needs of the defense industry, aviation and space industry, electronics and other industries necessitated machining techniques to be adopted for processing thin, fragile or special and very thin products that could not be manufactured using the conventional processes or this would have been rather impractical and costly. Therefore, a new group of "non-conventional" manufacturing processes emerged to provide improved, convenient and economically advantageous means for specific types of production. These were based on latest scientific and technical achievements and some new findings for using laws of nature relating to light – lasers, sound – ultrasonic processes, magnetism, atomic physics – plasma, electronics and new "powder" metallurgy materials.

Non-conventional processes include:

a) Chemical machining (CM)
b) Electrochemical machining (ECM)
c) Electrochemical grinding (ECG)
d) Electrical discharge machining (EDM)
e) Wire electrical discharge machining (WEDM)
f) Laser-beam machining (LBM)
g) Electron-beam machining (EBM)
h) Water-jet machining (WJM)
i) Abrasive water-jet machining (AWJM)
j) Abrasive-jet machining (AJM) (using air, sand or beads)

Additionally, we could include here Ultrasonic machining (UM) and Deburring processes.

Question 1 b

The areas of application of non-conventional manufacturing processes are as follows:

a) Chemical machining (CM): This is used for removing a layer of metal material, either shallow or deep, by means of etching using chemical compounds, like acids, bases, etc. This is a comparatively old process and it has several options: 1. chemical milling, 2. chemical blanking and 3. photo-chemical machining. Chemical milling is usually applied where larger quantities of material is to be removed from large plates or panels in the aircraft industry, space industry or cutting in depths of up to 12 mm. The process is used to make large aluminium alloy, etc. plates and sheet-metal parts lighter. Chemical blanking is used for manufacturing various scales, dials, rulers, etc. in the instrument-making industry and fine mechanical engineering industry as well as for manufacturing a variety of thin component parts in the mechanical engineering industry. The photo-chemical blanking is applied for manufacturing printed circuit boards for the electronic industry, electrical wiring, electronic chip sets and very thin component parts (depths of up to 0.0025 mm) for the aero-space industry, optics, microelectronics, instrument-making industry, printing industry, crafts – engraving metal or other material articles.

b) Electrochemical machining (ECM): This is based on “dissolving” ions of the processed

b) Electrochemical machining (ECM): This is based on "dissolving" ions of the processed material (metal) in the area around the tool, which is the electrode (-) of the DC source and the processed part is the (+), the ions thus being removed from the conductive electrolyte. This is used in wide machining applications for high-alloyed rigid steels and materials and also for manufacturing complex cutting shapes – turbine propellers, tools – stamps, moulds, dies. The technique is suitable for drilling small holes and cutting into hard materials

c) Electrochemical grinding (ECG): This process is a combination between ECM and a conventional grinding machine. The difference is in the electrical insulation provided in the machine spindle and grinding wheel and the use of an electrolyte instead of a coolant. The tool – the grinding wheel is the (-) of the electrical source and the part being machined is the (+). The technique is applied in machining carbide tools and alloy tools, carbide steel parts, etc. alloys featuring high strength characteristics. Used for grinding, milling and drilling small holes. Not suitable for manufacturing diesл

d) Electrical discharge machining (EDM): This is a widely applied and very useful method based on the erosion of metals caused by the discharge occurring between the electrode and the processed part. The technique is applied for manufacturing tools and dies – for machining cavities and contour shaping and cutting. Used to cut and machine very hard and hardened conductor materials. Could find application in various machine engineering fields, etc. Also applied in automated processes involving CNC machining centers. Used to manufacture complex dies, for example for extrusion of aluminium component parts, etc.

e) Wire electrical discharge machining (WEDM): This is an optional EDM technique where the electrode is a continuous wire, which is used to cut the metal material similar to a band saw.

The depth of the cutting plates is adjustable to up to 300mm. The tool (the wire) is usually made of copper, brass or tungsten and of outside diameter 0.25 mm.

