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DESIGN OF OPTIMUM ENVIRONMENT CONDITIONS FOR ULTRAPRECISION TURNING

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ПРОЕКТУВАННЯ ОПТИМАЛЬНИХ ПАРАМЕТРІВ НАВКОЛИШНЬОГО СЕРЕДОВИЩА ДЛЯ УЛЬТРАПРЕЦИЗІЙНОЇ ОБРОБКИ

У найбільш промислово розвинених країнах миру розвивається нова культура виробництва, заснована на автоматизації, інформатиці, і мікроелектроніці. Це називається ультрапрецизійним виробництвом, субмікро- або нанотехнологією. Його певні характеристики перевищують межу точності 1мкм, також покоління плоских поверхонь площинності менш ніж Ra< 0.08 мкм. Виробництво інструментів високої точності й устаткування висуває спеціальні вимоги для персоналу, робочої зони й інструментів виробництва. Ця робота представляє деякі з найбільш важливих технічних аспектів планування робочої зони.

В наиболее промышленно развитых странах мира развивается новая культура производства, основанная на автоматизации, информатике, и микроэлектронике. Это называется ультрапрецизионноым производством, субмикро- или нанотехнологией. Его определенные характеристики превышают предел точности 1мкм, также поколение плоских поверхностей плоскостности менее чем Ra< 0.08 мкм. Производство инструментов высокой точности и оборудования выдвигает специальные требования для персонала, рабочей зоны и инструментов производства. Эта работа представляет некоторые из наиболее важных технических аспектов планирования рабочей зоны.

In the leading industrial countries of the world a new culture of production has developed based on automation, computer science, and microelectronics. It is called ultraprecision production, submicron or nano-technology. Its specific characteristics are exceeding the magic 1μm accuracy limit and the generation of flat surfaces of a surface roughness less than R_a< 0.08 μm. Production of high-precision tools and equipment puts special requirements of people, working area and production tools. For lack of space, this paper, will present some of the more important technical aspects of planning the working place.

1. INTRODUCTION

High accuracy constructions, technologies and measurements are today indispensible in the area of precision mechanics, optics, microelectronics, automation, mechatronics, machines tool and various tools. Accuracy requirements have been continuously increasing. Thus, „high precision" means a relative order of values.

Its specific characteristics are exceeding the magic 1 μm accuracy limit and the generation of flat surfaces of a surface roughness less than $R_a \leq 0.08$ μm [2, 3]. Assuring ultraprecision production on a commercial scale is a question of strategic importance for the structural change of our industry. Bringing the Hungarian industry to an up-to-date level is an essential task also in the area of production.

2. ENVIRONMENTAL CONDITIONS

Ultraprecision machining and measurement are very sensitive to environmental conditions, amongst these, to vibration, temperature changes, dust content of the air and air movements [1, 2, 3].

2.1. Minimum of vibration and mechanical modeling

Vibration may originate from exterior sources (e.g. another machine tool) and from the ultraprecision lathe itself. The machine (cutting unit) must be placed on a rigid, vibration free basement independent from the building.

Generally passive basement should be applied because of economical aspects. Mechanical modeling of machine basing can be accomplished as follows (Figure 1, 2, and 3)

Exterior exciting force $u(t)$ and vibration $y(t)$ are:

$$u(t) = u_0 \sin(\omega t), \qquad (1)$$

$$y(t) = A\sin(\omega t - \varepsilon), \qquad (2)$$

where A – amplitude, ω – angular frequency, ε – phase of displacement.

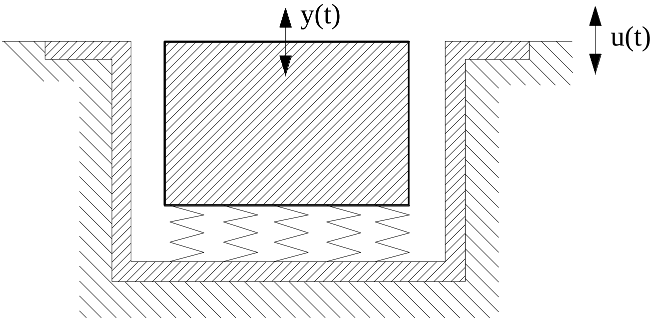

Figure 1 – Machine basing on an elastic base. Movement of the mass in y direction is mitigated by a gravel bed

