Transactions of the VŠB – Technical University of Ostrava, Mechanical Series
No. 2, 2010, vol. LVI
article No. 1776

Zuzana ANDRÁSSYOVÁ [*], **Martin KOTUS** [**]

EVALUATION OF CNC MILLING MACHINE CAPABILITY FOR TRANSMISSIONS GEAR MANUFACTURING

HODNOTENIE SPÔSOBILOSTI CNC FRÉZKY NA VÝROBU OZUBENIA PREVODOVIEK

Abstract

The study deals with the machine capability analysis for the helical gear manufacture. It includes the gear parameters measurement and further manufacture process evaluation by the statistical quality control (SQC). On the basis of individual quality coefficients, general stability and normality of measured values the machine capability is evaluated.

The results suggest that the milling machine capability influences the whole process of helical gear manufacturing significantly. Therefore, it is relevant to pay a good attention to all needed steps and their interactions.

Key words: helical gear, process quality, milling, machine capability.

Abstrakt

Štúdia sa zaoberá analýzou spôsobilosti zariadenia na výrobu šikmého ozubenia. Zahŕňa meranie parametrov ozubenia a následné hodnotenie výrobného procesu štatickou kontrolou kvality. Na základe jednotlivých ukazovateľov kvality, celkovej stability a normality nameraných hodnôt je hodnotená spôsobilosť výrobného zariadenia.

Výsledky naznačujú významný vplyv spôsobilosti frézky na celý process výroby šikmého ozubenia. Preto je potrebné venovať pozornosť všetkým potrebným krokom a ich vzájomnému pôsobeniu.

Kľúčové slová: šikmé ozubenie, kvalita procesu, frézka, spôsobilosť výrobného zariadenia.

1 INTRODUCTION

Nowadays gear mechanism is one of the most extended and the most significant type of transmission systems. Relative motion of turning power is transmitted by the rotary kinematic couple of gear wheels, which are difficult to manufacture. Their effective use demands high tooth preciseness, long life, noiselessness and smoothness of gearing, high mechanical efficiency etc. Therefore high gear quality level is necessary for correct function of gear transmission.

Work focuses on helical gear milling process on the CNC milling machine Gleason - Pfauter P100. CNC milling enables more productive, more stable, higher quality manufacturing without direct operator interference during the manufacturing process. Achievement of high gear quality requires evaluation of manufacturing machine capability for the process. On account of that, it is possible to confirm or to refute the capability of CNC milling machine hypothesis to manufacture within known regularities and required standards.

Objective of the work is to approach the statistical regulation usage as well as method for milling machine capability evaluation of the helical gear manufacturing process. Evaluations of milling machine capability and determination of input data by measuring defined quality characteristics are

[*] Ing. Zuzana Andrássyová, Slovak University of Agriculture, Faculty of Engineering, Department of Quality and Engineering Technologies, Tr. A. Hlinku 2, 949 76 Nitra, E-mail: andrassy@student.uniag.sk

[**] Ing. Martin Kotus, PhD., Slovak University of Agriculture, Faculty of Engineering, Department of Quality and Engineering Technologies, Tr. A. Hlinku 2, 949 76 Nitra, E-mail: martin.kotus@uniag.sk

needed for every quality characteristic separately. It also involves assessment of effects and changes that are caused by realization of corrective actions aiming to convenient results.

It is very important to seek the most adequate and precise evaluation methods for manufacturing machine capability analysis as well as to analyse the interactions of factors, which affect the quality of gear manufacturing process.

2 METHODOLOGY

CNC Milling machine capability test is proceeded to ensure the helical gears manufacture process with demanded accuracy and precision.

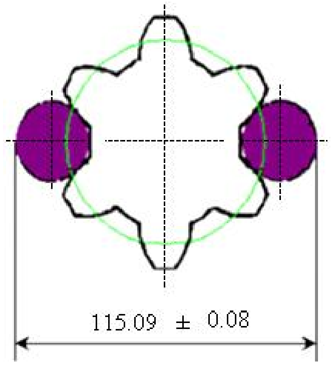
The methodology includes following steps:

a) select the quality characteristic (variables) for exact type of helical gear,
b) collect the entering data for evaluation,
c) monitor and analyse the measured data of chosen samples,
d) define the stability for measured data,
e) calculate the machine capability indexes C_m, C_{mk}.