Another optional EDM technique is the electrical discharge grinding where a conventional internal grinding machine is used the grinding stone of which is a conductor material (brass, graphite) playing the role of the electrode and the part being machined is any conductor material. Mostly used for grinding hard carbide alloys of titanium, tungsten, cobalt and tool steels; for machining fragile and brittle small-size components, surgical tools, optical devices, electronic devices, etc.

f) Laser-beam machining (LBM) is used for similar applications to those stated above – cutting, drilling, marking and for surface machining and welding operations involving various materials: metals, ceramics, plastics, leather, textiles, composite materials (in the aircraft industry, etc.).

g) Electron-beam (plasma) machining (EBM) is used in similar applications to those described for LBM but performed in a vacuum surrounding medium: precise cutting and welding of various materials.

h) Water-jet machining (WJM): This technique is used for dynamic cutting and machining various materials: plastic, rubber, foodstuffs, paper, leather, insulation materials, composite materials of up to 25mm thickness. Finds application in the food industry and the production of plastics.

i) Abrasive water-jet machining (AWJM): for "shooting" under pressure and applying dynamic action to the surface of the machined component part. Used for the same applications and materials as those described for WJM.

j) Abrasive jet(gas) machining (AJM): Applied for machining small holes, cleaning surfaces from removing sand or scale in foundry applications, stamped forgings and also for non-metal and fragile materials, as well as for deburring operations.

Question 1c

As described in paragraph 1b above, machining operations feature similar or various spheres and sites of application. Non-conventional manufacturing processes are applied where conventional methods are not applicable, such as cutting and machining very hard, fragile, brittle or small-size component parts.

v) Process efficiency comparison (material removal rate comparison) (MRR): This is based on the data and formulae used to calculate the quantity of removed material (metal chips) per unit time of operation. For example, for EDM the material removal rate $MRR = 4 \times 4^4 IT_w^{-1.23}$ [mm^3 / min]. This equation points out the major factors that influence the MRR rate – the current I (A) and electrode wear T_w. It is a known fact for this particular process that increasing the current I and reducing the discharge frequency (number of discharges per second) [Hz] will reduce process efficiency (material removal rate). For the ECG process the material removal rate $MRR = CI_\eta/A_0$, where in this particular case C is a constant value which depends on the type of machined material (values for C are taken from tables – for Al C-2.0; for Cu C = 4.4, for Fe …) These expressions could be used to evaluate, compare and draw conclusions on the value of energy used in the process and hence, estimate process efficiency.

vi) Tool wear [R]. We will discuss this factor separately and as an integral part of the factors used to judge for the suitable manufacturing process. Here again we use available data and formulae to make calculations. Hence, for EDM $R = 2.25\ T_r^{-2.3}$, where $T_r = T_W / T_E$; T_W is the melting temperature of the material and T_E is the melting temperature of the electrode (tool). Using copper, graphite or tungsten electrodes can extend tool life but would result in different tool cost. We can estimate tool consumption for a certain period based on tool wear and eventually estimate the efficiency of the selected process also considering the MRR rate.

vii) Environmental considerations: It is important to assess the environmental impact of the eventually estimate the efficiency of the selected process also considering the MRR rate.

vii) Environmental considerations: It is important to assess the environmental impact of the process. Processes like EDM, which involve machining in a kerosene fluid, de-ionized water, etc. do not normally emit harmful substances into the atmosphere and are a preferred selection from an environmental viewpoint compared, for example, to laser-beam machining or other thermal metal cutting techniques.

The LBM method could be very dangerous to operators as it might cause radiation and harmful fumes. The AJM should by all means be used with protective clothing for operators or air-tight automated chambers. The process emits dust and flying "damaging" metal particles, etc. It is necessary that the machines in most of the described processes are equipped with the required air filters, settlement sedimentations and air conditioning systems.

viii) Personnel skills: To be able to compare and select the most suitable non-conventional process it is important to give consideration to the required personnel skills available in the company. Described machining processes generally require higher qualification and more costly labour. This is even more important when CNC-control machining centers are used. Some of the processes could also employ low-skilled operators but training cost and labour safety measures will be involved here.

Conclusion: A more precise and correct selection, assessment and comparison of the processes could be made using the table describing the general process characteristics – Appendix 1.

Question 3a

1. Tool wear – causes and significant factors

1.1 Introduction

When processing metals using cutting tools, which is usually accompanied by chipping (sometimes no chipping is involved), tools wear and get damaged. Worn tools are usually re-sharpened for re-use or replaced when unrecoverably damaged.

The causes for this phenomenon are various and result from the nature of the different machining processes involved (metal cutting, alloy cutting, cutting other types of material) and also from all other subjective factors involved and influencing the process.

Processing, i.e. cutting conditions usually involve significant energy consumption, occurrence of substantial forces, vibrations, shocks and emission of heat. In this sense, cutting conditions are heavy processing conditions and therefore lead to faster tool wear or damage especially when hard, tough and high-strength materials are to be processed or when high-speed processing or fast-feed processing aimed at increasing production efficiency is involved.

1.2 Causes and significant factors

and high-strength materials are to be processed or when high-speed processing or fast-feed processing aimed at increasing production efficiency is involved.