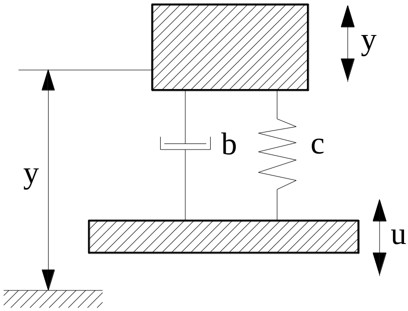

Figure 2 – Model of machine basing (c – spring stiffnes, b – damping)

Coefficient of magnification (v) is:

$$A = vu_0 \tag{3}$$

$$v = \frac{\sqrt{1 + 4\xi^2 \left(\frac{\omega}{\alpha}\right)}}{\sqrt{\left[1 + \left(\frac{\omega}{\alpha}\right)^2\right]^2 + \xi^2 \left(\frac{\omega}{\alpha}\right)^2}}, \tag{4}$$

where:

$$\xi = \frac{b}{2m\alpha}; \ \alpha = \frac{1}{\sqrt{m \cdot c}},$$

b – velacity dependent damping; *m* – vibrational weigh: mass of machine, basing and workpiece; α – natural frequency of the vibrational system.

When is $\xi = 0$ (undamped case), then:

$$v = \frac{1}{1 - \left(\frac{\omega}{\alpha}\right)^2}. \tag{5}$$

If data arleady exists for ξ, then the calculation can made more accurate by (4).

Maximum of sprig force and phase of displacement during the operation

$$F_{r.d.\max.} = \frac{u_0 - A}{c}. \tag{6}$$

and

$$tg\varepsilon = \frac{2\xi \left(\frac{\omega}{\alpha}\right)^2}{\left[1 + \left(\frac{\omega}{\alpha}\right)^2 \left(4\xi^2 - 1\right)\right]}. \tag{7}$$

Figure 3 show the amplitude – frequency response of the system. The undertune (AH) range can be taken into account only for reduction of vibration.

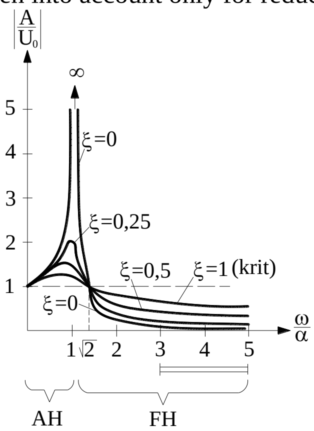

Figure 3 – Amplitude frequency characteristic curve

On base of the calculations and the literature the followings can be suggested.

An increase in the dimensions of the basement decreases vibration. The independent basement at University of Miskolc (ME) has the dimensions of 2000x2000x800 mm, is a poorly reinforced concrete block surrounded by hard rubber plates of about 20 mm in thickness. It is placed in a pebble bed which also decreases or absorbs vibration. The lathe cannot be fixed to the basement, can stand on feet isolalting or damping vibration only. Conducted vibration can be limited to a minimum value by selection of the spring constant and damping factor of the vibration damping feet. Subsequent correction can take place based on the vibration measurements carried out after installation, and then machine feet of adequate damping effect can be mounted. The machine is finally placed on 4 pcs. of air spring.

According to the manufacturer, for UP-1 ultraprecision lathe for high precision work the allowable amplitude of the natural vibration of the machine basement is A ≤ 0,25 μm, eigenfrequencyis F ≤ 50 Hz and its acceleration is a ≤ 7 mm/s^2. Permitted values for submicron accuracy are as follows: A ≤ 0,1 μm; F ≤ 5 Hz; a ≤ 3 mm/s^2. For enhanced optical accuray between high precision work and submicron accuray the natural vibration characteristics of the machine basement can be in the range between the limiting values presented above (Table 1.) The conduction of vibration on to the machine and the machine basement (e.g. from a hydraulic supply unit, etc.) must be hindered, by the use of flexible hoses or tubings, for example.

