BALKANTRIB'O5
5th INTERNATIONAL CONFERENCE ON TRIBOLOGY
JUNE.15-18. 2005
Kragujevac, Serbia and Montenegro

TRIBOLOGICAL ASPECTS OF MACHINE TOOLS ELECTROMOTOR PROPULSION SELECTION

Branko Tadić, Miroslav Babić, Fatima Živić, Mašinski fakultet, Kragujevac

Abstract
Machine tools electromotor propulsion selection is conducted from aspect of highest load machine can sustain during usage. Moreover, necessary engine power, computed on the values of the extreme working conditions, in the sense of stability is increased in some cases two or even more times. Consequences of such electromotor selection are utterly negative energy effects. Resized motor energy capabilities result in completely useless energy losses, in most cases totally insensitive to load changes due to its high installed power. The document includes theoretical analisys results and experimental testing concerning abovementioned problems. Theoretical and experimental analisys, included in the document, suggest the necessity of the more complex approach for the selection of machine tools electromotor propulsion, targeting significant energy losses.

Keywords: *Machine tools, electromotors, analisys, theoretical, experimental*

Introductory analysis

Nowadays, investigations concerning the area of energy losses in all aspects of human industry are topical issue. Great number of industrially developed countries regards and plans energy losses as long term development programes of national and strategic interest. To target energy losses (analysis, identification of energy loss, suggestions, etc), most of the countries have formed national expert teams. All of the abovementioned points out the significance of energy losses issue for the industrially developed countries.

In that sense, great possibilities for potential energy savings are found in metalworking industry or in other words in electromotors as prime movers.

Electromotors are seldom used in conditions bearing full load. For example, testing of sixty electromotors in four different factories showed that motors on average work on 60 percent load. Motors working on loads under 50 percent of possible loading have coefficient of utilization significantly lessened, in other words energy losses occur. Great number of motors operating in these exact conditions in production systems are being used, which was confirmed by many studies concerning issues of replacement so called "too big" motors with energeticly efficient motors. There are several general reasons: critical conditions motor failure prevention; unknown motor working load leads to selection of motor highly reliable for fullfilling working demands: possible future motor load increase prevention etc.

Costs of using energeticly oversized motors are high in terms of higher motor costs, more expensive accompanying electrical equipment and increased energy expenses due to lessened coefficient of utilization.

General guidelines for investigations worldwide in area of testing energy losses in electromotor propulsion is analysis of potential replacement of oversized motor by energeticly more efficient motor. Such a replacement may provide significant decrease in energy losses and therefore financial savings. However, issue of optimal load in electromotors cannot be easily generalized for all motors used in industry, but each case of application has to be examined separately.Replacement of oversized motors by

energeticly efficient motors is the main issue of a number of studies favouring this approach for energy saving in industry.
For example, in very lucid study by american association CIPCO, dealing with energy saving issues, energy saving achieved when 7.46 kW motor operating on 25 percent load is being replaced by 2.24 kW motor operating on 83 percent load has been examined. On annual level saving amounts to $172. Bearing in mind the fact that abovementioned data refer to energy saving achieved by substitution of only one electromotor, potential saving arising with possible replacement of electromotors in a whole factory or industry can easily be forseen. According to estimates, by replacement of only ten percents of electromotors in metalworking industry in USA, $18.548.400 can be saved on annual level. We should bear in mind the fact this amount would be even bigger given that previous saving analysis had been performed for substitution of 7.46 kW motor by 2.24 kW motor as well as the fact that electromotor power span in machine tools ranges from 0.1 kW to 110 kW, therefore average examined power is far higher than power given in previous analysis.
As it was mentioned before, this issue cannot be generalized, at least not for all machine tools in industry. However, abovementioned clearly points out the potential of possible savings and therefore justifies actualization of current investigations.