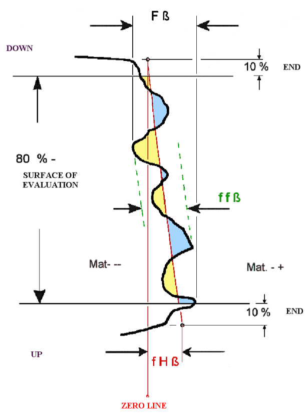
2.1 Selection of quality characteristics (variables)

The most important quality characteristics for helical gear are selected as following:

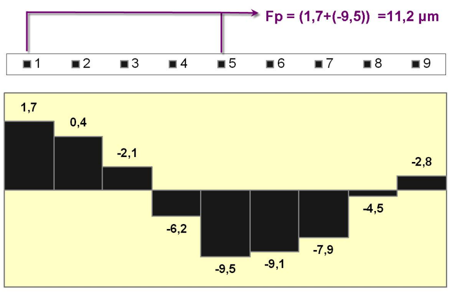
- Ø diameter measured by diametric two-ball dimension ***MdK = 115.095 ± 0.08 mm*** (fig. 1a),
- Ø angular deviation ***fHβ left = 32.00 ± 0.08 µm*** (fig. 1b),
- Ø angular deviation ***fHβ right = 3.00 ± 0.08 µm*** (fig. 1b),
- Ø circumferential flap deviation ***F_r = 22.50 + 45.00 µm*** (fig. 1c).



a) diametric two-ball dimension



b) side tooth profile



c) calculation of total deviation pitch

Fig. 1 Quality control characteristics of gear

2.2 Collecting data

Consecutive sample size consisting of 50 gears (*N = 50*) is manufactured on the milling machine Gleason - Pfauter P100. Samples are taken one by one from the manufacturing process in short term. Data of measured variables are collected for each quality characteristic separately as following: diameter measured by diametric two-ball dimension *MdK* on measuring machine Promes, angular deviation *fHβ* and circumferential flap deviation F_r on measuring machine Klingelnberg Höfler P26. Tolerances of selected quality parameters are define from the gear specifications. Measured variables are applied into the individuals control chart.

2.3 Stability test for diameter and sample standard deviation

Following formulas are used for calculating:

- average of the sample average

$$\overline{X_i} = \frac{1}{n} \sum_{j=1}^{n} X_{ij} \tag{1}$$

where:

n - number of observations in each subgroup (n = 5),

i - 1, 2, 3, ..., n,

j - number of measured item in subgroup,

X_{ij} - value of an individual item i in subgroup j.

- sample standard deviation

$$s_i = \sqrt{\frac{1}{n-1} \sum_{j=1}^{n} (X_{ij} - \overline{X}\, j)^2} \tag{2}$$

- sample mean

$$\overline{\overline{X}} = \frac{1}{k} \sum_{i=1}^{k} \overline{X_i} \tag{3}$$

where:

k - number of subgroup (k = 10);

- average of the sample standard deviations

$$\bar{s} = \frac{1}{k} \sum_{i=1}^{k} s_i \tag{4}$$

- upper and lower intervention limits for diameter

$$HMZ_{\overline{X}} = \overline{\overline{X}} + 1.3\bar{s} \geq \overline{X}\max \tag{5}$$

$$DMZ_{\overline{X}} = \overline{\overline{X}} - 1.3\bar{s} \leq \overline{X}\min \tag{6}$$

where:

$\overline{X}\max, \overline{X}\min$ - extreme diametric values;

- upper intervention limit for sample standard deviation

$$HMZ_s = 2.1\bar{s} \geq s_{\max} \qquad (7)$$

where:

s_{max} - extreme sample standard deviation value.

