72 pistol. The rounded nail tip hit the insert beyond the area of rack face-chip contact. Velocity of the flying insert fragment was more than twice the used maximum cutting velocity. A close-up of the set-up is shown in Fig. 1.

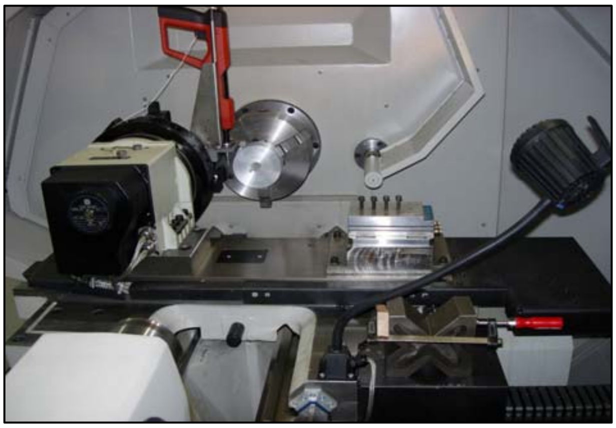


Fig. 1. Experimental set-up with a device for impact-type interrupting of the cutting process

The experiments were performed on a NC lathe (FAT TUR 560 MN×2000. A SECO CER 2525M20Q tool shank with a 20ER5.0FG diamond-coated carbide insert was used. The tool tip geometry was: γ_o= 3 , α_o= 10 , λ_s= 0° , κ_r= 0°.

In the first part of the study concerned with mechanics of decohesion three cutting speeds (100, 650, 1200 m/min) and two values of feed (0.08, 0.24 mm/rev) were used. The stage of chip morphology investigation involved a broader range of cutting parameters: cut layer width of 4 mm, feed $f = 0.19$ mm/rev and a variety of cutting speeds $v_c = (50; 150; 300; 500; 700; 900; 1200$ m/min).

The cylinder-shaped specimens were squeeze cast so that they contained ring-shaped zones reinforced with saffil fibres. The arrangement enabled the investigators to compare mechanisms of decohesion acting in composite areas and bulk matrix material.

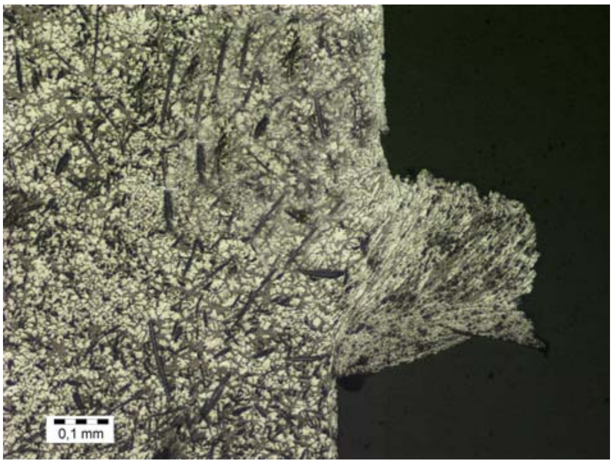


Fig. 3. Chip base of aluminium composite (cutting parameters: $v_c = 100$ m/min, $f = 0.08$ mm/rev)

3. RESULTS AND DISCUSSION

3.1. Mechanisms of chip formation

Mechanisms of decohesion active in cutting particular materials depend to a large extent on their mechanical properties. The investigated aluminium MMC is less prone to plastic deformation than its AK9 matrix. Its higher hardness and strength properties can be attributed to ceramic reinforcement. Despite differences in ductility of the two constituents in either case chip is formed by plastic shearing. Metallic grains undergo severe plastic deformation when passing through the cutting zone. Marked traces of work hardening under an angle of η (Figs. 2 and 3). Origins of those lines are located at the shear plane whose defining angle is Φ. The work hardening lines at the bottom side of chip are bent and aligned parallel to the tool rake face. This is due to high friction and adhering interaction between the tool and the chip.

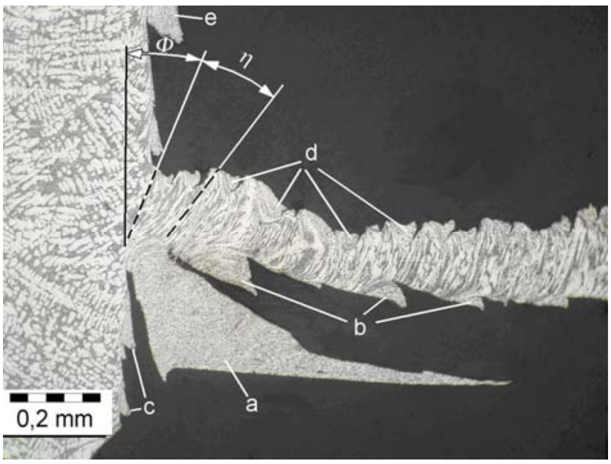


Fig. 2. Chip base of aluminium alloy AK9 with a visible built-up edge (cutting parameters: $v_c = 100$ m/min, $f = 0.08$ mm/rev)

Ceramic fibres exhibit a different behaviour under cutting conditions. They deform elastically and eventually break (Fig. 4). At the upper and middle zones of chip the fragments of broken fibres are aligned predominantly along work hardening lines in contrast to the bottom chip zone where they lie parallel to the tool rake face. Only a fraction of fibres were found to lie slanted or perpendicular to the matrix deformation direction. Ceramic fibres act as glide arresters and thus hinder plastic deformation. This is why composite microstructure within the cutting zone and the chip is less fragmented than in the equivalent areas of pure Al alloy (Fig. 5).

The built-up edge was observed in both types of materials and especially in cutting at lower speeds (50–300 m/min) (Fig. 2). Considerable amount of the built-up material (a) gets adhered to the bottom side of chip (b) and removed off the workpiece.

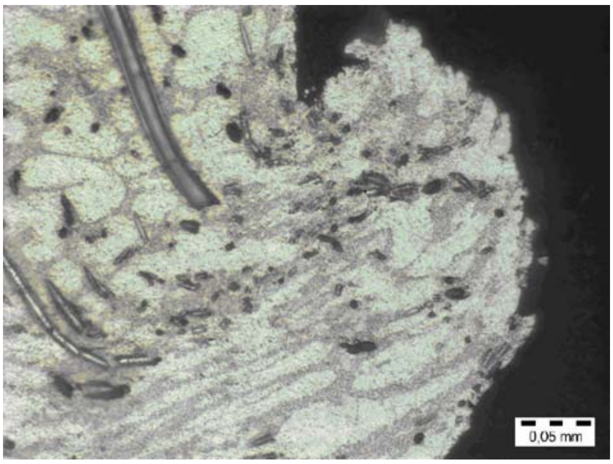


Fig. 4. Chip base with visibly deformed ceramic fibres (cutting parameters: $v_c = 650$ m/min, $f = 0.24$ mm/rev)

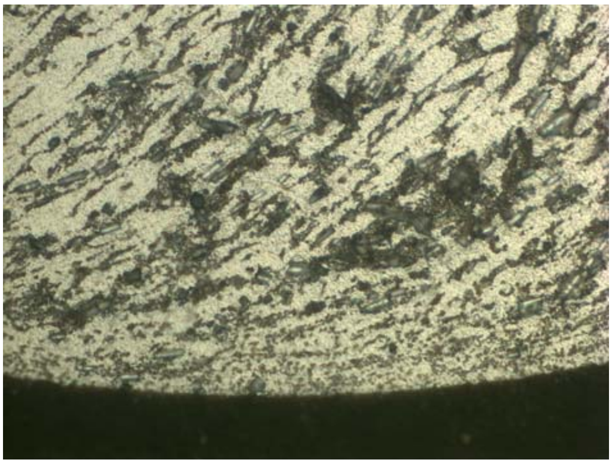


Fig. 5. Bottom side of a chip with visible ceramic fibres (cutting parameters: v_c = 650 m/min, f = 0.24 mm/rev)

The remaining fragments (c) get embedded into pre-machined surface and consequently removed along with the top chip zone (e, d). The built-up edge in composite is less developed, its structure is different from that present in the chip – it is more fragmented, seems to be almost ground. The difference is confirmed by mesohardness measurements – the built-up material is harder than the chip one. The Al alloy built-up edge varied over the 137–175 HV range while the composite built-up edge matrix hardness variation was 115–160 HV. The difference in hardness of chips produced in cutting of pure Al alloy and the composite was much smaller: the respective hardness ranges were 110–115 HV and 98–110 HV. The summary of mesohardness measurements is shown in Figs 6 and 7.

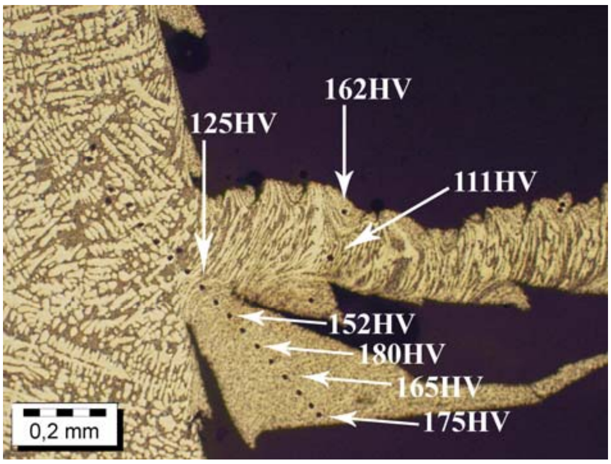


Fig. 6. Mesohardness of the aluminium built-up edge and chip (cutting parameters: v_c = 100 m/min, f = 0.08 mm/rev)

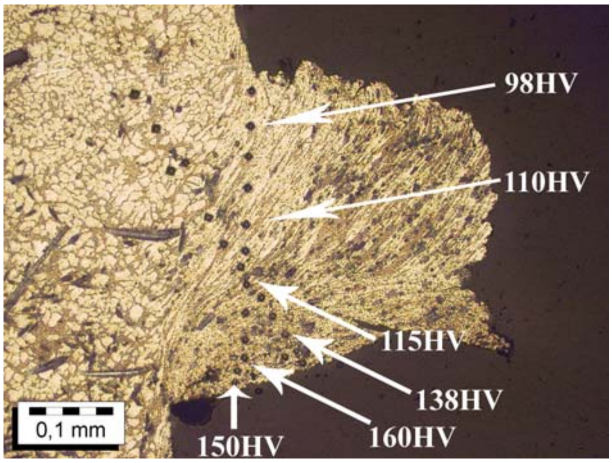


Fig. 7. Mesohardness of the composite built-up edge and chip (cutting parameters: v_c = 100 m/min, f = 0.08 mm/rev)

3.2. Morphology of the chip

Optical micrographs of longitudinal sections of chips are shown in Table 4. The cutting speed range that gives rise to built-up edge formation was confirmed. For speeds lower than 300 m/min there are remains of the built-up edge clearly visible both at the bottom and top zones of chip. Those harder particles make the chip inhomogeneous. The built-up edge is more pronounced in pure alloy. As cutting speed rises, the built-up edge vanishes giving place to a heavily deformed thin layer at the bottom side of the chip.