Problems with selection of electromotor propulsion in machine tools

Electromotor as machine prime mover is being selected primarily according to values of necessary torque and speed, in other words number of revolutions. When speaking about electromotors as propulsion prime movers of machine tools problem arises in determining necessary and tangible torque. Machine tools in most cases operate in different load conditions. From statistic point of view dispersion of required torque is very high and may exceed central load many times. For example, given machine tool during its usage operates on electromotor shaft torques presented in rising order as M_1, M_2, M_3, M_n. Most of its operating time electromotor is conditionally exposed to an average load M_{av} and operates with significantly lower coefficient of utilization. Highest loads in electromotors M_{n-m},.....M_{n-1}, M_n rarely occur during exploatation period of electromotor. However, from the loading aspect, electromotor is designed for highest possible load (load M_n and higher loads-safety factor). Machine tools designers appear to know only for limit area of possible loads in other words required torques. From the same reason, it is common case to select machine tool electromotor according to highest possible loading. Besides that as a safety measure (highest possible load is often not known) safety factor is being introduced. In such a manner motor becomes oversized two or even more times compared to highest possible load. In domestic metalworking industry modern geometry cutting tools and high quality tool material prevail. Those tools, as a rule, in physical sense demand less effective power in cutting processes. From the aspect of electromotor, application of modern cutting tools should decrease demands for necessary installed electromotor power, which is not the case in domestic industry. Namely, in the following chapter issue of oversized electromotors is being dealt with by using theoretical analysis and experimental results targeting their low sensitivity to load changes.

Bases of theoretical analysis

According to results of investigation and review of literature resources concerning issues of oversized electromotor propulsion (electromotor) in machine tools the need for certain theoretical explaination of this phenomenon emerges. Low electromotor propulsion insensitivity to even relativly higher load changes is being analysed in the following example.
Two productive operations are being examined, operation “A” and operation “B”. Operation “A” is performed with tool equipped with tool material M_a , operation “B” being performed with tool material M_b. Let us suppose tool material M_b has better tribological properties and that lower cutting resistance occurs during processing that in processing of tool material M_a.

Required effective power, necessary from the physical aspect of realization of the process can be formulated as:

$$P_{Aef} = F_A \cdot v ,$$

$$P_{Bef} = F_B \cdot v = (F_A - \Delta F) \cdot v ,$$

respectively,

P_{Aef} – effective power required for the realization of productive operation “A”,
P_{Bef} – effective power required for the realization of productive operation “B”,
F_A – tangential cutting resistance occuring during performing of operation “A” (resistance occuring in the speed cutting vector),
F_B - tangential resistance occuring during performing of operation “B” (resistance in speed cutting vector),
ΔF - resistance remainder in operations “A” and “B” (supposing tangential resistance occuring during performing productive operation “B” is lower) and,
v - cutting speed for both productive operations

Tangible engaged motor power required for conducting abovementioned operations is:

$$P_{AS} = \frac{P_{Aef}}{\eta_A} = \frac{F_A \cdot v}{\eta_A},$$

$$P_{BS} = \frac{P_{Bef}}{\eta_B} = \frac{F_B \cdot v}{\eta_B} = \frac{(F_A - \Delta F) \cdot v}{(\eta_A - \Delta \eta)},$$

respectively,

P_{AS} - tangibly engaged power for conducting operation “A”,
P_{BS} - tangibly engaged power for conducting operation “B”,
η_A - motor coefficient of utilization for conducting operation “A”.
η_B - motor coefficient of utilization for conducting of operation “B” and,
$\Delta\eta$ - coefficient of utilization remainder of productive operations “A” and “B”.