If conditions for upper and lower intervention limits for diameter are complied, the process location is considered to be in-control (stabile). The same rule is valid in case of upper intervention limit for the sample standard deviation.

2.4 Normality test

Evaluation of normality for each gear quality characteristic is assessed after the measuring variables and stability test for diameter $\overline{X}$ and for sample standard deviation s. Empirical values of distribution function are applied to the probability plotting made for normal distribution. If the conditions of normality (small distances of the applied values deviations from distribution line overlapped by empirical points) are complied, statistical assessment of manufacturing machine continues. In case, conditions of variation are not complied, therefore corrective action for the exact state is preceded.

2.5 Manufacturing machine capability

Following formulas are used for calculating:

- average of the individuals

$$\overline{X_N} = \frac{1}{N}\sum_{i=1}^{N} X_i \qquad (8)$$

where:

N - number of measured variables,

Xi - value of an individual item i,

i - 1, 2, 3, ..., N.

- standard deviation of the individuals

$$s_{N-1} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_i - \overline{X_N})^2} \qquad (9)$$

- machine capability index Cm

$$C_m = \frac{USL - LSL}{6s_{N-1}} = \frac{T}{6s_{N-1}} \geq 1.66 \qquad (10)$$

where:

USL, *LSL*- upper and lower specification limits;

- machine capability index Cmk (It is evaluated with lower index Cmk.)

$$C_{mk} = \frac{USL - \overline{X_N}}{3s_{N-1}} \geq 1.67 \qquad (11)$$

$$C_{mk} = \frac{\overline{X_N} - LSL}{3s_{N-1}} \geq 1.67 \qquad (12)$$

3 RESULTS AND EVALUATION

Measured values were applied into the individuals control chart (fig. 2) and thereafter known regularities were evaluated.

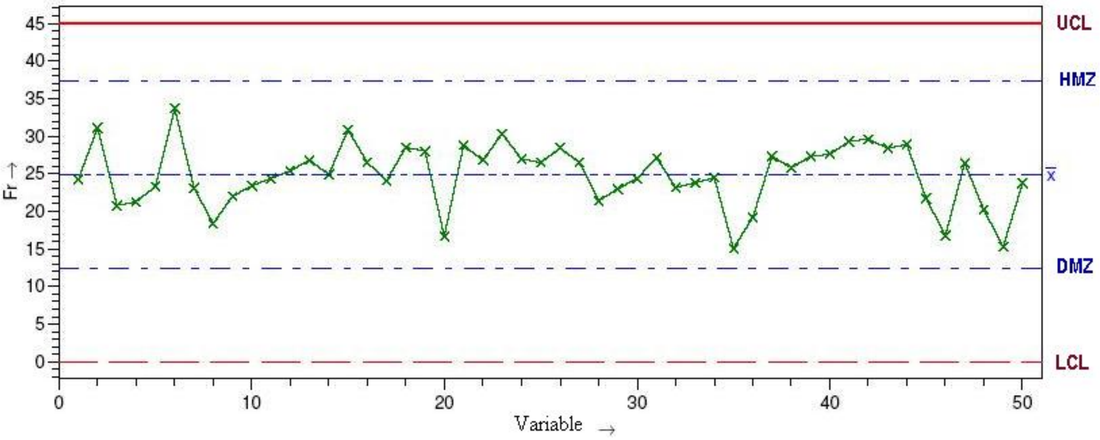


Fig. 2 Individuals control chart for circumferential flap deviation F_r

Stability test conditions for diameter of circumferential flap deviation F_r.

- $HMZ_{\overline{X}} = 30.278$; $\overline{X}_{\max} = 27.84$; $\left(HMZ_{\overline{X}} \geq \overline{X}_{\max}\right)$
- $DMZ_{\overline{X}} = 19.382$; $\overline{X}_{\min} = 20.6$; $\left(DMZ_{\overline{X}} \leq \overline{X}_{\min}\right)$

Stability test conditions for standard deviation of circumferential flap deviation F_r.