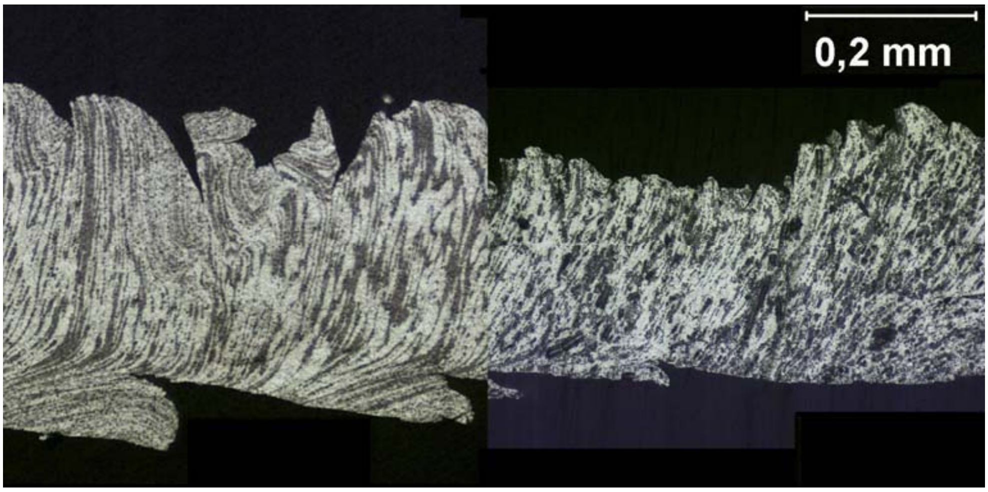
Table 5 gives values of the fibrousness angle ψ and thickening index k_h of chip as a function of cutting speed. The obtained data show that the chip fibrousness angle rises by 3.5 times over the investigated cutting speed range (v_c = 50 – 1200 m/min). A similar 2.5-fold increase was found in the composite. The angle itself was larger in the composite than in pure AK9.

The thickening index k_h decreases with increasing cutting speed. For the cutting speed range tested, in Al alloy the decrease was 40%, but in the composite the decrease was 27%. At speeds lower than 300 m/min the index of AK9 chip was 1.25 that of composite chip. At the highest speeds used the index of AK9 chip was 1.15 that of composite chip. The above results can be explained by observing that ductile alloy cut at low speeds is prone to upsetting, while fibres act to lower this susceptibility. At higher speeds conditions of parting chip and base Al material get gradually better approaching those found in composite. The observation is confirmed by a decreasing difference in the thickening index values of the two materials at higher cutting speeds.

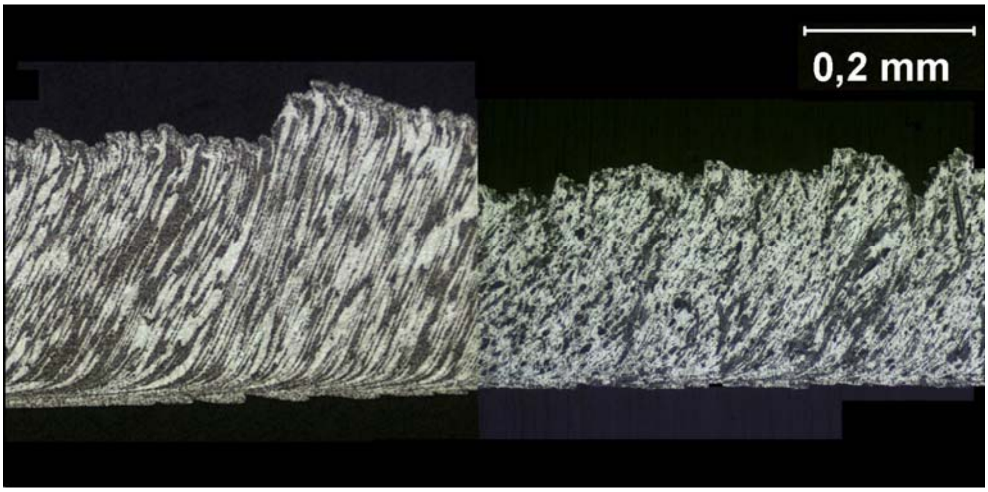
In evaluating types of chips produced the selected tool rake face was flat in order to have no effect on the chip process formation. In Al alloy over the whole range of cutting speed the continuous chip was formed while in composite cut at speeds higher than 300 m/min the chip was discontinuous. In addition to that, in the latter case the chip curls got tighter with increasing speed.

T a b l e 4

Micrographs of chips produced in orthogonal cutting of AK9 (left) and composite (right)



v_c=50 m/min



v_c=300 m/min

v_c=1200 m/min

Table 5

Chip fibrousness angle ψ and chip thickening index k_h as a function of cutting speed and material selected

v_c	Chip fibrousness angle ψ		Chip thickening index k_h	
m/min	AlSi 9Mg	Composite	AlSi 9Mg	Composite
50	10°	18°	1.64	1.3
150	16°	35°	1.8	1.2
300	20°	38°	1.55	1.15
500	24°	40°	1.45	1.08
700	27°	40°	1.3	1.03
900	30°	40°	1.2	1.03
1200	35°	45°	1.16	1.02

3.3. Machined surface

Investigation of the machined surface gives much insight into mechanisms of decohesion. The examination was done on a JSM 5800LV JEOL scanning microscope. Fig. 8 shows machined surface of the composite after being turned at a speed of v_c = 100 m/min. The surface finish is very bad with clearly visible built-up edge chunks pushed inside the plastic matrix and signs of material dragging. Ceramic fibres are hardly visible–they are either pushed inside the bulk metal or covered by particles not moved away from the workpiece. The few visible fibres are short fragmented sections.

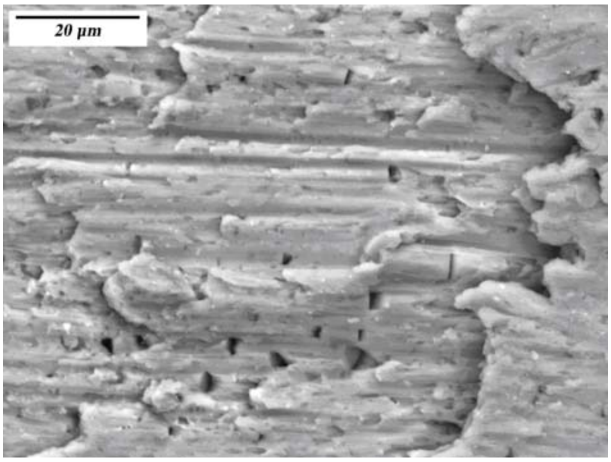


Fig. 8. Machined surface of the aluminium composite (cutting parameters: v_c = 100 m/min, f = 0.08 mm/rev)

Figs 9 and 10 show specimens turned at speeds of v_c = 650 and 1200 m/min, respectively. This time there are no signs of material dragging or built-up edge particles.

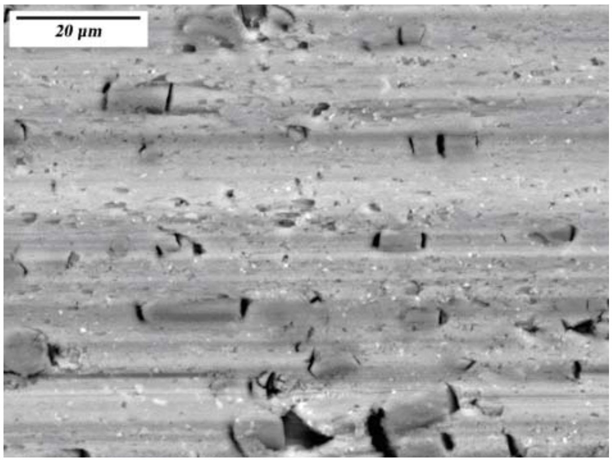


Fig. 9. Machined surface of the aluminium composite (cutting parameters: v_c = 650 m/min, f = 0.08 mm/rev)

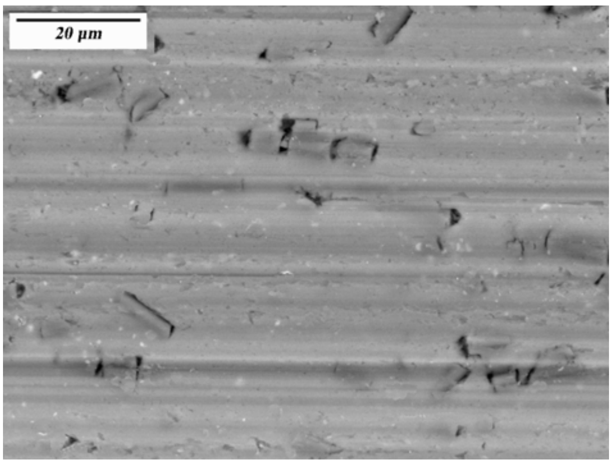


Fig. 10. Machined surface of the aluminium composite (cutting parameters: v_c = 1200 m/min, f = 0.08 mm/rev)

The surface finish is much higher. The fibres, similarly as in cutting at low speeds, are generally aligned in accordance with the cutting direction. The directionality is due to the friction action at the tool edge – machined surface interface. There is hardly no interphase debonding though fibre end faces do show lack of contact with the matrix. This can be attributed to large tensile stresses left at the workpiece outer layer by a moving cutting edge. Individual fibres were found to be broken into two fragments of whose one was fixed in the matrix perpendicular to the surface and the other was parallel to the surface – the effect of a tool not being capable of shearing through the fibre.

4. CONCLUSIONS AND OBSERVATIONS

The investigation can be summarized as follows:

1. Decohesion in cutting both the Al alloy and its composite form is largely the result of plastic shear except for the fibres that first deform elastically and then break in a brittle fashion.
2. The ceramic fibres undergo severe fragmentation when passing through the chip separation zone. Most of them are removed with the chip material, those pressed into machined surface are predominantly oriented along the cutting direction.
3. High tensile stresses acting upon the workpiece area just left by the cutting edge give rise to debonding between matrix and fibres. The fibre fragments embedded in the chip material are not affected by this defect.
4. Fragmented saffil fibres are predominantly aligned along hardening traces observed within the chip volume. This is also the case at the bottom side of the chip where the traces are parallel to the rake face.
5. In cutting the AK9 alloy with cutting speeds $v_c < 300$ m/min a sizeable built-up edge is formed. In cutting the composite the effect is by roughly 50% smaller.
6. Mesohardness of the built-up edge in cutting the AK9 alloy is by 25% higher than that for the composite. This is due to smaller fragmentation of microstructure and smaller plastic deformation of the composite. A similar phenomenon, though less pronounced, can be noticed in the chip where mesohardness of the composite matrix chip was found to be 10% smaller as compared with that for the matrix alone.
7. The fibrousness angle rises with the cutting speed. At cutting speeds of $v_c = 50 - 1200$ m/min it rises from 10° to 35° in AK9 and from 18° to 45° – in the composite. The higher angle values in the compound material can be attributed to higher friction at the chip – rake face interface.
8. Thickening indexes for the chip decrease considerably as the cutting speed is increased. Over the speed range of $v_c = 50 - 1200$ m/min they are reduced from 1.8 to 1.16 for AK9 and from 1.3 to 1.02 – for the composite. The thickening index in the composite is always smaller than in the matrix.
9. The radius of the chip curl usually gets larger as cutting speed is increased. The composite chip behaved the other way – chip coils got tighter as cutting speed rose. It is strange because chip fibrousness angles in this study rose considerably with cutting speed reaching as much as 45° at a speed of $v_c = 1200$ m/min. That would suggest that the material gets reoriented in the direction opposite to the direction the chip assumes to coil itself up. Despite that the coils got gradually tighter.
10. Machinability of the composite in cutting is satisfactory and is not worse than that of the bulk matrix. There *is* some difference at lower cutting speeds $v_c < 200$ m/min.