Namely, it is a known fact that coeffiecient of utilization decreases with decrease of engaged power.
Motor coefficient of utilization is a complex function of engaged power versus installed motor power and can be formulated as follows:

$$\eta = f(\frac{Pef}{P}),$$

P_{ef} - effectively required motor power
P - installed motor power

Changes in coefficient of utilization as abovementioned is very complex function. However, it is a known fact that in the higher proportions P_{ef}/P motor coefficient of utilization η has a rising trend. Motor coefficient of utilization for conducting operation “B” would be generally formulated as follows:

$$\eta_B = \eta_A - \Delta\eta,$$

for, according to starting assumption proportion of engaged and installed power in this case is lower and therefore coefficient of utilization is lower.
Should proportion of tangibly engaged powers in operations “A” and “B” (variable ζ in formula) be inducted into analysis, we get the following formulation:

$$\zeta = \frac{P_{AS}}{P_{BS}} = \frac{I_A \cdot U}{I_B \cdot U} = \frac{F_A(\eta_A - \Delta\eta)}{\eta_A(F_A - \Delta F)},$$

respectively,

I_A, I_B - appropriate electrical powers being used by motor in the course of an experiment “A’ and “B” to load electric system.

Through analysis of the abovementioned formulation following conclusion can be drawn:

- from the theoretical point of view it is absolutely possible that coefficient ζ has value approximative to 1, especially when ΔF has a lower value.
- if that is the case electrical powers values I_A and I_B are as well very aproximative,
- high values for $\Delta\eta$ are present while working with motors bearing small load given the installed power.

Experimental investigation

Investigating plan in productive conditions includes eight independent experiments (E1-E8) conducted in “IVEKO KAMIONI, ZASTAVA” factory. In the specific productive operations machine loads in machines operating with different kinds of tools as for different kinds of tool material and different tool geometry were watched for. Machine loads were watched for via effective electric power which was used by propulsion system to load electrical system. Namely, current intensity measurements were performed at line connections while working with different kinds of tools. Due to the largeness of the operation only final results are given (Table 1.- attachment)

Experimental results analysis

Experimental results analysis leads to conclusion that all machines, in other words electromotors operate on substantially lower loads compared to nominal ones. Full load currents on average make twice as much the power of working load currents. All of the examined motors operate on average with 40-57 percent installed power. Statistical processing of experimental results resulted with interval for engaged motor power in wide population (metalworking industry). According to conducted test we can claim with 95 percent probability that electromotor propulsion in machine tools in domestic metalworking industry operate on loads ranging from 30-70 percent. In such conditions it is absolutely feasible for motors to be insensitive to low load changes caused by geometrical changes and tool material quality. All this indicates large energy losses as a consequence of energeticly oversized propulsion electromotors and great potential for saving energy.

Conclusions

Review of the literature resources leads to conclusion that industrially developed countries pay attention to problems concerning saving of energy in all aspects of human industry. From that aspect, metalworking industry, surely presents essential industry branch. Tribology as a science and a technology made a great break through in all and especially this branch of industry. Usage of modern machine tools, mulitlayer tool coatings and modern geometrical tools led to multiple decrease of indirect energy losses. However, tribological advantages of modern tools cannot have the full effect in sphere of direct energy losses. Reasons for that lie in problems concerning energeticly oversized propulsion of machine tools in other words electromotors. Results presented in this study explicitly indicate the fact that electromotors reffered to in the production process are needlessly oversized given the tangible loads. The fact that in all of eight examined productive operations electromotors were bearing the load of approximately 50 percent of nominal power will suffice. In such conditions coefficient of utilization is extremely low and motor operates with high energy losses. Even though, from the statistic point of view, this was rather minor assay it is highly probable that the situation is very similar on the level of whole domestic metalworking industry. Therefore large scale action (replacement of oversized motors with energeticly more efficient motors, machine selection according to load etc.) should be taken in purpose of cutting energy losses making large energy savings.