1.2 Causes and significant factors

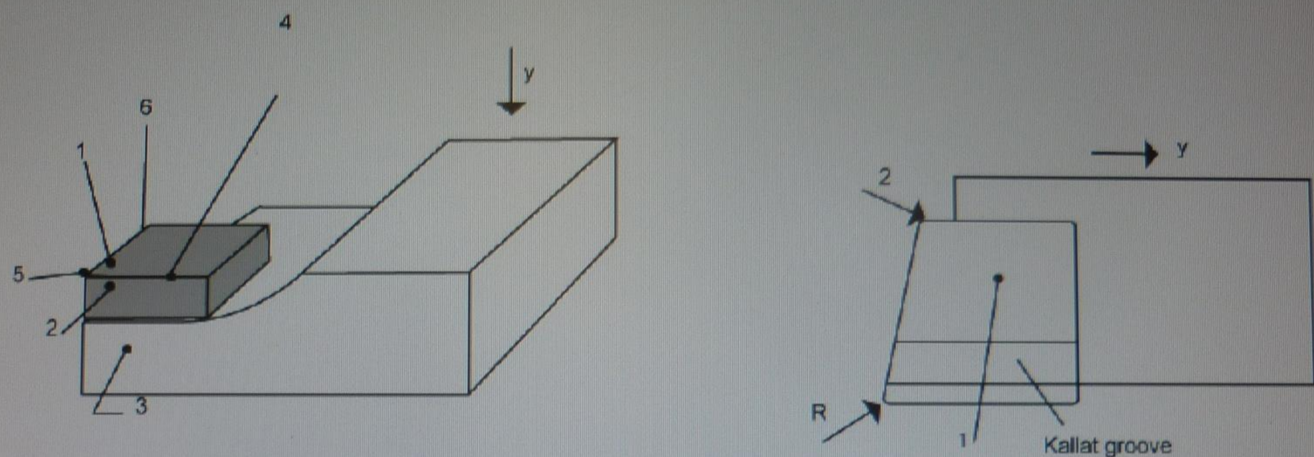
Generally, causes for cutting tool wear or damage are cutting edge wear or the occurrence of obvious breaking out on cutting edges or internal cracking and stress. These are determined by the extent of applied pressure and slipping of metal chips as well as the nature of surface being machined. Included in the cumulative load is also the tool temperature in the area where the load is applied. Tool temperature usually rises due to the heat Q emitted during the processing (cutting) operation.

$$Q = \frac{P_z.V}{427}[ccal/min] \quad (1)$$

where Q is the emitted heat; P_z is the shear force [dN] and V is the cutting speed [m/min].

Although <u>cutting speed</u> is an independent variable, the forces and temperatures generated are dependent variables and are functions of numerous parameters. Similarly, <u>wear</u> depends on tool and workpiece materials (their physical, mechanical and chemical properties, tool geometry, cutting fluid properties and various other operating parameters). The types of wear on a tool depends on the relative roles of these variables. Due to the complicated relations and numerous factors influencing tool wear, various experimental methods and data is usually used to define the type of wear.

Let us consider, for example, tool wear on a conventional lathe knife – figure 1.



Key:

1. Front face
2. Rake face
3. Flank face
4. Cutting edge
5. Tool tip
6. Auxiliary cutting edge

Considering the geometry and characteristic elements of a lathe knife, tool wear usually occurs in

5. Tool tip
6. Auxiliary cutting edge

Considering the geometry and characteristic elements of a lathe knife, tool wear usually occurs in indicated significant cutting edges and faces along with unrecoverable breaking (damage) with significant breaking out of the cutting tool and internally observed and hidden cracking. In other words, tool wear results in the tool being incapable to continue the process carried out between the machine, tool and workpiece (due to different tool size, surface integrity, internal structure, etc.). The term "tool life" is used to identify the time period until the tool is made incapable to perform its functions.

The most significant types of wear are crater wear and flank wear, as well as tool tip and cutting edge breaking out and cracking. These types of wear occur in different ways for different tool materials – figure 2 (for example, carbides, high-speed steels, ceramics, diamond, etc.)