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Р е з и м е

МЕХАНИЗАМ НА ДЕКОХЕЗИЈА ПРИ РЕЖЕЊЕ НА АЛУМИНИУМСКИ КОМПОЗИТНИ МАТЕРИЈАЛИ

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Клучни зборови: алуминиумски композитни материјали; режење; декохезија

Претставени се особините и примената на алуминиумските композитни материјаали. Опишан е алуминиумскиот композитен материјал зајакнат со влакна од сафил, кој беше предмет на истражување. Презентирано е проектираното помагало за експлозивно прекинување на процесот на режење. Определено е однесувањето на основата и зајакнувањето на композитот за време на одделување на материјалот со помош на резачкото сечило. Изведени се мерења на мезотврдоста на конституираната структура, настанатите струшки, како и на создаденото зајакнато сечило. Презентирани се микрофотографии од површини добиени со стружење. Во трудот се анализирани градбата, видот и обликот на создадените струшки. Пресметан е аголот на создавање текстура и коефициентот на здебелување на струшката. Изведените истражувања овозможија да се дефинира механизмот на декохезија за време на одделување на материјалот при режење на алуминиумските композити. Добиените резултати од истражување на композитниот материјал се споредувани со резултатите на истражување на алуминиумска легура која претставува основа во композитниот материјал.

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MODERNISATION OF THE UNIVERSAL MEASURING MICROSCOPE MODEL UIM-21 SUPPORTED BY A PROCESSOR QM–Data 200

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A b s t r a c t: A solution for modernisation of the metrological characteristics of the universal measuring microscope UIM-21 is presented. The modernisation phases, expertise, modernisation and adjusting of the component parts and the calibration are noted. The trends in the field of modernisation and upgrading of the metrological performances of measuring microscopes are accentuated. The recommendation for equipment choice is shown and the characteristics of the necessary equipment for realisation of the modernisation are described. The characteristics and metrological capabilities of the modernised universal measuring microscope supported by the processor QM–Data 200 are described.

Key words: measuring microscope; metrological characteristics; modernisation; processor QM-Data 200

1. INTRODUCTION

Due to their comprehensive metrological characteristics, the universal measuring microscopes are often present in the laboratories which deal with the metrology of geometrical characteristics and quality research (Fig. 1). The measuring microscopes are used in dimensional measurements of objects which cannot be measured with contact methods, in cases when the object which is analysed cannot be directly or indirectly enclosed with a measuring tool or when the object has a complex form [1].

The universal measuring microscope of the model UIM-21 (Fig. 2) is designed for linear and angle measurements in rectangular and polar coordinates. It is used for measurements of thread parts, cutting tool, profile patterns, cams, cones, radii of roundness, distance between the axes of the openings with different dimensions etc. [2]

In the composition of the additional equipment of the microscope the partition heads, the rotary tables, the changeable object glass and lens, the special equipment for measurement of helix and etc. are included [2].

The measurements are usually conducted through an optical way, using a non-contact method, and through this act the influence of the measurement forces as a factor for causing errors is excluded. During this kind of measurements the object itself is not measured, but its magnified picture. The quality of the captured picture in the ocular scope largely depends on the operator's capability for adjusting, the kind of lighting, as well as the errors which are the result and characteristics of the component elements of the optical measurement system. These errors often cannot be identified and determined immediately and they have a direct effect on the quality of the received results. Namely, quality evaluation of the measuring results expressed by the indeterminacy of the measuring results mostly depends upon the expertness of the operator, the applied method, the components which participate in the composition of the optical measuring system necessary for the realisation of the measurements, and of the conditions on the premises. The necessary time for conducting the measurement process, the tiredness of the operator, the possibility of causing accidental and subjective errors when recording the values have also influence on the measuring results.

Fig. 1. Laboratory for metrology of geometrical characteristics and quality research at the Faculty of Mechanical Engineering in Skopje

Fig. 2. An aspect of a universal measuring microscope of the model UIM-21

The non-contact method conjugated with the optical systems for a picture analysis in the ocular scope and the optical measuring systems with dual Archimedes' spiral, enables small speed for conducting the measurements, without a possibility of a dimensional identification of the analysed object with small number of captured points. The non-contact method in many cases is not satisfying. The solution for more complex measurement tasks is complicated, if sometimes impossible. [3]. The rapid development of the production technology gives opportunities for construction of new optical digital measurement microscopes designed for non-contact measurements [4], with a significantly superior quality and accuracy from the previous generations of microscopes, i.e. classical microscopes.

The trend of simplifying the measurement processes with usage of optical measurement techniques has imposed a need for increased quality of conduction of the optical measurements, and quicker, easier and safer conduction of the measuring process.

These are at the same time the factors which are taken in consideration when conducting the modernisation of the already existing measurement microscopes, with the purpose of surpassing their drawbacks. This is done in the course of improving the metrological characteristics and approaching the characteristics of up-to-date measurement microscopes [4, 5].

2. DIRECTIONS OF MODERNISATION OF THE CLASSICAL UNIVERSAL MEASURING MICROSCOPES

The confirmed metrological characteristics of the universal measuring microscopes from the previous generation, known also as classical microscopes, microscopes with glass linear scale and oculars with a double Archimedes' spiral etc., as well as the model UIM-21, still motivates some interest for their modernisation, i.e. modernisation of the measuring process, extension of its capabilities and increasing the efficiency of the measuring process.

The process of modernisation of the metrological characteristics of the classical measuring microscopes includes conduction of an expertise, modernisation and adjustment of the component parts as well as their calibration [6].

The expertise is the basis for identification of the measuring microscopes' technical condition and defining the activities needed for retrieving their metrological characteristics. At the same time, the techno-economical analysis represents a basis for adoption of the suggested solutions for modernisation of the measuring microscopes in order of the desired quality of modernisation level.

The modernisation of the classical measurement microscopes encompasses overhaul of the mechanical parts, replacement of the optical measurement systems consisted of glass linear scales and optical oculars with dual Archimedes' spiral, replacement of the existing lighting, and measurement process modernisation during the picture analysis in the ocular scope as well as the way of recording the picture. The calibration is the last stage and it consists of adjusting the component parts, checking and defining the accuracy, i.e. edition of appropriate certificates for the measuring microscopes with defined indeterminacy. This activity is in the jurisdiction of the accredited laboratories for calibration of length and angle. The necessity of conducting training for the operators of the modernised microscopes should be mentioned.

Following the world trends for development of the metrological characteristics of the measuring microscopes, the directions of modernisation of the already existing measuring microscopes, substantiated with the experiences from concluded modernisations in this field in many countries [2], it can be ascertained that this kind of intervention is profitable as an activity for improving the characteristics of the measuring microscopes.

The analysis of the accessible solutions of the already conducted modernisations of the universal measuring microscopes, as well as the new models of universal measuring microscopes, has enabled a conclusion that the modernisation as an activity for bettering the metrological characteristics of the measuring microscopes is most often conducted through [3, 5, 7, 8, 9, and 10]:

– replacement of the existing glass linear scales and oculars with a dual Archimedes' spiral or through a superstructure of the existent measurement optical systems with incremental optoelectronical linear scales, replacement of the mechanical micrometer systems with digital ones, as well as lighting, with the purpose of providing an improved quality of the picture in the scope of the system for visualisation and length identification in the working space in the direction of three axes;

– connection of the incremental optoelectronic linear scales with digital indicators, i.e. with a computer through an adequate interface, enabling visualisation and recording of the measurement results, as well as their statistical processing;

– a replacement of the optical systems designed for visualisation and analysis of the picture in the scope of the ocular with a CCD camera with appropriate resolution and her connecting to a computer, an activity which enables recording of the analysed picture and its visualisation on the monitor;

– introduction of computer processing of the measurement results and the analysed picture, with the application of own or commercial software, as well as processors (QM-Data 200 from Mitutoyo Company …) manufactured for this purpose, with a possibility of connection to a computer.

3. MODERNISATION OF THE UNIVERSAL MEASURING MICROSCOPE

The process of modernisation of the universal measuring microscope begins with an expertise, where the techno-economical analysis of the suggested concept solution has an important position. Firstly, the necessary means for leading the classical measuring microscope in the original condition, defined with its metrological characteristics marked in the technical directions when purchased are analysed. The size of these means depends above all, on the condition in which the measuring microscope is. Next is the analysis of the necessary means for conducting the modernisation of the measuring microscope, for the purpose of approaching its metrological characteristics to up-to-date measuring microscopes. These means have a defined purpose of achieving as smaller difference as possible between the metrological characteristics of the modernised measuring microscope and the updated microscopes.

The final decision is a result of a mathematical calculation of the total means necessary for a realisation of the modernisation of the measuring microscope in accordance with the suggested concept solution in comparison to the necessary means for buying a new microscope.

The process of bringing the classical measuring microscope of the model UIM-21 in its original condition in direction of achieving the needed metrological characteristics is realised in the Laboratory for metrology of geometrical characteristics and quality research at the Faculty of Mechanical Engineering in Skopje [6]. A few stages of this process are presented on Figure 3.

The evaluation of the condition of the measuring microscope of the model UIM-21 confirmed that the wholesome modernisation of the measurement process is profitable.

The concept solution includes: a purchase and embedding of linear scales for three axes, additional lighting, display for visualisation of the read coordinates on three axes, a CCD camera, a processor QM-Data 200, a connection to a computer, a monitor, and a printer [7, 8, 9].

