RESEARCH IN METALWORKING EFFICIENCY IN DEPENDANCE ON BENCH FACILITIES

Gunars Verdins, Daina Kanaska
Latvia University of Agriculture
gunars.verdins@llu.lv, daina.kanaska@llu.lv

Abstract. The efficiency of metalworking is characterized by amount of productivity as well as expenses for achievement of the necessary possibilities and qualities.The productivity of CNC benches as well as the technical possibilities and possible precision of parts in dependence on the bench facilities are researched in. Coherence of economic efficiency in dependence on introduction of additional equipment is worked out. There is evaluated the influence of different tool and blank change equipment as well pneumatic chuck on productivity. Approximate coherences are worked out, which show the expansion of the bench possibility in dependence on the choice of enlarged parameters of the working area, as well as the effect of growth of bench axe number on the costs of one hour bench working.

Key words: efficiency, productivity, CNC bench, additional facilities.

Introduction

The competitiveness and profitableness of companies in mechanical engineering metalworking industry largely depend on the efficiency of the production process. The efficiency of metalworking, for working processes where metal liming or chip are disconnected from the workpiece, is possible to evaluate by different criteria – productivity, quality, possibilities. Productivity also became a major concern. Generally defined as output per employee per hour or as time, spent for manufacturing of one part. Productivity basically measures the operating efficiency. An efficient operation makes optimum use of all resources, such as materials, energy, capital, labor machinery**,** and available technology. With rapid advances of the science and technology of manufacturing, the efficiency of manufacturing operations began to improve and the percentage of total cost represented by labor began to decline [1].

To define time, spent to manufacture one part, in calculations machine time, auxiliary time, time for machine and working place service as well as time for rest and personal needs are included. Machine time largely depends on regimes of cutting and technical parameters of the bench. When procedure of time standard rating is made for CNC control benches, the part of operations, traditionally included in auxiliary time (tool change, tool move up and move away, taking out of parts, setup of new blank, discharge of chips and other operations), has to be included in machine time. The speed to make auxiliary operation depends on the technical parameters of the bench, quality of program, facilities on the bench. Standard facility usually includes minimal facility, which is necessary for the working process. Additional facility provides a possibility to intensify the working process, to decrease the amount of auxiliary time, as well as the duration of working; to increase the specific weight of the machine time in the base cycle time or to increase the specific weight of the cutting time in the computed machine time. At the same time, additional facility increases the price of the bench.

The aim of the research is to clarify how the facility and technical parameters of CNC benches affect the efficiency of the metalworking process as well as to work out recommendations to help make a reasonable decision, when the CNC bench is purchased or modernized.

It is possible to increase the productivity of CNC control benches by using fast-acting mechanisms for tool change, pallet exchange mechanism, turning tables, automatic receiver of finished parts, chip discharge conveyor, parts transportation conveyor, purification of the cutting space by compressed air, equipment for tool adjustment, hydraulic or pneumatic chuck and vice, bar-advancement workpiece feed mechanism, cooling through spindle and cutting tool, and others.

Methods of calculations

One of the common methods for estimation of the efficiency from additional facility operation E [2] can be expressed as:

$$E = (T_{m1}.t_1 - T_{m1}.t_2) / (D_{c2} - D_{c1}), \quad (1)$$

where T_{m1} – costs of bench working per1 hour, in LVL;

t_1 – time, spent for manufacturing of one part by standard facilities operation;
t_2 – time, spent for manufacturing of one part by standard facilities operation, as well as additional facilities;
D_{c1} – price for bench without additional facilities;
D_{c2} – price for bench equipped with additional facilities.

The costs of bench working per1 hour depend on a number of factors. These costs are possible to calculate by using expression [3]:

$$T_{m1} = (D_{c1}/t_d + D_{c1}\cdot 0.5k + D_{c1}/t_d \cdot K_{ta} + C_{el} + C_{telp})/t_{kop} + C_{main}, \tag{2}$$

where t_d – bench life;
k – coefficient of crediting costs;
K_{ta} – coefficient of machine service costs;
C_{el} – electricity costs, LVL;
C_{telp} – premises rent costs, LVL;
t_{kop} – fixed period of time, h;
C_{main} – variable costs, LVL·h^{-1}.

The electricity costs can be calculated as multiplication of 1 kWh costs C_{kW}, power of bench motors as well power of lighting equipment N_{dz}, loading coefficient K_n, fixed period of time t_{kop}:

$$C_{el} = C_{kW} \cdot N_{dz} \cdot K_n \cdot t_{kop} \text{ (LVL)}.$$

The variable costs develop from the costs of services as well electricity costs: $C_{main} = f\,(K_{ta} + C_{el})$. The premises rent costs can be calculated as: $C_{telp} = C_S \cdot S_d \cdot t_{kop}$ (LVL), where C_S – cost of 1 m^2 of premise per month, S_d – area, bench occupied, m^2.