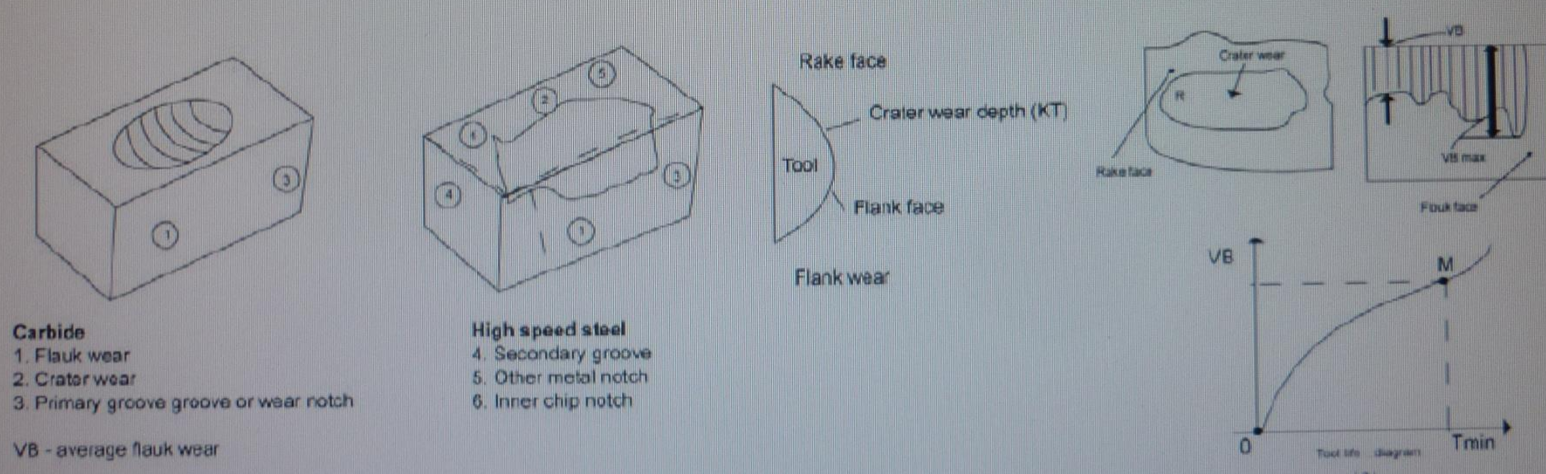


Figure 2

Key:

1. Flank wear
2. Crater wear
3. Primary groove or wear notch
4. Secondary groove
5. Other metal chip notch
6. Inner chip notch
7. VB – average flank wear.

Tool life is as illustrated in Figure 2: (a) – the tool is within the normal required process parameters between points O and M. Following point M, KT and VB have reached the allowable limit.

calculated using Taylor's relation:

$$VT^n = C \quad (2),$$

Where *V* is the cutting speed 9m/min], *T* is time [min] and *n* is a constant value which depends on cutting conditions and *C* is a constant value.

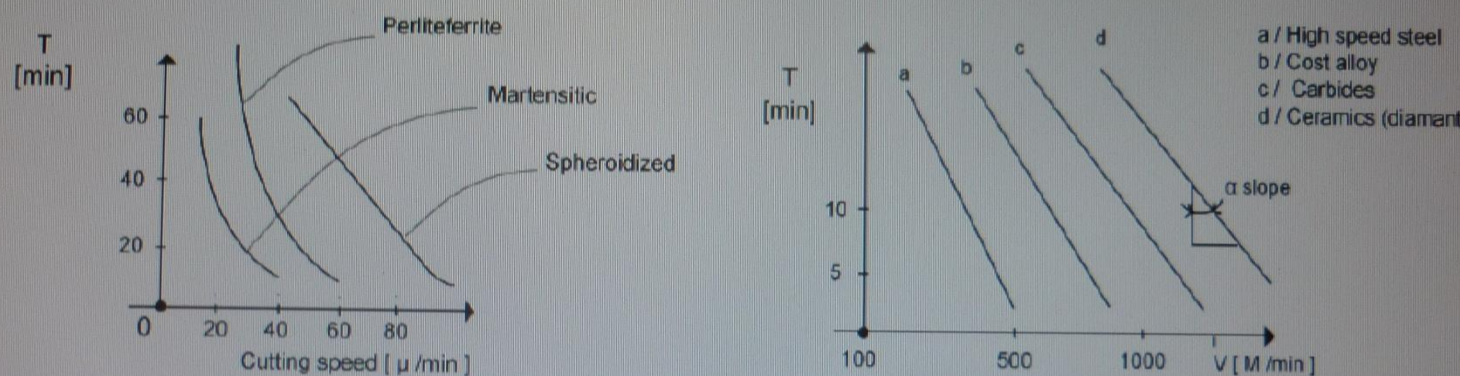


Figure 3

Above expression is a synthesized relationship between a number of factors that influence wear. From the diagrams illustrated in figure 3 we can observe how *T* is influenced by *V* depending on tool-workpiece materials.