Table 1 – Accuracy grade

Characteristic	1.accuracy grade precision mechanical	2. accuracy grade optical	3. accuracy grade high precision, submicron
Self-vibration of the machine base - amplitude A - eigen frequency F - acceleration a	A ≤ 0,25 μm F ≤ 50 Hz a ≤ 7 mm/s^2	0,1 μm <A<0,25 μm 5 Hz < F < 20 Hz a ≤ 5 mm/s^2	A ≤ 0,1 μm F ≤ 5 Hz a ≤ 3 mm/s^2
Allowed: air tempe-rapture change Δ t	Δ t ≤ 1°C/h	0,2°C/h < Δt< 1°C/h	Δt ≤ 0,2°C/h
air dust content	max. 40000 pcs/m^3 of the dust grains of max. 0,5 size		
air flow velocity	v ≤ 0,3 m/s		
Noise level: base level/operating	< 35 dB (A) / < 55 dB (A)		

2.2. Air-conditioned cabin

The ultraprecision lathe operates in an air-conditioned cabin, which can only be entered through an air-lock. This is realised by the installation solution shown in Figure 4. The local circumstances and cost limitations have affected the accuracy. The relative largest accuracy has been targeted in the high precision working area.

It has been successfully acomplished. Only the base machine and control (CNC) were placed there. The heat and noise sources (hydraulic supply unti, oiul cooler, heavy-current cabinet, the exhaust plant for chip removal, fog (entrainment) were placed outside the working area. These do not require costly air conditioning. The permitted variation in the temperature of the air for high precision accuracy is t ≤ 1°C/hour, for submicron accuracy t ≤ 0,2 °C/hour, and lies between the two values for enhanced optical accuracy.

For an even higher accuracy, not even the process of cutting can be directly observed. Heat radiation of the human body is equivalent to that of a 300 W electric bulb, which is also a disturbance factor. In this case a TV-chain will be needed for controlling the cutting process, and manipulation of the workpiece will be accomplished by remote control (by manipulator or robot).

Dust content requirements for the working area are as strict as for a on operating theatre. An amount of 40.000 pcs/m^3 of grains of maximum 0,5 μm is allowed. For the velocity of the fresh air arriving from the air-conditioner a limit of v ≤ 0,3 m/s is specified. At the site of the machine operator this air velocity is v'=0.1 m/s in reality. For maximum cleanliness or accuracy a clean coat, slippers and cotton gloves are required.

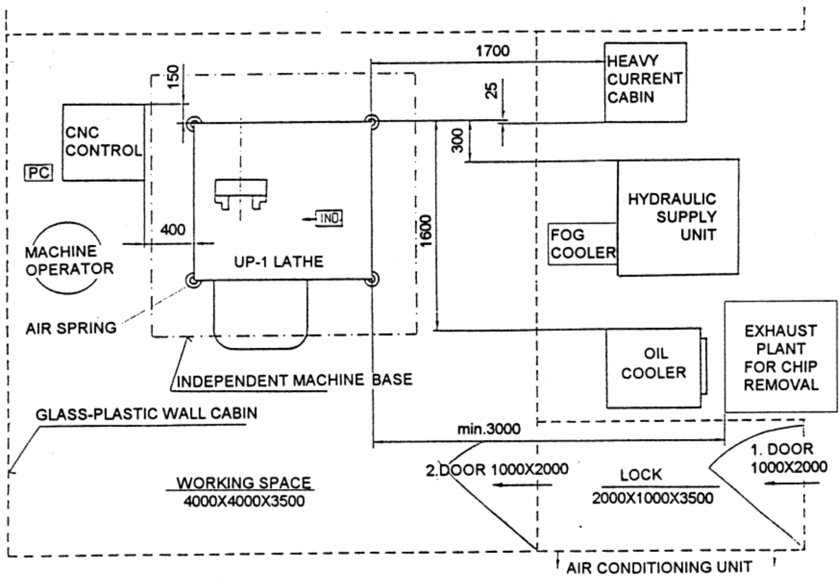

Figure 4 – Installation scheme of ultraprecision turning laboratory

Air humidity in the established laboratory is 50 % on the average, regulabilty is between 30-70 %. The intensity of illumination is about 2000 lux. Colour dynamics is also ggod, yellow and cream colours are dominant. The area of the working space for 2 workers exceeds the value 4 m^2/person.

Environmental conditions are also favourable for human labour.

3. OPERATING STATES OF THE LABORATORY

The two types of the operating states of the laboratory are a consequence of its tasks (training jobs and research). The quality requirements are the strictest for research and development, as well as for industrial and reference jobs. Accuracy and surface roughness demands are also the highest, which can only be accomplished by means of a relatively perfect adjustment of the WTCM and CNC system and the strictest environmental conditions (W- workpiece, M- Machine tool, T- tools). Preparation of the workpiece and the machining equipment, the required measurements, etc. take place in the laboratory in a closed system. 1-2 machine operators stay in the system for a considerable time.