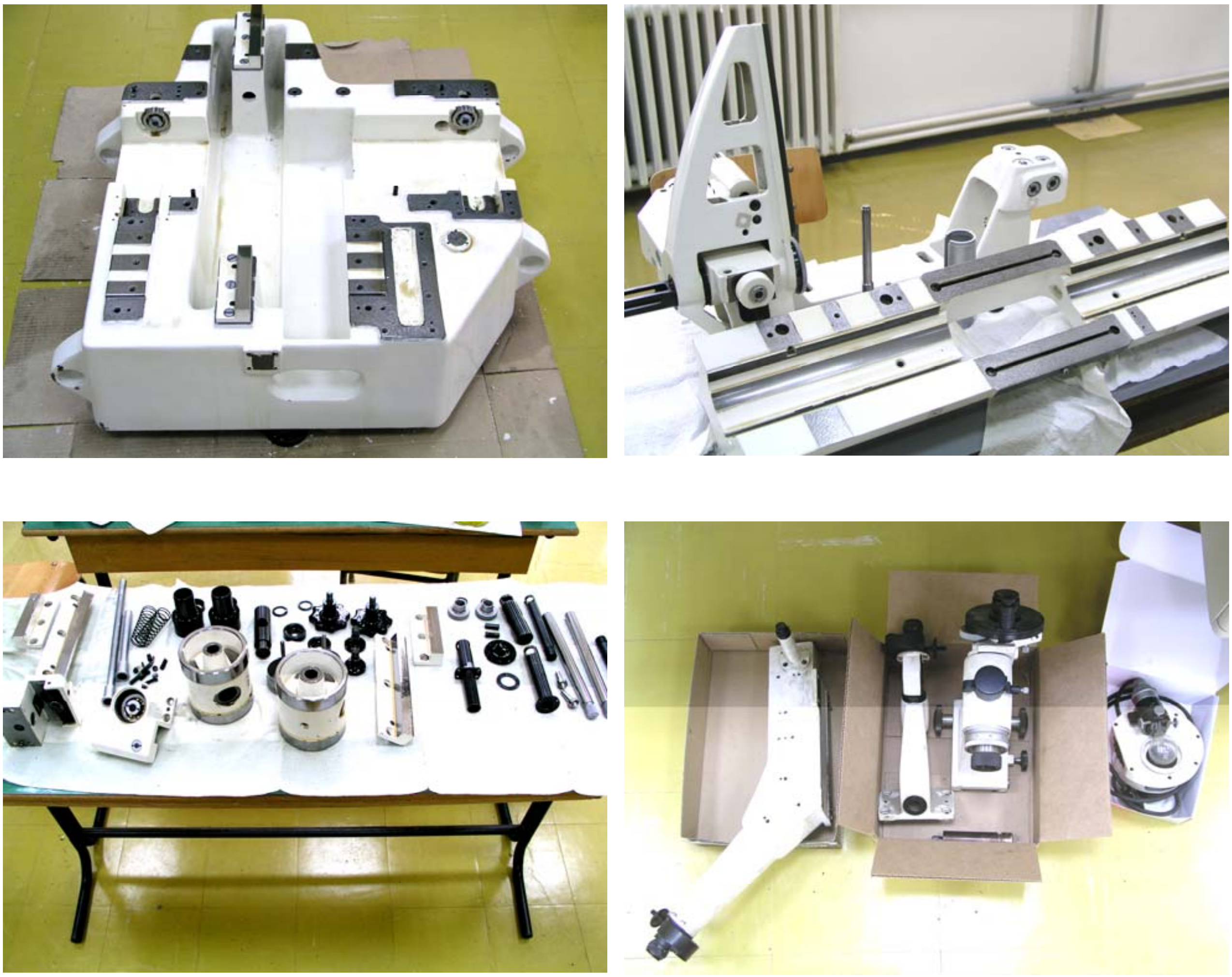

Fig. 3. Stages of the conducted process for bringing the metrological characteristics of the measuring microscope in their original condition

The modernisation of the process for identification of the length measures in the working measurement space of the measuring microscope in the direction of the axes X = 200 mm, Y = 100 mm, and Z = 100 mm is predicted with the addition of new incremental optoelectronical linear scales.

The existent glass linear scales and oculars for reading with a dual Archimedes' spiral remain in use as a component part of the measuring microscope for the purpose of conducting educational activities.

The new incremental linear scales are set in a position suitable for a free conduction of the measuring microscope processes (Fig. 4a). As crucial criteria when choosing the linear scales, the compatibility of the connection between the linear scales and the processor QM-Data 200 (Fig. 4b) from the manufacturer Mitutoyo, the measurement range of the linear scales which is necessary and the embedding dimensions as length, width, and height of the new linear scales necessary for the setting of the movable and immovable places of the measuring microscope are accepted.

The analysis regarding the fulfillment of the above mentioned criteria has shown that the most suitable and easily adjusting to the universal measuring microscope are the linear scales of the type AT 500 – HL /HR from the Mitutoyo Company manufacture programme, with an appropriate measurement range in the direction of the axes X = 200 mm, Y = 100 mm, and Z = 100 mm (Fig. 5).

The places of setting the new linear scales of the measuring microscope are presented on Figures 4a and 4b, and the connection of the linear scales to a processor QM-Data 200 on Figures 4b and 6.

In cases of simpler modernisation, without a processor QM-Data 200, the connection of the linear scales is conducted with a display for visualisation of the read coordinates on the axes *X*, *Y*, *Z*. This is presented on Figure 6.

A significant place in the analysis of the picture in the scope of the ocular has its quality, most of all the sharpness of the picture plays a significant part due to a more exact defining of the edges of the researched object.

It is decided that the improvement of the visualisation in the scope of the ocular should be done with a use of a CCD camera (Fig. 7).

a) b)

Fig. 4. Places for setting the new linear scales [10]

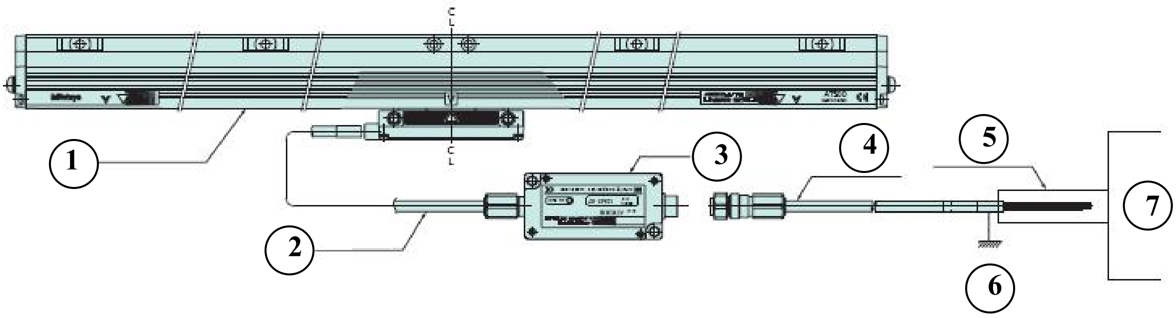

Fig. 5. The linear scale, type AT 500 – HL /HR from the Mitutoyo Company.
1 – main unit of the linear scale; 2 – main cable; 3 – I/F box; 4 – signal cable; 5 – connector A; 6 – grounding; 7 – NC controller

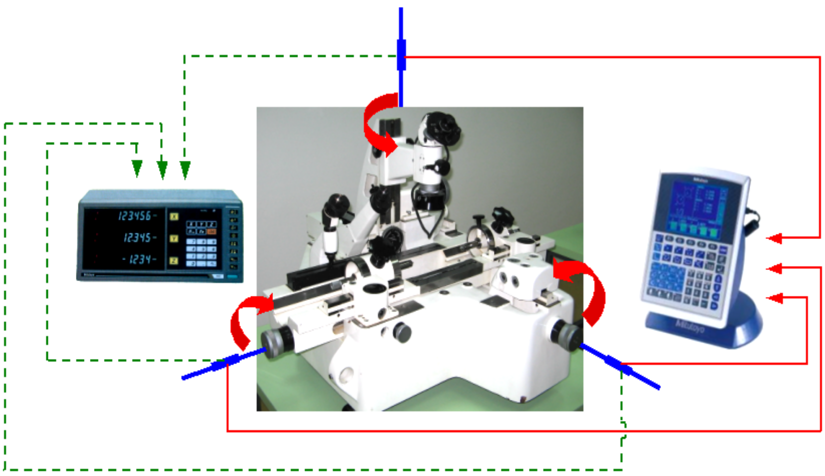

Fig. 6. Principled scheme for setting and connecting the new linear scales to the processor QM-Data 200, in the process of modernisation of the measuring microscope UIM-21

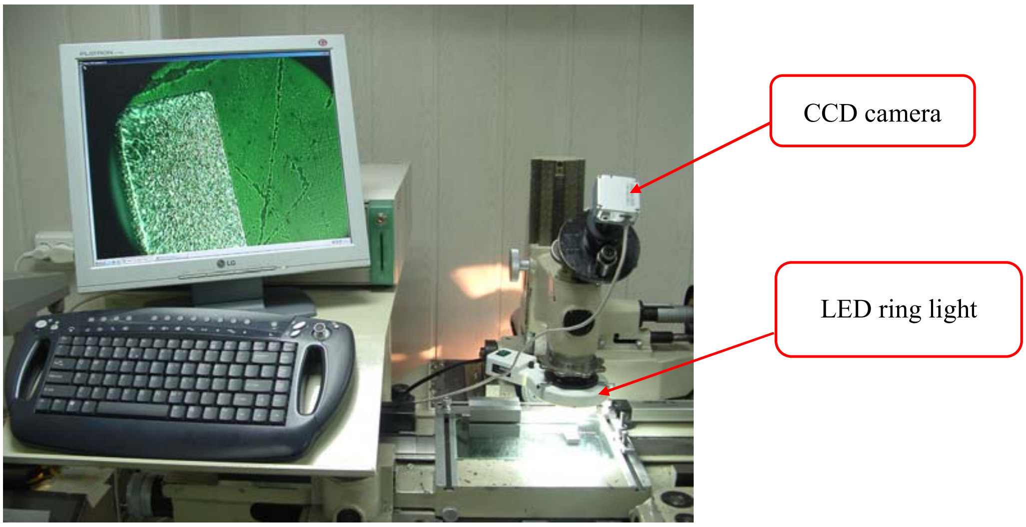

Fig. 7. An improvement of visualisation of the picture in scope of the measuring microscope with the use of a CCD camera and LED ring lighting [10]

The use of a CCD camera enables an increase of the picture in the scope to more than 100 times [7], position defining of the edges of the researched object is also made easier and precisely stated, which act has an immediate influence on the accurateness of the dimensional identification and on further calculations. Lighting has also an immediate influence on the picture quality in the scope of the ocular. For this purpose a ring lighting of the type 176-366A from Mitutoyo company is used (Fig. 7).

The next step in the modernisation of the measuring microscope is the automation of the measurement process, through recording of the measurement process results, their processing, setting the identification acts of the analysed objects in an automatic regime, and conducting complex calculations for a realisation of the predicted measurement tasks. For that purpose, a processor QM-Data 200 from the Mitutoyo Company (presented on Figure 8) is selected, with an option for a connection to a computer and a possibility of additional analysis of the received results in MS Excel [9].