Workpiece material

Tool material

a) High-speed steel
b) Cast alloy
c) Carbides
d) Ceramic (diamond)

α- the slope angle: determines the value of "n"

It is obvious here that tool life increases when the speed V is reduced and the hardness and toughness of the material being processed are reduced, too. If we apply the expression (2) we can calculate that under certain conditions (fixed *n* and *C*), tool life *T* increases by 300% when *V*[m/min] is reduced by only 50%. It is a proven fact that for a constant tool life to be maintained, the speed is reduced when the feed *f* and the depth *d* are increased and vice versa.

1.3 Difficulties in forecasting (predicting) tool wear

All explained above makes it clear why it is so hard and sometimes even impossible to give precise forecast for tool life. It is not always possible to predict the influence that numerous factors and their combinations may have. If we take, for example, the expression for P_z(shear force) given above

$$P_z = C_{pz} t^{X_{pz}} S^{Y_{pz}} HB^{pz} .k_m .k_\varphi .k_r .k_j .k_h \quad (3)$$

where the following parameters are included: feed, cutting depth, hardness and a number of we assume that the main factor influencing tool life "T" is the applied load expressed by the applied forces, temperature (heat), shocks, vibrations, then the applied load is in turn influenced by:

- the cutting conditions: speed, feed, depth, cooling, type of processing
- material type: Al, Fe….., size, geometry, quality: porosity, abrasive inclusions, oxides
- the machine-tool-workpiece system: stability, power, vibration resistance characteristics, type
- tool type and characteristics: ceramics,   Figure 4: A machine-tool-workpiece system
- high-speed steels, carbides; geometry, shape, angles, grooves, chipping, etc.
- cooling: intensity, coolant type
- other factors: operator, operator's faults, low qualification, processing technique (incorrect processing technology).

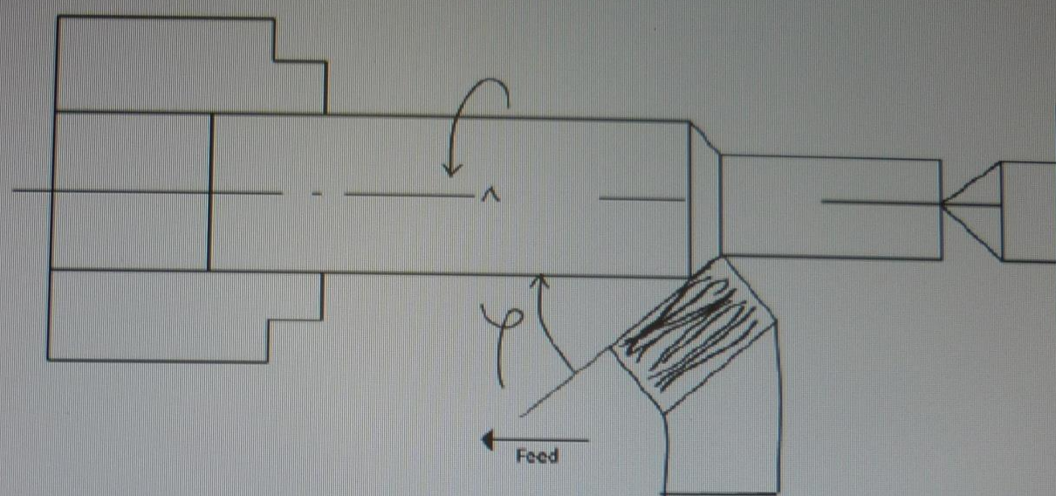


Figure 4: A machine-tool-workpiece system

When cutting long workpieces the change in the angle φ on the tool holder can sometimes cause unexpected vibrations, tool wear or breaking off due to operator's fault (poor qualification).

The complexity of the problem can also be demonstrated using the expression for $T = C^{7} V^{7} d^{-1} f^{4}$.

Question 3 b

Monitoring the condition of tools throughout various machining processes is very important for any production process and has significant influence on process efficiency. This is usually performed in two ways: a) Directly and b) Indirectly