For training jobs, the strict environmental conditions or requirements can be only partly met because in addition to the 1-2 machine operators 2-4 university students or experts participating in an extension training „burden" the cimate of the working space. Climate/conditioning equipment compensating for such overload would multiply the installation costs. Its space requirement is also considerable. The laboratory is also a model workplace. The conditioning equipment operates continuously. The most accurate machining and measurement possiblilities can be predicted for the morning hours (heat inequalities can be better equalized at night). Thus, accuracy also depends on scheduling the work. The climate characteristics in the system (temperature, pressure, humidity) are continously measured and registered. The filtering and the dust content of the system have to be periodically checked, and the ultrafilters have to be replaced. Table summarizes the checking measurements.

4. APPLICATION OF THE ULTRAPRECISION TURNING LABORATORY

Nowadays the industries listed in the introduction cannot do without what is called ultraprecision technologies. Some parts have to be produced with a size, shape and position accuracy of 1 ... 0.2 μm and with a surface roughness of R_a=0.08 ... 0.005 μm. Such strict roughness specifications in themselves mean extremely flat and polished surfaces which are today common for metallic mirrors, optical lenses, for the cylinders of copiers, for data storage disks, etc. [2]. The working place established is also suitable for the accomplishing such tasks.

The technical characteristics of the UP-1 ULTRATURN ultraprecision lathe are presented in [2]. This lathe can replace high accuracy grinding. Parts made of various materials (aluminum and its alloys, copper, bronze, other metals and

nonmetallic materials) of very complex shape are manufactured on this machine.

The tools applied are ultraprecision, superhard cutting edges made of natural diamond in most cases.

The machining of steel, mostly hardened steel, parts (e.g. hydraulic elements, high precision bearings made to order) by means of cubic borone nitrid (CBN) tools is a new area of application [4, 5].

For ultraprecision lathes, swapping the places of the workpiece and the tool is a characteristic way of manufacturing (fly cutting). A multiangular mirror for the printing industry affixed to a round table mounted on a tool holder, for example, is made with a diamond insesrte milling head held in the main spindle.

5. CONCLUSION, CHANGE OF VIEW

The objectives of the laboratory are: undergraduate and postgraduate tranin-ing, professional and specialist training, reference and R&D jobs.

The winderpread introduction of new technology acts as a propelling force al-so in the areas of structures and technologies, creating new possibilities. Such a new area is mechatronics establishsed by the integration of the mechanical and electronic tools and information, which is also a promoter of further development.

Mechatronics and manufacturing with increasing accuracy make new con-structional solutions possible. Design engineers specify an accuracy of 1 μm or below. Production engineers with their available professional knowledge and ex-pertise and the high technology, can affectuate of accomplish the enhanced accura-cy according to the drawing. Obviously we cannot forget that enhanced accuracy has its price.

Designers and technologists must become familiar with the new high technol-ogy and the possibilities it offers and must introduce it in the production in order to fulfil the requirements. One of the possible tools of its correct introduction is er-gonomy.

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References: 1. Weck, Manfred: **Werkzeugmaschine – Fertigungssysteme**. Band 2. (4. Auflage). VDI Verlag, Düsseldorf, 2003. 2. Szabo, O.: **Installation of an Ultraprecisional CNC Lathe Laboratory, its Accuracy and Application**, *Mechatronics,* 3 (3), Pergamon Press, Oxford, 1993, pp.215-219. 3. Szabo, O.: **Design of Optimum Environment Conditions for Production of High Precision Prod-ucts**. Gép, LIII. 2002. 8-9. pp.:23-27. 4. Kundrak, J., Karpuschewski, B.; Gyani,, K., et al.: **Accuracy of Hard Turning** Juornal of Materials Processing Technology V. 202 Issue: 1-3 pp. 328-338. 5. Kun-drak, J., Felho, Cs.; **Tool Life Planning of Cutting Tool Based on the Roughness of Cut Surfaces,** 10th International Scientific Conference New Ways in Manufacturing Technologies, Presov, 17th-19th June 2010, Slovak Republic, ISBN 978-80-553-0441-0, pp. 161-168.

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