Its use basically changes the classical concept of measuring the working object. The processor enables an automatic display of the measurement results; the graphic assistance presented on LCD monitor leads us during the measurement sequences.

There is a possibility of defining the object (circle, centre of ellipse etc.) with a minimal number of captured points – coordinates and also a possibility of accepting a larger number of captured the coordinates (up until 100) for increasing the accuracy. Also, there is a function which enables the coordinate system alignment, which excludes the need for tuning of the axes of the working piece with the axes of the measuring microscope; the measurement procedures (part programs) can be memorised and repeated, which is especially useful when measuring a series of parts; an own menu can be created for our specific needs and also MACROS for loading on a previously memorised measurement sequences can be made; for the purpose of automatic recognition of the measuring the object's kind and making the preselection unnecessary, there is (AI) function for an automatic identification.

For all measurement results comparative analyses of the nominal values with the given tolerances are possible, as well as a use of various statistic evaluations. Also, there is a possibility for transferring the results in a tabular shape (CSV) for processing in MS Excel as well as the possibility of their memorisation on an appropriate information holder.

The above mentioned possibilities of the QM-Data 200 processor are a result of previously defined relations between the information about the coordinates of one captured point, middle point of two or more points, the point of the centre of three and four points, the diameter of the orifice and the circularity (with 100 points), a middle point of an ellipse, middle point of an rectangle, width and length (with 5 points), a middle point of an orifice and the intersected point of two lines, the length between two points and the coordinate differences, an angle of a line relative to the *X*-axis and straightness of the line defined with at least two points or as a middle value of a hundred points, characteristic values of an ellipse (the largest and smallest diameter, an angle between the main axis of the ellipse and the *X*-axis), the mutual position between two straight lines (the intersection and complementary angle).

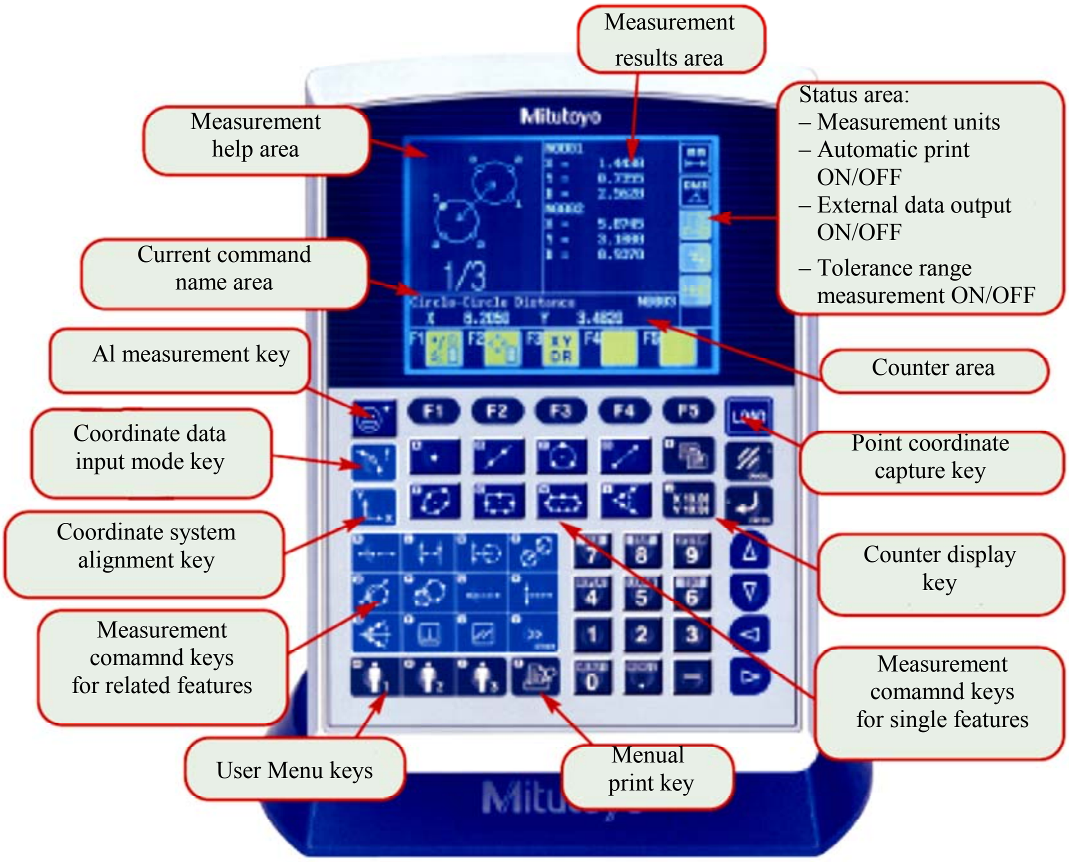

Fig. 8. Appearance of the monitor of QM-Data-200 processor from the Mitutoyo Company.

There are possibilities of adjusting the coordinate measurement system with a rotation and translation; defining the intersection between a line and a circle, drawing an angle centre line, the normal distance between a point and a line, the intersecting points between two circles, normality between two lines, minimal and maximal distance between a line and a circle, coordinates of the middle point from two points, parallelism between two lines, distance of the centres between two circles, coordinates of the tangent point of a circle, middle point between two centers of circles, tangent angle of two circles with *X*-axis, a radius of edge, a distance between the point and the centre of a circle and etc.

4. CONCLUSION

The realised activities in the presented paper enable an underlining of the main goal of the modernisation process of the laboratory measuring microscope UIM-21, which is its modernisation and whole recovery of its measuring capabilities.

The process for modernising the metrological characteristics of the measuring microscope begins with:

– an expertise, as a basis for identification of the measuring microscope's condition;

– modernisation, which is conducted on the basis of a previously adopted solution and in the range dependent on the necessary level, and

– adjustment of the component parts of the measuring microscope i.e. its calibration.

With modernisation of the measuring microscope its metrological characteristics are expanded from the aspect of installed software and the needed level according to the requests in the up-to-date standards. The useful value of the modernised measuring microscope, and its operating time is extended.

With the relatively small investment for modernisation of the classical measuring microscope UIM-21, the purchase of a new and expensive measuring microscope is avoided.

With the implementation of the mentioned new elements in its modernisation, the measuring microscope UIM-21 receives measurement performances close to the performances of the up-to-date measuring microscopes.

Today, when there are more and more requests for quality and increase of the competition on the market, it is practically inconceivable to have an absence of activities for continuous updating of the measurement techniques and implementation of the modern measuring devices in the metrology of geometrical sizes and quality research.

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Р е з и м е

МОДЕРНИЗАЦИЈА НА УНИВЕРЗАЛЕН МЕРЕН МИКРОСКОП ТИП UIM-21 СО ПОМОШ НА ПРОЦЕСОР QM-Data 200

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Клучни зборови: мерен микроскоп; метролошки карактеристики; модернизација; процесор QM-Data 200

Претставено е решение за осовременување на метролошките карактеристики на универзалниот мерен микроскоп модел UIM-21. Набележани се етапите при осовременувањето, како што е изведување на експертиза, модернизација и нагодување на составните делови на мерниот микроскоп, односно негова калибрација. Потенцирани се трендовите во областа на модернизацијата за подобрување на метролошките перформанси на мерните микроскопи. Дадени се препораки за избор на опрема и опишани се карактеристиките на опремата неопходни за реализација на модернизацијата. Опишани се карактеристиките и метролошките можности на модернизираниот универзален мерен микроскоп со помош на процесор QM-Data 200.

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Review

OPEN PROBLEMS IN PARALLEL ROBOTICS

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A b s t r a c t: Text More than 20 years parallel robots attract the interest of the scientific community and in many applicative domains like, production of motion generators, machine tools, precision positioning devices, medical equipment, pick and place machines, etc., where their potential advantages (high accuracy, rigidity, speed, acceleration and load carrying capability) could be very useful. The objective of this paper is to notify some of the open problems in parallel robotics, which is a limitation factor of the wider practical application of this type of robots.

Key words: parallel robots;open problems;research

1. INTRODUCTION

A ***parallel robot*** is composed of two or more closed-loop kinematic chains in which the end-effector (mobile platform) is connected to the base (fixed platform) by at least two independent kinematic chains. Between the base and the end-effector platforms are serial chains (called ***limbs*** or ***legs***) [90] (Fig. 1).

The parallel robot could be named as a hexapod, a Stewart platforma, Gough platform, a Stewart-Gough platform, a parallel kinematic machine (PKM) or a parallel manipulator. The theoretical work on parallel mechanisms dates back to as early as 1645 by Christopher Wren, then in 1813 by Cauchy and in 1867 by Lebesgue. Variable-length-strut hexapods, as those used in motion simulators [31, 84] have existed almost 50 years.

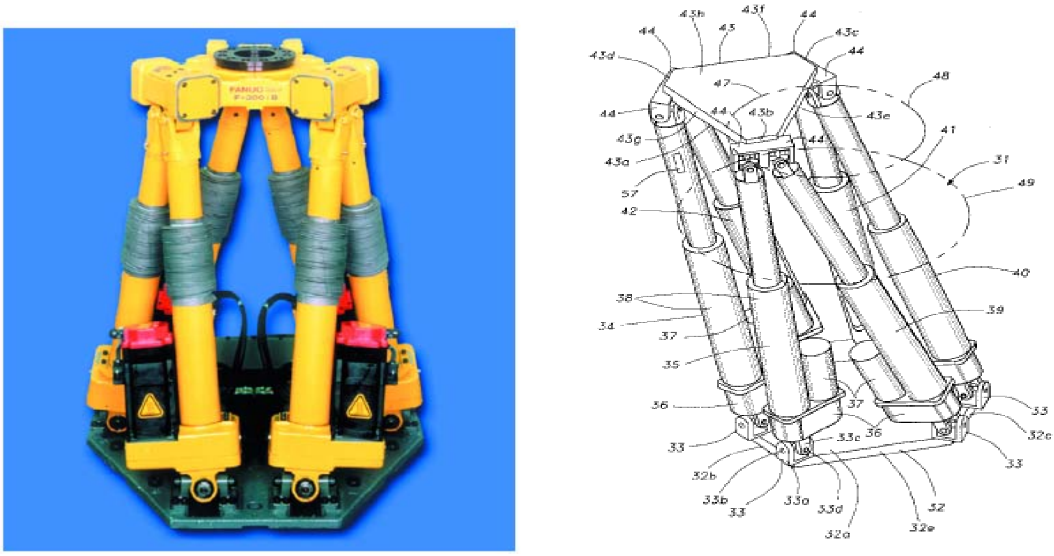

Fig. 1. A Fanuc parallel robot [94] (US patent No. 5987726) [93]

Parallel mechanisms are stronger than the serial ones because the load is distributed among all legs, but also because, for some architectures, the legs are only subjected to axial loads. Also, parallel robots theoretically should be more precise since they are more rigid, and since the errors in the legs are averaged instead of accumulated. Finally, these robots are faster since they usually have their heavy motors mounted on the base (Fig.1).