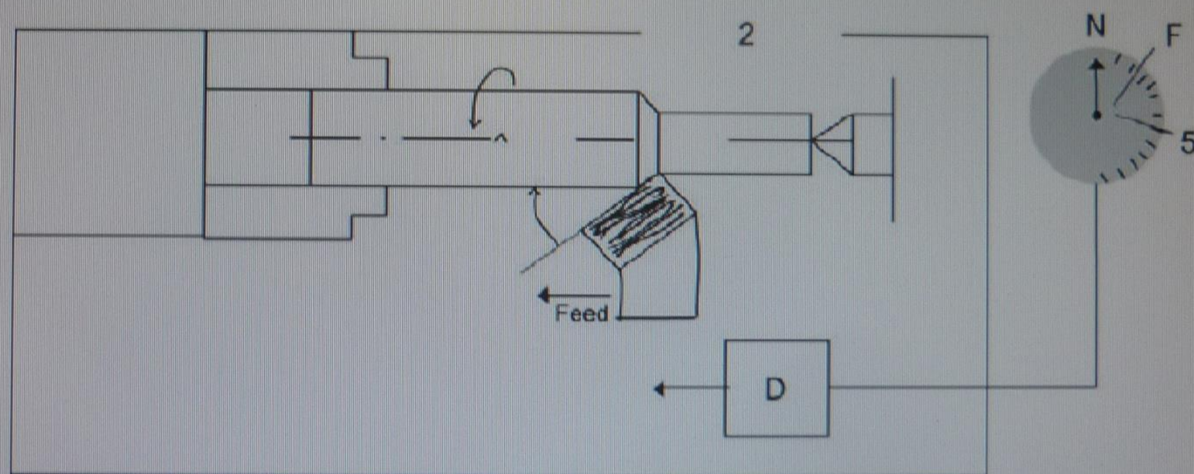
a) The direct method involves visual observation by the operator for any signs of wear, wear hardening (getting dull) or breaking off. It usually requires the operator to stop the machine to dismantle and replace the worn tool. This method of monitoring tool condition involves visual observation or examining under special microscope for some out-of-service adjustment.

b) The indirect method uses indirect information to monitor the condition of the tool: noise, vibrations, size of machined workpiece, shear forces, surface roughness, etc. This is a relatively new method, convenient for CNC machines and is used to assess the condition of the tool "on-line" within the process.

vibrations, size of machined workpiece, shear forces, surface roughness, etc. This is a relatively new method, convenient for CNC machines and is used to assess the condition of the tool "on-line" within the process.

1. Method of monitoring tool wear based on measured forces, vibration and deformations

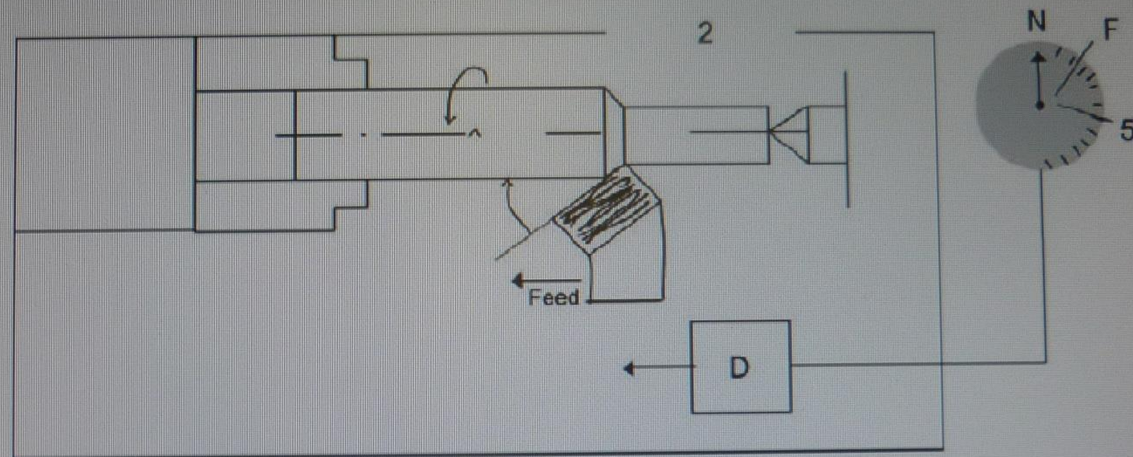
The method is based on the principle of measuring the value or the change of the shear force P_z, vibration amplitude or frequency and deformation observed in the machine-tool-workpiece system to monitor the condition of the cutting tool – Figure 1.



Key to Figure 1:

1. Machine

The method is based on the principle of measuring the value or the change of the shear force P_z, vibration amplitude or frequency and deformation observed in the machine-tool-workpiece system to monitor the condition of the cutting tool – Figure 1.