For evaluation of the bench productivity the amount of parts, manufactured in a fixed period of time n, can be used, which can be expressed as: $n = t_{kop}/t_{det}$.

The time spent for manufacturing of one part t_{det} can be expressed as:

$$t_{det} = t_{op} + t_{ap} + t_{at} + t_{pv} = t_{maš} + t_{pal} + t_{ap} + t_{at} + t_{pv}. \tag{3}$$

It is not possible to change substantially the time for rest t_{at} and personal needs t_{pv}, in case of introduction of additional facilities. Therefore, the main attention is paid to the possibility to reduce the machine time $t_{maš}$, auxiliary time t_{pal}, time for machine and working place service t_{ap}. In the machine time for CNC control benches there are also included: time for tool change, idle running displacement time as well as in case of completion with pallet changing device- time for parts changing also. The machine time of CNC benches $t_{maš}$ includes: time for chip cutting $t_{grieš}$, time for tool change t_{instr}, time for tool displacement $t_{pārv}$. However, the time for tool displacement consists of: time for tool supply to the working area t_{piev}, time for tool tapping movement t_{iegr}, as well as time for tool discharge from the part t_{izv} and time for tool returning in the initial position t_{aizv}. Each from the mentioned movements has different displacement or feed speed.

The time for blank change t_{sag} and time for part size control t_{kontr} are examined separately.

In cases, when the workpiece change operation occurs together with continuation of the work shaft rotation, what is possible when pallet changing devices are used, then the time for workpiece change has to be included in the machine time. It includes the time for bench stalling t_{apt}, time for releasing of machined workpiece t_{atb}, for taking out $t_{izņ}$, for transportation t_{tr}, for putting in of the next workpiece t_{iev}, for clamping t_{iesp}, as well as time, that is necessary for bench running-up t_{pal}. The time for chip cutting $t_{grieš}$ depends on the cutting regime, which respectively is affected by the used tool qualities, shape, sizes; t_{instr} depends on the speed of operation of the tool changer, which is a constant value for each bench; t_{piev} and t_{aizv} depend on the distance of displacement and speed of idle running, which does not exceed the maximal possible value for concrete bench; t_{iegr} value is the choice of the technologist and depends on the tool as well as on the mechanical characteristics of the workpiece. The speed of all mentioned above operations depends on the bench facilities. In cases, when the workpiece size control goes on in-process, it is not necessary to evaluate the time for the workpiece size control. After all factors mentioned above, there is evaluated the tame, spent for manufacturing of one part t_{det}, it can be expressed as:

$$t_{det} = t_{grieš} + t_{instr} + t_{piev} + t_{iegr} + t_{izv} + t_{aizv} + t_{apt} + t_{atb} + t_{izņ} + t_{tr} + t_{iev} + t_{iesp} + t_{pal} + t_{kontr} + t_{ap} + t_{at} + t_{pv}.$$

The potentialities of the bench depend on the number of axis, set of facilities, as well as dimensions of the working area – width, length and height. As dimensions of the working area increase – the price of the bench increases also. To clarify, how the increase of the correspondent dimensions affects the change of the bench price, analysis of prices in-between different one company benches is carried out, as a result to clear how much the price *C* changes in dependence on the changes of the diameter *D* or the length *L* of the workpiece. These coherences may be estimated from the formulas:

$$K_d = dC / dD, \quad (4)$$

$$K_L = dC / dL \quad (5)$$

where K_d – coefficients indicating for how much LVL price of medium size bench increases, if diameter *D* of potential workpiece would increase for 1 mm;
K_L – coefficients indicating for how much LVL price of medium size bench increases, if length *L* of potential workpiece would increase for 1 mm.

Results and discussion

The costs of bench working per1 hour T_{m1} in LVL in dependency on the regime of operation may be estimated from formula (2). The results of calculation are summarized in Table 1.

Table 1.

Costs of bench working per1 hour T_{m1} in LVL in dependency on regime of operation

Bench operation time per year, h	Costs of machine service, LVL	Electricity costs, LVL	Variable costs, LVL	Costs of bench working per 1 hour, LVL
5616	7500	631	16200	5.97
3744	5000	420	10800	6.10
1872	2500	210	5400	8.90
940	2500	105	2700	14.67

To estimate the effect of additional facilities operation on the efficiency of metalworking, expression (1) is made use. To estimate the costs of the bench working per1 hour, expression (2) is made use of.