On the other hand, parallel robots have a more limited and complex-shaped workspace. Moreover, the rotation and position capabilities (if both present) of parallel mechanisms are highly coupled which makes their control and calibration extremely complex. Furthermore, parallel mechanisms generally have singularities within their workspace and computing the resulting end-effector position for a given set of actuator inputs is, in general, a very difficult and complex problem allowing up to 40 solutions.

A general overview of the main characteristics of the parallel robots are given in the tTable 1.

Table 1

Feature	Parallel robot
Workspace	Small and complex
Solving forward kinematics	Very difficult
Solving inverse kinematic	Easy
Position error	Averages
Force error	Accumulates
Maximum force	Summation of all actuator forces
Stiffness	High
Dynamics characteristics	Very high
Modelling and solving dynamics	Very complex
Inertia	Small
Areas of application	Currently limited, especially in industry
Payload/weight ratio	High
Speed and acceleration	High
Accuracy	High
Uniformity of components	High
Calibration	Complicated
Workspace/robot size ratio	Low

In the past two decades parallel robots very much attracted the interest in the robotics community. A great interest for parallel robots come from the ***potentially interesting features*** of parallel mechanisms: high accuracy, rigidity, speed and large load carrying capability, which in a very large number of cases may overcome the drawbacks of the more complex kinematics, dynamics and smaller workspace. The great interest could be exemplified by a large number of papers published on this subject together with the application of parallel robots in very different domains such as fine positioning devices, simulators, motion generators (platforms), ultra-fast pick and place robots, machine-tools, medical applications, haptic devices, entertainment, force sensors, micro-robots, etc.

But in fact all these advantages of parallel robots are only ***potential***. Any real parallel robot will present in practice impressing performances only if all its components (either hardware or software) present a high level of performance. However in many cases unexpected difficulties in the design and control of such a complex system have led to performances which, although still better than conventional serial mechanical architectures, were fare below what was expected. In some cases, for example, the machine tools, performances were even the worst [89].

In the following we will give some examples of some open problems in parallel robotics, which makes limitation of wider practical application of this type of robots.

2. OPEN PROBLEMS IN PARALLEL ROBOTICS

2.1. Mechanical design

A lot of different mechanical architectures of parallel robots, more than 100 according to [60] with 2 to 6 DOF have already been proposed and it is probable that not all of them have been discovered. The analysis of the literature shows that more than 80% of the parallel robots are with 3 DOF and 6 DOF. The rest are parallel robots with 5 DOF, 4 DOF, and 2DOF. Unfortunately there are not so many proposed architecture that have only 4 or 5 DOF, while many applications require such a number of DOF. For example 4-DOF is sufficient for most pick-and place applications, and 5-DOF is adequate for every machine tool application.

There is a recent trend to propose parallel robots with 4 and 5 DOF: [19, 69, 16, 18, 26, 50, 99, 21, 98, 104, 10].

It is really an interesting research area but many questions arise with this type of robots:

- The proposed structures have ***in theory*** only 4 or 5 DOF and rely on geometrical constraints to obtain this reduced number of DOF. In practice however these constraints will never be perfectly fulfilled and hence these robots will exhibit parasitic motions. Open problems are to determine what will be the maximal amplitude of these parasitic motion, produced by given manufacturing tolerances [11, 33], and the dual problem of determining the amplitude of the manufacturing tolerances so that the maximal amplitude of the parasitic motion will not exceed a given limit.
- Having less actuators and sensors may sound economically interesting, but it is unclear, if classical parallel robots with 6 DOF which are redundant with respect to the task, are more appropriated. First of all their kinematic chains are identical (which is not the case for the most of 4 and 5 DOF robots). That will reduce the maintenance costs. Then by using the redundancy it is possible to optimize the performances of the robot for a given task.

Redundancy is also an interesting and open research area. In the field of parallel robots redundancy has been used to increase the workspace of the robot (such as in the Eclipse parallel robot [45]) and to deal with singularities [65]. The main unsolved problem for the redundant parallel robot is to determine how to use the redundancy for an optimal use of the robot.

2.2. Joints

Parallel robots require higher kinematic pairs with relatively large amplitude of motion and, in some cases, relatively high load. Current available joints (either ball-and-socket or U-joints) are not completely satisfactory from this view point, although recent products like the INA joints have been developed especially for parallel robots [25]. Hence the development of higher kinematic pairs with 2 to 4 DOF is a key issue [4, 81]. As for any mechanical joints these joints must have a low friction, no hysteresis and must have a very reduced backlash. But in addition these joints must be designed so that it is possible to add sensors to measure partly or totally the amplitude of the motion of the joints, which is important for the forward kinematics. Compliant joints are also an interesting field of research, especially for micro-robots [62].

2.3. Forward kinematics

The biggest kinematics problem in parallel robotics is the forward kinematics, which consists in finding the possible position of the platform for given joint coordinates. The forward kinematics is a more complex problem than its dual inverse kinematics counterpart for serial robots. The need of the forward kinematics is a controversial question. It may be thought that forward kinematics is an academic question that may be useful only for off-line simulation purposes and a parallel robot will be position controlled using inverse kinematics only. Pure position control is very difficult for parallel robots, especially when there are constraints on both the trajectory and the velocity of the robot (for example when the robot is used as a machine tool). In that case velocity control, which imply solving the forward kinematics, will be much more appropriate.

Although there are many mechanical architectures of parallel robots the forward kinematics problem for most of them may be reduced to solve the forward kinematics problem for a few key architectures. For example solving the forward kinematics for the Gough platform [64] allows to solve the forward kinematics of the Hexa [68] or the Hexaglide [37, 17, 36] although the mechanical architectures of these robots are quite different.

It is now well known that the forward kinematics of the Stewart-Gough platform may have up to 40 solutions and that all these 40 solutions may be real. Numerous works have provided a deep understanding of the problem which in turn has led to efficient algorithms for determining all the solutions of the forward kinematics using elimination, the Groebner basis or interval analysis. Although impressing progress has been made these algorithms are not yet real-time and furthermore it cannot be said that forward kinematics is a fully solved problem. The research continues with the works [58, 100, 40, 30, 79], etc.

The true forward kinematics problem is to determine the current position of the platform being given the joint coordinates. The algorithms provide all the solutions and hence it is necessary to sort the solutions to determine the current position. In fact the true unsolved forward kinematics problem is the combination of the current algorithms with a sorting algorithm that will reject solutions that cannot be realized physically because of the presence of singularity or of the possible interferences on the trajectory. It is also unclear if this will be sufficient to eliminate all solutions, or only one.

Another approach to solve the forward kinematics is to add extra sensors to the robot. Each extra sensor will provide an additional equation, leading to an over-constrained system which, hopefully will have an unique solution. The problem is here to determine the minimal number of sensors and their location in order to have an unique solution with the simplest analytic form and quite robust with respect to the sensor errors. Some of these problems have been analyzed in [8, 45, 29] but this issue is far from being solved. Adding extra sensors may play also an important role in the robot calibration.

2.4. Singularity analysis

There are various ways to introduce the concept of singularities but the most spectacular one is to consider the static behaviour of the robot. Let F be the wrench applied on the platform of the robot and τ the set of joint forces. These quantities are linearly related by

$$F = J^{-T}(X)\tau \qquad (2.1)$$

where J^{-T} is the transpose of the inverse Jacobian matrix of the robot that is position dependent. Each component of the joint forces vector τ_i may be obtained as a ratio:

$$\tau_i = \frac{A}{\left|J^{-T}\right|} \qquad (2.2)$$

where $\boldsymbol{A}$ is the minor associated to τ_i. Hence, if $\boldsymbol{A}$ is not 0, the joint force τ_i will go to infinity at any position, called *singular position*, where the determinant of J^{-T} is 0, causing a breakdown of the robot (in fact the breakdown will occur before reaching the singularity).

Although the condition $\left|J^{-T}\right|$ seems to be a simple condition as the matrix J^{-T} has an analytical form, the full calculation of this determinant leads to a complex expression with a large number of terms (especially if the robot has 6 DOF).

This remains an important topic of study although many progress have been made in this field, for example the geometrical classification of the singularities or algorithms for detecting singularities in a given workspace [59]. We should also mentioned the works of other authors dealing with singularities for different types of parallel robot manipulators like [44, 13, 2, 3, 83, 95, 96, 47, 102, 103, 51, 41].

Singularities for different configurations of parallel robots still remains open field for research.

Another open question is the global analysis of singularity in relation to the workspace and trajectory planning. In that field we should mention the work of [24].

2.5. Workspace

One of the main drawbacks of parallel robots are their reduced workspace. Furthermore computing this workspace is not an easy task. Opposite of classical serial robots, here the translational and orientation workspace are coupled. Classically the first approach to solve this problem is to fix the values of some DOF until only 3 DOF are free. This is usually done by fixing either the orientation of the platform or the location of its center. In the first case the geometrical approach that determines geometrically the possible motion of the center of the platform for each kinematic chains leads usually to the best result as it provides exact calculation with a compact storage and easy representation.

Orientation workspace is more difficult to deal with as there is no universal way to represent this workspace. Here we could mentioned the works [7] and [70].

Another approach is to calculate an approximation either of the border or of the whole workspace using a numerical method. Some of these approaches have the advantage to be able to deal also with limits on the motion of the passive joints and to allow for workspace verification (i.e. to check if a desired workspace is included in the workspace of the robot). They may also calculate various types of workspace.

The analysis of the workspace for different types of parallel robots is given in [20, 6, 54, 96, 24, 49, 71, 72].

The workspace analysis for different configurations of parallel robots still remains open research field.

Other unsolved problems are:

- a fast algorithm to compute the maximal motion of the platform,
- an algorithm that allows to check for links interference. This is a much more complex problem than may be thought in the first moment. It is necessary to determine all the hy-

per-surfaces in the workspace for which a pair of kinematic chain intersects in order to split the workspace in interference-free regions and then to determine in which region the initial assembly modes is located to obtain the interference-free workspace of the robot. This is a difficult task even for robot with very simple kinematic chains [15].

2.6. Motion (trajectory) planning

Motion planning is a classical problem for serial robots. But in the case of parallel robots the problem is somewhat different. For serial robot obstacle avoidance is the main reason for motion planning, but for parallel robot is the workspace. Possible problems are:

- verification if a given trajectory lie completely within the workspace of the robot,
- determine if two positions may be reached by a singularity free and interference free trajectory that lie completely within the workspace of the robot

Problem 1 can be solved for almost any arbitrary time-function trajectory using interval analysis [59], while problem 2 has some particular solutions [22, 24, 82, 85].

A lot of work have to be done in this area.