References

[1.] Zahar S. Machine tools 1, Yugoslav tribology society, 1993
[2.] Ivković B., TIS – information, Tribology in industry, No.4, 1990
[3.] Science Direct database, http://www.sciencedirect.com,
[4.] Springer-Link database http://www.link.springer.de
[5.] Teodorović V., Electric propulsion machines I, Naučna knjiga, Beograd, 1967.
[6.] Replacing an oversized and underloaded electric motor, fact sheet, http://www.motor.doe.gov , 2003.
[7.] Replacing Oversized, CIPCO Energy Library, http://cipco.apogee.net/, 2003.
[8.] Bhattacharjee K., Tyagi A., Industrial energy conservation: issues for improving industrial operations, TERI Newswire 7(17), 2001.
[9.] Lobodovsky K., Ganeriwal.R, Gupta A., Field measurements and Determination of Electric Motor Efficiency, Sixth World Energy Engineering Congress, Atlanta, Georgia, USA, 1983.
[10.] Cowern E.H., RMS Horsepower Loading, The Cowern Papers, http://www.motorsanddrives.com,2001.

Attachment

Table 1.

Basic data	Experiment E_1	Experiment E_2	Experiment E_3	Experiment E_4	Experiment E_5	Experiment E_5	Experiment E_7	Experiment E_8
Name of the operation	face side processing	adaptor processing	adaptor processing	Ring processing	Internal lathe processing	Turning	Turning	Turning
Machine part	adaptor	cleading	cleading	Ring	Connection	disc	Adaptor	Connection
Machine	Universal lathe “MORANDO “ – PA25	Contouring lathe “FISHER “	Contouring lathe “FISHER “	Universal lathe “MORANDO “ (PA-25)	Universal lathe “MORANDO “ (PA-25)	Numeric lathe (“GILDEMAISTER” CT60)	Numeric lathe (“ADA” – EEN500)	Universal lathe (“MORANDO ” – PA25)
Material JUS-standard	Č 0148	Č 4730	Č 4730	Č 4730	Č 3990	SL 22	Č 4730	Č 1220
Cutting speed	120 m/min	142 m/min	142 m/min	125 m/min	148 m/min	163m/min	166m/min	Č 1220
Cutting depth	1,5 mm	3,15 mm	0,8 mm	1,3 mm	1,5 mm	2,25 mm	1,5 mm	2 mm
Feed	0,25 mm/rev	0,25 mm/rev	0,25 mm/rev	0,20 mm/rev	0,20 mm/rev	0,25 mm/rev	0,20 mm/rev	0,15 mm/rev
Toolholder	CSSPN-2525-12	R.170385032-22 (“ COROMANT “)	R.170385032-22 (“ COROMANT “)	CTUPR-25T-16 (“ COROMANT “)	RF15123-2525 (“ COROMANT “)	DCLNL2525M12	PCLNR2525M12	R.123.G20-2552B (“ COROMANT “)
Indexable insert -I	SPKN-1203EDR PU10116 “ VOXAL “	TNMG220408 P25K20 “ TIZIT “	TNMG220408 P25K20 “ TIZIT “	TPGR160408 GC015 “SANDVIK ”	TCMT06T104 UF235	CNMG120408-ENTM	CNMG120408-ENTM	R.123G2-0300-0502 CM4125 (“ COROMANT “)
Indexable insert-II	SPKR-1203EDTR ME12T25M “ SECO “	TNMG220408 PGP415 “ CORUM“	TNMG220408 PGP415 “ CORUM“	TPGR160408	TPGR160408	CNMG120408-ENTM	CNMG120408-WM	-
Idle motion power - I_{ph}	4,8 A,	4,8 A,	4,8 A	12 A	8,5 A	8,5A	9A,	7A,
Electric power for processing with indexable insert ” I” – I_1	5 A	5 A	5 A	12 A	11 A	11 A	12,6 A	7,2 A
Electric power for processing with indexable insert” II” – I_2	5 A	5 A	5 A	12 A	11 A	11 A	12,6 A	-
Full motor loading power - I_n	8,8 A	8,8 A	8,8 A	30,5 A	22,3 A	22,3 A	22,3 A	15,2A
Motor power P_n	4 KW	4 KW	4 KW	15 KW	11 KW	11 KW	11 KW	7,5KW
Engaged motor power P_{an}(%)	56,8	56,8	56,8	39,3	49,3	49,3	56,5	47,4