It was supposed for calculations if the price for the bench equipped with standard facilities is 50 000 LVL; the bench lifetime is 10 years; coefficient of crediting costs is 8 %; coefficient of machine service costs is 0.5; 1 kW electricity cost is 0.08 LVL; power of bench motors– 10 kW, loading coefficient 0.4; area, necessary for bench placement is 15 m^2; working process goes on 2 shifts or 4160 h per year and 10 % of working time (416 h) is spent for machine service and repair. Suppose that the variable costs are 3 $LVL \cdot h^{-1}$.

The costs of the bench 1 hour working, except salaries can be calculated as:

$$T_{m1} = (50000/10 + 50000 \cdot 0.5 \cdot 0.08 + 0.5 \cdot 50000/10 + 0.08 \cdot 10 \cdot 0.4 \cdot 3744 + 5 \cdot 15 \cdot 12)/3744 + 3 = (5000 + 2000 + 2500 + 1198 + 900)/ 3744 + 3 = 11598/3744 + 3 = 3.10 + 3 = 6.10\ LVL \cdot h^{-1}.$$

To state how the choice of the fast-acting tool changer affects the efficiency of metalworking, the time of tool change was fixed by using the principle “chip-chip”. This time is for 2...5 seconds longer than the time, fixed by using the principle “tool-tool”, which can be 0.6…11 seconds and if the tool is changed manually – any longer.

In the calculations it was supposed, that medium cost of the fast-acting tool changer is 5000 LVL and it is used for 10 years. Operation of tool change goes on for three seconds instead of 10 seconds. The tools are changed five times during the time the part is manufactured; time of part treatment – 1 min; amount of parts – 1000 items.

Thereby, the coefficient of the tool efficiency E_{instr} can be estimated as:

$$E_{instr1} = (6.10 \cdot 0.03 - 6.10 \cdot 0.0208)/(50500-50000) = (0.183-0.127)/500 = 0.000112.$$

If the time of the part treatment respectively will be 3 or 6 min, the value of the tool efficiency accordingly would be:

E_{instr3} = (6.10·0.064– 6.10·0.054)/(55000-50000) = (0.390 – 0.329)/ 5000 = 0.0001142;

E_{instr6} = (6.10·0.1139– 6.10·0.1042)/(55000-50000) = (0.6948 – 0.6356)/ 5000 = 0.0001184.

The calculations demonstrate – the amount of parts, which are treated, do not affect the value of the coefficient of the tool efficiency substantially.

How does making use of a pallet changer affect the efficiency of metalworking in conditions, if the part is treated for 1 min.? The cost of the pallet changer is 6000 LVL. To remove the workpiece and fix the next one on the CNC milling machine is spent in the medium time of 10 s. Making use of the pallet changer this process goes down to 4 s. For the amount of parts – 1000 items we come by:

E_{pal} = (6.10·0.0194-6.10·0.0178)/600 = (0.11895-0.10858)/600=0.000017283.

How does making use of the pneumatic chuck instead of the manual three-jaw chuck affect the efficiency of metalworking? The cost of the pneumatic chuck is 600 LVL. The time for change of the workpiece by making use of the manual three-jaw chuck goes on in the medium 5 s, while using of the pneumatic chuck– 3s. For manufacturing of 10000 parts we come by:

E_{pat} = (6.1·0.01805-6.1·0.0175)/60=0.000054166.

From the examples mentioned above, we come to the conclusion – the efficiency of metalworking in dependency on additional equipment can be expressed approximately as:

$$E = T_{m1} \cdot dt/(dD_c / t_{izm}), \tag{6}$$

where dt – demonstrates the economy of time for operation caried out;
dD_c/t_{izm} –division of price difference between unequipped and equipped (with additional equipment) benches on duration of exploitation in years.

The effectiveness, affected by the increase of the technological possibilities of the bench, is evaluated by using formulas (4) and (5), as well as by summarizing the information from the KNUTH and HAAS catalogues [4; 5]. The prices of unequipped, universal, CNC control benches (types ST and SL) produced by HAAS in dependence on the sizes of the working area (max machining diameter D, max length of workpiece L mm) are shown in Table 2.