2.7. Calibration

Although this problem has been solved for serial robots, this is not the case for parallel robots. Indeed, for a serial robot, small errors in the geometric parameters of the robot lead, in general, to a large difference between the real position of the end-effector and the expected one. This difference may be evaluated by measuring the position of the end-effector and then be used in an optimization procedure which will determine values of the parameters the decreasing the positioning errors. Applied to the parallel robot this method leads to calibration results that are in general disastrous. One of the advantages of the parallel robot is that large errors in geometric parameters may lead to quite small errors in the position of the end-effector. Furthermore the measurement noise has a large influence on the results of the calibration process.

There are two types of calibration methods:

- ***external*:** an external measurement device is used to determine (completely or partially) what is the real position of the platform for different desired configurations of the platform. The differences between the measured position and the desired position give an error signal that is used for the calibration [92, 105, 27, 86, 73, 74, 75, 76, 42, 23, 80, 87].
- ***self-calibration*:** the platform has extra sensors (for example sensors that are used for the FK) and only the robot measurements are used for the calibration [63, 101, 27, 38].

The first method is difficult and tedious to use in practice but it usually gives good results. The second method is less accurate, but it is easy to use and has also the advantages that it can be fully automated.

An interesting theoretical problem is to determine what are the measurement configurations of the platform that will lead to the best calibration. Of course there is an open problem to put the calibration in use in a real, industrial environment.

2.8. Dynamics

Another advantage of parallel robots is that they can reach a high acceleration and velocity, due to the low mass of the moving elements [37, 17].

The first problem here is to determine an appropriate dynamic model of the robot. Various formulations may be used [56, 43, 97, 61, 48, 28], although some simplifying assumptions have to be made.

The second problem is implementation of control algorithms, so that the use of the parallel robot dynamic model, will really improve the motion control of the robot, compared to more classical control laws [17, 37, 36, 32, 91, 14, 39, 78, 46, 88, 5, 77].

Computing the dynamic model of a parallel robot is time consuming (and involves also solving the forward kinematic problem). An important problem here is to determine what should be the computation time of the calculation of the dynamic model, so that its use in a control loop will really lead to an improvement of the performances of the robot. This is a very complex issue especially if it is considered that the control algorithm is not continuous.

2.9. Synthesis and optimal design

It is well known that the performances that will be reached by any mechanism depend upon:

- the ***topology*** of the mechanism,

- the ***dimensions*** of the components of the mechanism.

This is especially true for closed-loop, parallel, mechanisms that are ***highly sensitive*** to both factors. When we design a parallel mechanism so that its performances should best fit to the list of requirements, both aspects must be taken into consideration:

- ***topological synthesis.*** i.e. finding the general arrangements of joints, links that will describe the general kinematics of the structure.
- ***dimensional synthesis,*** i.e. finding the appropriate dimensioning of the mechanism.

Synthesis of a parallel robot is an open field (there are very limited number of papers dealing with this problem) [1, 9, 26, 57] and the main task for the development of parallel robots in practice.

The problems caused by using parallel structures in the field of a machine-tool has shown that designers which have a deep understanding of open-loop mechanisms but, have not experience in closed-loop ones are focused only on the development of the basic mechanical components of their machine and have almost completely neglected the analysis part.

Topology synthesis is a very complex problem for parallel mechanisms at the opposite of open-loop mechanisms for which the number of possible kinematic combinations is relatively reduced. Currently topological synthesis for parallel robots is restricted to find a mechanism with a given number of DOF without considering other performance criterion(s).

Parallel mechanisms, robots, are highly sensitive to dimensioning. One classical example given by [59] is that by changing the radius of the platform of the Stewart-Gough platform by 10% we may change the minimal stiffness of the robot over its workspace by 700%.

According to [59] none of the existing dimensional synthesis methods are appropriate for parallel robots which have usually a large number of design parameters. Furthermore these methods lead to a unique solution: in the case of parallel robots there will not be a single solution to a design problem and providing only one design solution is not realistic. The main difficulty comes from the criterions which have to be considered: some of them are antagonistic (workspace and accuracy – a very accurate robot will usually have a small workspace and vice-versa) or not continuous (no singularity within the workspace), etc.

Therefore a design methodology should provide not only one single solution but, if possible, all the possible design solutions, or, at least, an approximation of the set of all design solutions.

With the optimal design (also includes topological synthesis and dimensional synthesis) which is the crucial issue for development efficient parallel robots, several interesting problems could be solved, like optimization of:

– robot kinematics (workspace, accuracy, maximal motion of the passive joints, dexterity, accessibility, motion pattern, kinematic error);

– robot dynamic (robot max acceleration, robot max speed, inertia, centre of mass);

– robot flexibility (robot stiffness and robot natural frequencies).

Optimal design is open and an actual problem. Very few papers could be found in this area [66, 67, 52, 53, 12, 34].

2.10. Controller

A parallel robot will be an effective system only if the robot controller allows dealing with the specific characteristics of parallel robots. Unfortunately the current trend, especially in the field of machine tools, is adaptation of the existing hardware for the purpose of controlling parallel robots.

This trend could be justified at the beginning of parallel robotics; in the long term this will have a very bad effect on the robot performances.

Analyses in the machine-tool field have shown that more of the 70% errors on the fabricated parts are induced by the controller, the CAD system is responsible of approximately 20% of the errors, and the Stewart-Gough platform (if optimally designed) less than 10% [59].

Hence research should be focused mostly on the controller. The hardware of the controller should support:

- the possibility of using appropriate control laws capable to deal with inherent non-linearities of parallel robots,
- parallel computation (that will drastically improve the sampling time),
- specialized integrated circuits that will be devoted to basic computation tasks such as inverse and forward kinematics.

3. CONCLUSION

In this paper we notified some open problems in parallel robotics. Some of the problems are long term, but others should be solved as soon as possible in order to enable wider application of parallel robots in practice.

Serial and parallel robots probably will live parallel a long years. If we compare about 20 years research in parallel mechanisms and more than 200 years in research to reach the current level of knowledge for serial mechanisms, it is easy to conclude that this process of solving problems in parallel robotics will be in the long term.

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Р е з и м е

ОТВОРЕНИ ПРОБЛЕМИ КАЈ РОБОТИТЕ СО ПАРАЛЕЛНА КИНЕМАТСКА СТРУКТУРА

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Клучни зборови: паралелни роботи; отворени проблеми; истражување

Повеќе од 20 години паралелните роботи го привлекуваат вниманието на научната јавност од една страна, а од друга страна наоѓаат и практична примена во различни апликации како што е производството на различни симулатори за движење, алатни машини, уреди за прецизно позиционирање, медицинска опре-

ма, машини за манипулација со делови и предмети, итн., каде што нивните потенцијални предности (висока точност, крутост, брзина, забрзување и способност за манипулација со потешки товари) можат да бидат многу полезни. Целта на овој труд е да укаже на некои од отворените проблеми кои се јавуваат кај роботите со паралелна кинематска структура и кои претставуваат ограничувачки фактор за нвна поголема практична примена.

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Professional paper

CERAMIC CUTTING TOOLS – SPECIFICATION AND APPLICATION AREAS

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A b s t r a c t: Today ceramics is the collective name for a range of different cutting tool materials. Originally ceramics meant aluminum oxide (Al_2O_3), which dates back to the very first tools made. But in recent times, ceramics cutting tools were first used at the beginning of the 20th century, along with the high speed steel.

Ceramics have undergone considerable development and the inserts of today are not comparable to the early ones. Machinery and methods of application have also changed to better accommodate the excellent productivity that can be offered by ceramics. Still, however, this now more versatile material only represents a few percent of cutting tool material used [1].

Key words: ceramics; cutting tools; aluminium oxide; silicon nitride

1. INTRODUCTION

Ceramics cutting tool are hard, with hot hardness, and do not react with the workpiece materials. They have long tool-lives and can machine at high cutting speeds. Very high metal removal rates are achieved in the right application.

Some of main property differences between non-metallic ceramics when compared to steel is a density of around a third of steel, very high compressive strength, no plastic elongation such as that of steel and very brittle in comparison, the modulus of elasticity for pure ceramics is almost twice that of steel, ceramics have very low thermal conductivity while steel has high [1].

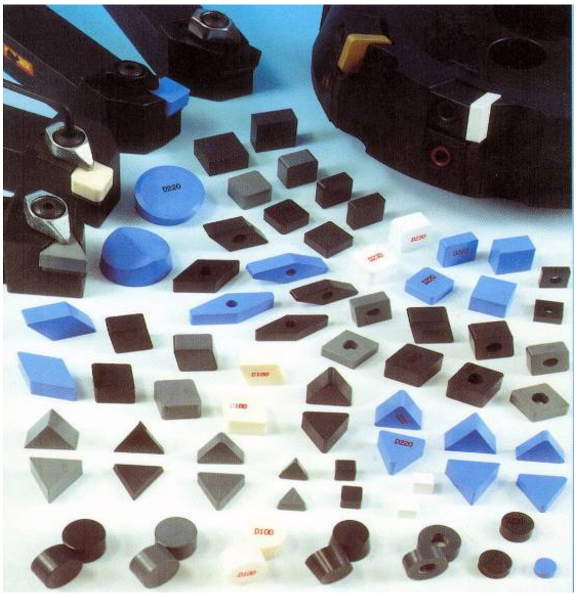

Fig. 1. Ceramic cutting tools

2. TYPE OF CERAMICS MATERIALS

Today, a standardized vocabulary does not exist, such as at sintered carbides or high-speed steel. The following graduation is generally accepted. There are two basic types of ceramics [1]:

- Aluminum – Oxide based (Al_2O_3)
  – pure,
  – mixed,
  – reinforced;
- Silicon – Nitride based (Si_3N_4).

2.1. Aluminum – Oxide based

The pure oxide based ceramics has relatively low strength, toughness values as well as low thermal conductivity. These are obviously not the best values to have in metal cutting and are the reason why cutting edge fracture occurs if conditions are not right.

The mixed aluminum oxide based ceramic material has better thermal shock resistance through the addition of metal phase. This type is less sensitive to cracking through improved thermal conductivity.

The reinforced ceramics, based on aluminum oxide based is a relatively new development. This type is also called whiskers ceramics [5], from that of the single crystal fibre called whisker. These whiskers are only about one micron in diameter and length about twenty microns.

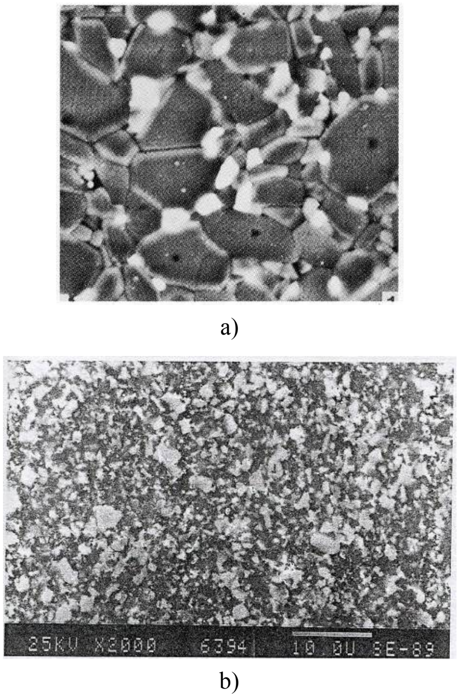

Fig. 2. Structure of aluminum oxide based ceramics [1, 2]
a) pure Al_2O_3, b) Al_2O_3 + 30% TiC

2.2. Silicon – Nitride based

This ceramics is a completely different material and is better than Al_2O_3 based ceramics in standing up to thermal shock and as regards toughness. It is the number one choice for machining grey cast iron with very high removal rates.