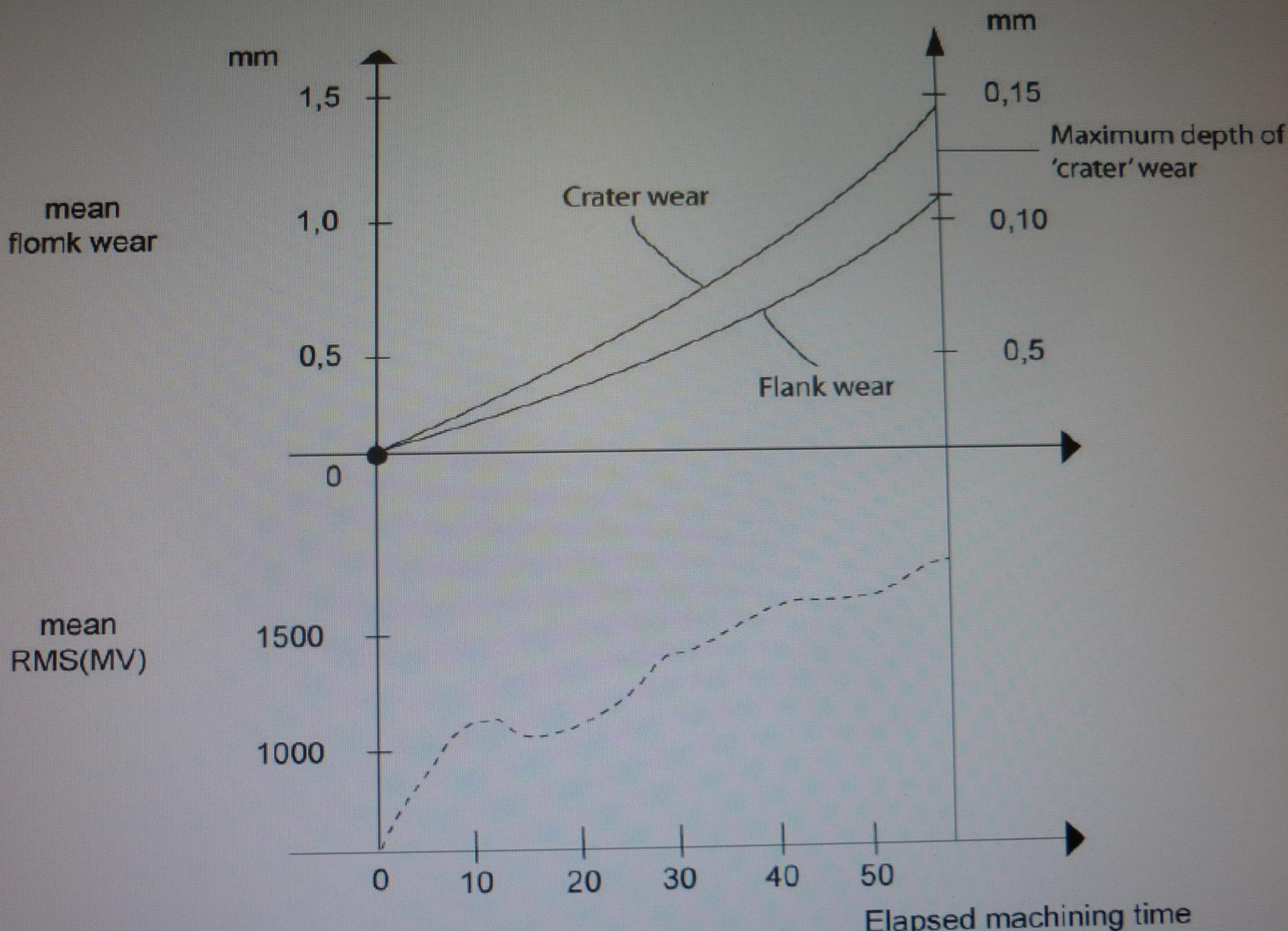


Key to Figure 1:

1. Machine
2. Workpiece
3. Tool positioned in tool holder
4. Sensor
5. Indicator

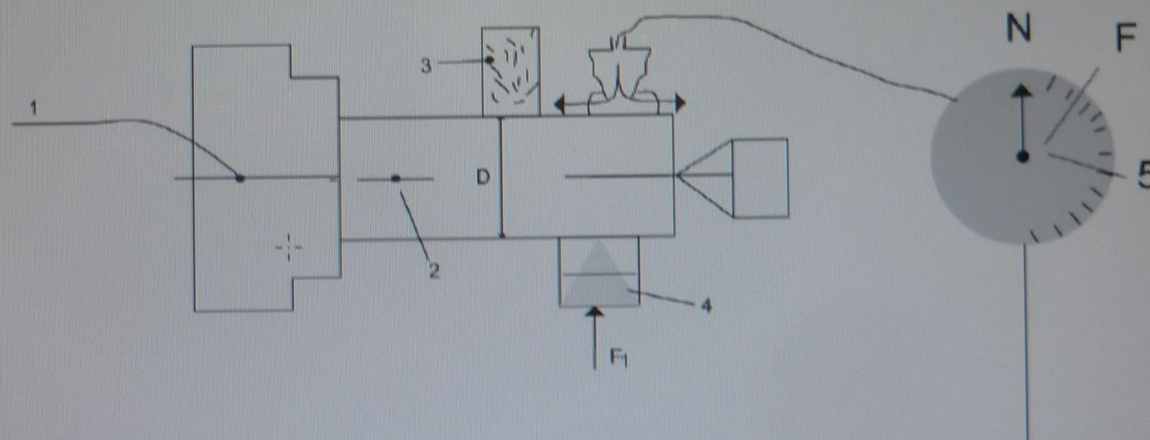
The sensor 4, a piezoelectric transducer (crystal) senses deformations, a rotation of the tool holder

CNC control whenever set limits are exceeded to stop the machine and a "warning" alarm signal to the operator.



3. Pneumatic method

This is an older method very often used in serial and mass production. The condition of the tool is monitored based on the size of machined workpiece. The principle of the method is based on measuring the "gap" between a compressed air (or other type of fluid) nozzle and the machined surface, monitoring the pressure in the system (the volume of air being discharged) – figure 3. The volume (quantity) of discharged air is used to monitor the size [μm] of the gap between the nozzle and the machined surface of the workpiece 2. When the indication goes beyond point F on the indicator 5 the system sends electrical indication to the machine controls and signals the operator.



3.1 Advantages

This is a widely used and relatively inexpensive method for a number of grinding and other machines used in serial and mass production. Also useful for measuring during screening – reels, metal beads, etc.

4.1 Advantages

Widely applied and suitable for machining centres and CNC-control machines.

4.2 Disadvantages

- This method does not provide for monitoring tool condition all the time.
- Data accuracy is influenced by metal chips and other types of contamination.
- Monitoring more complicated types of tools is fairly difficult to perform.
- (In some cases) the method requires operation time.
- Involves relatively expensive and complex equipment.

5. Selection

Considering all described above the most suitable method for universal machines, such as lathes, milling machines, etc. is method No1 and the most suitable method for machining centres and CNC-controlled machines is method No.4.

Question 3 c

Question 4: Acceptance sampling

4a Acceptance sampling is often viewed to be at odds with a TQM (Total Quality Management) philosophy.

Why is acceptance sampling still in use by many companies and how might it conflict with the goals of a "world class" operation?

1. Introduction

Lot-by-lot acceptance sampling by attributes is the most common type of sampling. With this type of sampling a predetermined number of units (samples) from each lot is inspected by attributes. If the amount defective is less than the prescribed minimum, the lot is accepted, if not, it is rejected as being below standard. Each lot in the shipment or order is sampled and either rejected or accepted. Acceptance sampling can be used either for the amount defective or for defects per unit. Sampling plans are established for each class of defect severity (critical, major, minor) or on a demerit-per-unit basis. A single sampling plan is defined by the lot size N, the sample size n and the acceptance number c. (Example: N = 5000, n = 250, c = 20. 20 in 250 are defectives). Acceptance sampling can be performed in a number of different situations where there is a consumer-producer relationship.

2. Why is Acceptance Sampling (AS) widely used by manufacturing companies and other

2. **Why is Acceptance Sampling (AS) widely used by manufacturing companies and other organizations?**

The basic and most significant reason is the fact that the method can be applied in a variety of situations related to quality management, complying with contractual terms, preventing unexpected situations, etc. Moreover, it delivers results or conclusions of sufficient accuracy for a wide variety of purposes.

The method is applied in situations where:

* The inspection results in damage or destruction to the product. If instead of this method (AS) a 100% inspection is applied, this will destroy the entire amount of finished produce. Example: Inspection of batches of ammunitions (cartridges, shells, etc.) or melting electrical fuses (for 10A)[J].

- Since 100% inspection of products would involve additional cost this would add to the cost of the final products (quality control inspections are included in the cost of the product).
- When a large variety of similar products have to be inspected (a wide product range based on a single type of product or principle) sampling will produce as good, if not better results than 100% inspection. Such mass inspections cause fatigue to quality control personnel due to the monotonous work which might in turn result in more errors than the average accepted percentage when using the Sampling acceptance method.
- When the $\bar{x}$ and R and p indicators are not provided in the information relating to quality – no diagrams are available (Paretto chart, etc.)
- When no automated means of control are provided and products are inspected manually or visually.