Table 2

Prices of CNC control benches in dependence on sizes of working area

Max diameter of workpiece, mm	Max length of workpiece, mm	Prices of unequipped CNC bench, LVL
356	356	34 000
381	521	45 000
406	660	55 000
648	1 118	82 000
648	2 038	118 000

On this basis (data from Table 2.) and making use of formulas (4) and (5) it is calculated, that for unequipped, universal, CNC ST and SL types benches prolongation of the working area for 1 mm costs 50 LVL, but enlargement of the machining diameter for 1 mm costs approximately 290 LVL.

The prolongation of the working area of the lathe produced by the company Ecoturn for 1 000 mm costs 14 000 or 10 000 EUR, accordingly 14 or 10 EUR for 1 mm.

In cases, when for the part or product it is necessary to provide high precision of interposition of surfaces, the benches are provided with additional possibilities: CNC benches are equipped with active tools (C axe), machining centers are equipped with 4th and 5th axes or with automatic CNC indexation tables.

The cost to equip the CNC bench for working with active tools or C axe for a medium size bench, for example, CNC bench produced by HAAS (lathe ST-10), is approximately 25 000 LVL. This facility provides a possibility to manufacture products with a higher rate of added value and in the same time to increase the costs of the bench 1 h working. For a definite case, if the mentioned above bench is used 3744 hours per year – the cost of 1 h working increases for 1.27 LVL or for 20.8 %.

The cost to change 3-axe machining centre Matrix Plus with a flexible column and the working area 2200x600x620 (price 128.000 EUR) to 5-axe machining centre Quintamill 800 with the working area 800x600x520 (price 219.000 EUR) is approximately 91 000 EUR.

Additional facilities cost information from a number companies was summarized, as well as the costs of bench 1 h working were calculated by making use of expression (2), consequently coherence (costs of bench 1 h. working in dependence on costs of additions facility) is got (Fig. 1). The coherence shows, that the linear connection is in-between the cost of the bench 1 h. working and additional facility cost. One euro, which is invested in additional facility, increases the costs of the bench 1 h. working for 5 Euro cents.

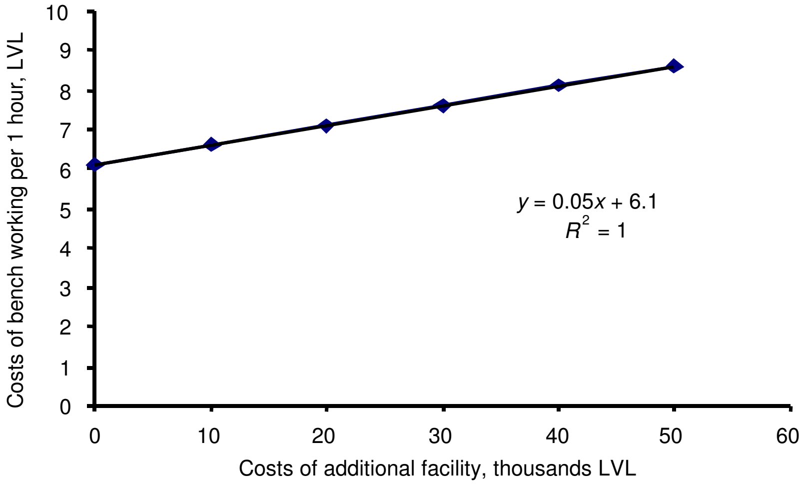

Fig. 1. **Costs of bench working per 1 hour in dependence on costs of additional facility**

Conclusions

1. The efficiency of metalworking depends on the facilities of CNC control benches, the intensity of operation and increasing of the efficiency involving additional costs.
2. The efficiency of metalworking in dependence on additional facilities can be estimated approximately as a proportion of economy of time for the operation carried out and the costs of additional facilities, as well as taking into account the duration of the bench exploitation.
3. Enlargement of the technologic possibilities is in close connection with the price of the bench: the increase of the working area, involvement of active tools; application of additional axes and rotation tables demand serious investments.
4. The productivity depends on the facilities of the benches, technologic parameters, physical-mechanical characteristics of the tools as well as the quality of programs.

References

1. Kalpakjian S., Schmid S.R. Manufacturing engineering and technology. (sixth edition). – New York, Prentice Hall, 2010, 1176 p.
2. Hans Warnike u.a. Kostenrechnung fūr ingenieure.5.Auflage, Carl Hanser Verlag Munchen, 1996, 307 p.
3. Tabellenbuch metall. U. Fischer, R. Gomeringer u.a. 43.Auflage. Lehrmittel. 2005, 422 p.
4. Knuth.de - Products catalogue [online] [21.12.2010.]. Available at: www.knuth.de.
5. HaasCNC.com - Products catalogue [online] [12.12.2010.]. Available at: www.HaasCNC.com.