The silicon nitride based ceramics is excellent at maintaining hot hardness at temperatures higher than those suitable for cemented carbides and is tougher than aluminum oxide based ceramics.

Silicon nitride shows a chemical affinity for hot steel and, therefore, is not usually recommended for machining steel. The hardness and toughness of silicon nitride based tools are outstanding at high temperature (500 – 900°C). This explains their successful use for cutting nickel based alloys (super alloys).

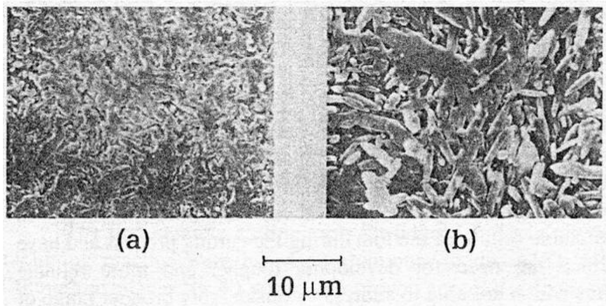

Fig. 3. Structure of silicon nitride based ceramics [2],
a) pressure for 90 min, b) pressure for 400 min

Table 1

Comparison of silicon nitride based, and alumina oxide based tool materials [2]

Material	Young's modulus GPa	Fracture toughness	Modulus of rupture MPa	Thermal conductivity W/m°K	Thermal exp. coef. 10^{-6}/°C	R °C
Al_2O_3	390	2,9	270	32,3	8,2	47
Al_2O_3 + SiC	400	6,0	675	35,2	7,4	155
Si_3N_4	300	4,4	775	19,4	2,5	305
Si_3N_4 + SiC	335	6,4	995	25,2	2,9	435

$R = \sigma(1 - \upsilon) / \alpha E$ at 1000°C

3. PRODUCERS OF CERAMIC TOOLS

There are many factors that influence the demand for ceramics cutting tools; the general state of economy, and in particular the market prospect for metal goods, such us vehicles, domestic appliances, production equipment, aerospace products, etc. Some observes maintain that the application of ceramics insert in steel and cast iron machining has stabilized, and significant growth can only be expected in hard part – turning and heat resistant alloy machining. Main producers and their rake – off at market is in Table 2.

T a b l e 2

Market for ceramics cutting tools by supplier at 2002 [4]

Company	%
Europe	
CeramTec	45
Kennametal + Widia	25
NTK	10
Sandvik	8
Toshiba/Kyocera/TaeguTec/Greenleaf/Other	12
TOTAL	100
U.S.A.	
Kennametal	28
Greebleaf	20
Sandvik + Valentine	19
CeramTec	13
NTK	10
Toshiba/Iscar/TaeguTec/Sumitomo/Kyocera/Other	10
TOTAL	100

3.1. Czech producer of ceramic cutting tools – SGAC Turnov

DISAL is registered trademark of cutting ceramics, produced by Saint Gobain Advanced Ceramics, Ltd. Turnov, Czech Republic. The company has developed highly advanced ceramics materials showing excellent thermal shock resistance, high rupture strength and outstanding wear resistance of cutting edges at high temperatures [3].

The company produces 4 basic series of ceramics cuting inserts [3]:

DISAL 100 – pure oxide ceramics (99% Al_2O_3)

It perform hardness and wear resistance under high temperatures of 1200 °C. It is used for high cutting speeds (up to 100m/min) especially in machining of grey cast iron and constructional steel in areas where interruptions are not factors.

DISAL 210, DISAL 220 – mixed oxide ceramics (based on Al_2O_3, ZrO_2 and CoO)

It offers besides hardness and wear resistance at high temperatures also higher toughness. This type is suitable for machining of grey cast iron, spherical as well as tempered cast iron, heat treated steel and high speed in a light interrupted cutting.

DISAL 320 – reinforced ceramics (based on Al_2O_3 and TiC)

While maintaining high hardness, and toughness this type is also thermal shock resistant, thus allowing machining in partially interrupted cutting and also coolant is acceptable. Machining of chilled cast iron, hardened steel (up to 64 HRC), medium and fine milling are particularly good area of application.

DISAL 420, 450, 460, 470 – silicon nitride ceramics (based on Si_3N_4)

It shows maximum toughness and high hardness. It is suitable for interrupted cut machining, also cooling is possible, good for machining of all cast iron types including cast iron with crust. It is special for mill (roughing), to achieve maximum cutting power.

T a b l e 3

Grade comparison chart of producers of cutting ceramics [3]

Company (material)	DISAL 100, 210, 220	DISAL 320	DISAL 420, 450, 460, 470
CERAMTEC	SN60, SN80	SH20F	SL100 – SL500
HERTEL	AC5	MC2	NC1
KENNAMETAL	K060	K090	K2000, 3000, 4000
KRUPP WIDIA	WIDALOX G	WIDALOX R, H	WIADIANIT
SANDVIK	CC620	CC650	CC680, CC690
NGK	CX3, HC1	HC2, HC6	SX5, SX8
SSYNGYONG	SZ200	ST100 – ST300	SN26 – SN800

4. MANUFACTURING CERAMICS

Manufacturing process of ceramic part (therefore cutting inserts for cutting tools) is very similar to the production of sintered carbides and cermets. The main different is, that ceramic materials do not include material with copulative function of hard particle. This fact is complication at manufacturing ceramic parts and goes up in price of manufacturing plants. Making microstructure and sintered of ceramic materials we can influence by additives. These additives make the liquid phase and enable thickly element ordering and faster and better consolidation of product.

Common procedure of ceramic manufacturing:

- preparation of mixture powder,
- grinding,
- blending,
- forming,
- drying,
- pre-sintering,
- sintering,
- heat treatment,
- surface finishing.

Base materials for ceramic manufacturing

The main materials for manufacturing ceramic inserts are firstly:

- oxides (Al_2O_3, ZrO_2),
- carbids (TiC, SiC),
- nitrides (Si_3N_4, TiN).

This is chemically very stability matters with high hardness, fortress and high heat resistance.

Table 4

Comparison of melting temperature and hardness

Material	Melting temperature (°C)	Hardness (HV)
Al_2O_3	2050	2000
ZrO_2	2700	
Si_3N_4	1900	1000
SiC	2200	2500

5. APPLICATION AREAS OF CERAMICS

Ceramics is efficient cutting material. The successful application of ceramics depends a lot on the match between the operation types, machining conditions, workpiece material, machine tool performance, generally stability, the method by which machining is performed and the cutting edge preparation, especially and presentation to the cut. The main conditions to effective using of ceramics cutting material are:

- High stiffness of system machinetool – cutting tool – workpieces (vibration preclusion, which increasing tool wears).
- Using of powerful machine tools with wide range of feed and cutting speed, and possibility to set high cutting speed. Suitable is gradual control of revolutions.
- Good condition of machine tool.
- Strong and reliable workpieces chunking, especially at high speeds, where high centrifugal forces are.
- Covering of machinetool work place.
- Choice of the right design and size of cutting inserts.
- Right selection of the cutting edge (size, angles, geometry).
- Overrunning unbelief to new cutting material at technologist worker and machine tool staff.

Analogous to sintered carbides, support singular producers of ceramics cutting tools recommend cutting conditions for their cutting inserts. At ceramics cutting tools is very important information cooling. At most of ceramics inserts are cooling prohibited. For hard materials machining (hardened steels, tempered irons,…) by ceramics cutting inserts is necessary to choose low cutting depth a_p.

Producers recommend ceramics materials only for continuous cutting at start of development and production. Gradually development improves mechanical properties, and now we can use this material for cutting by interrupted machining like milling. One of basic condition is prevention of vibration. We can achieve it by using of milling head with higher number of cutting edges.

Disposable ceramics cutting inserts are helpful especially in the large-lot production and mass production where maximum of efficiency under high rates in machining is required (sintered carbides tool are not able to withstand these condition) [3]. Table 3 shows the major applications areas for different kinds of ceramic tools.

Table 5

Main application areas for ceramic cutting tools [4]

Material	Application
Al_2O_3	General turning, boring and grooving of cast iron. Tube scarfing.
Al_2O_3 + ZrO_2	Turning of grey, nodular and malleable cast iron hardened to 300 HB at cutting speeds to 15 m/s.
Al_2O_3 + SiC	Machining of high temperature alloys. Roughing and semi finishing of super alloys, steel and cast iron. Interrupted cuts.
Al_2O_3 + TiC	Turning hard cast iron and heat-tread steels hardened to 64 HRC to a very fine surface finish. Small automotive gear parts to large form rolls for steel mills. General turning, boring and grooving of cast iron. Turning of hard materials (under 65 HRC). Finishing of heat resistant super alloys, cast iron and steel.
SiAlONs	Rough cutting of Ni – based super alloys for aircraft turbine engines. Rough cutting of Ni – based equipment used for corrosive applications in the oil and gas industry. Cuts requiring high feed, speed or depth capabilities.
Si_3N_4 based	Rough turning and milling of cast iron under severe condition up to 13 m/s. Turning of high temperature Ni – based alloys (steels are unsuitable).

6. CONCLUSION

There is describes two basic types of ceramic cutting materials at this paper, their manufacturing, comparison between different producers and using at machining. Ceramic cutting tools are not universal avaolable for cutting of every workpieces and do not push away classical cutting materials like high speed steel or sintered carbides, but have warrant at machining process for using at relatively higher cutting speeds and dispense of cooling. Unfortunately ceramic materials represent only a few percent of cutting tool material uswd at cutting processes.

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Р е з и м е

РЕЗАЧКИ АЛАТИ ОД КЕРАМИКА – КАРАКТЕРИСТИКИ И ОБЛАСТИ НА ПРИМЕНА

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Клучни зборови: керамика; резачки алати; алуминиум оксид; силициум нитрид

Денес керамиката е заедничко име за широк спектар различни материјали за режење. Под керамика се подразбира алуминиумоксид (Al_2O_3), кој е познат уште од времето кога биле направени првите алати воопшто. Во современа смисла на зборот, керамичките резачки алати се употребени за прв пат на почетокот на XX век, заедно со брзорезачкиот челик.

Кермиката претрпела значителен развој и денешните керамички плочки не можат воопшто да се споредуваат со првобитните плочки. Исто така се промениле и машините и методите на примена, со цел да се изврши подобро приспособување на можноста за висока продуктивност која ја нуди керамиката. Но, за жал, овој квалитетен материјал сѐ уште преставува само мал процент од материјалот кој се користи за режење [1].