- $HMZ_s = 8.800$; $s_{\max} = 5.709$; $\left(HMZ_s \geq s_{\max}\right)$

Results of stability test and normality test (fig. 3) showed that conditions of statistic evaluation for the circumferential flap quality characteristic were complied.

However results of the milling machine capability indexes C_m, C_{mk} (tab. 1) for circumferential flap deviation Fr signified effect of assignable causes, for which corrective actions were designed.

Corrective action were designed and accomplished for each quality characteristic separately considering effect of interference with the results of manufacturing machine. On account of the corrective action it was necessary to manufacture another 50 gear wheels and the process of evaluating repeated until the milling machine capability.

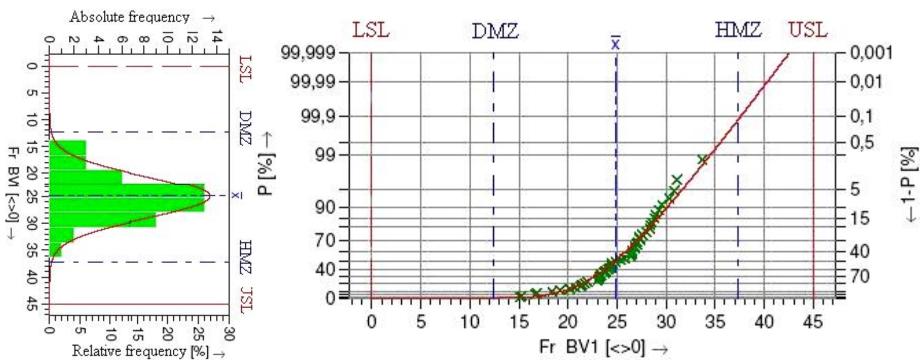


Fig. 3 Probability plotting and histogram for variables of circumferential flap deviation F_r

Negative result was also noted in case of the assessment of angular deviation *fHβ* (tab. 1) quality characteristic.

Tab. 1 Evaluation of the milling machine capability for each quality characteristic

Evaluation 1				
	MdK	***fHβ_l***	***fHβ_r***	F_r
$\overline{X}_N$	115.097	33.448	-1.084	24.834
s_{N-1}	0.00167	2.0695	2.021	4.148
C_m	7.98	1.29	1.32	-
C_{mk}	7.68	1.06	1.99	1.62
C_{mk}	8.29	1.52	0.65	1.99
Evaluation 2 (after reciprocal centring)				
	MdK	***fHβ_l***	***fHβ_r***	F_r
$\overline{X}_N$	115.97	33.36	-1.082	24.46
s_{N-1}	0.00167	1.981	2.205	4.105
C_m	7.98	1.35	1.32	-
C_{mk}	7.68	1.12	1.83	1.67
C_{mk}	8.29	1.57	0.59	1.99
Evaluation 3 (after angle correction)				
	MdK	***fHβ_l***	***fHβ_r***	F_r
$\overline{X}_N$	115.097	34.004	4.936	12.522
s_{N-1}	0.00187	0.564	0.591	4.192
C_m	2.68	4.73	4.51	-
C_{mk}	2.38	3.54	3.42	2.58
C_{mk}	2.98	5.91	3.07	1.99

Design of solution for accomplishing the manufacturing machine capability for circumferential flap deviation F_r.

On the basis of the information that circumferential flap deviation values depend on fixation of the gear wheel and fixation of the gear cutter, following solution was designed: - reciprocal centring of the gear cutter and the gear wheel axis.

Design of solution for accomplishing the manufacturing machine capability for angular deviation *fHβ*

Correction of angular deviation *fHß* is achievable by the manufacturing machine adjustment, therefore the following solution was designed: - correction of the side tooth line adjustment.

Correction of angular deviation *fHß_r* quality characteristic is achievable by process displacement into the middle of tolerance limits. Displacement was determined for a half of the tolerance. The milling machine capability for the helical gear production was accomplished after all corrective actions (tab. 1, evaluation 3).

4 CONCLUSIONS

Conclusion of the helical gear manufacturing process quality on the basis of the CNC milling machine capability study by evaluation of determined quality characteristics is following:

- Ø One of the most important factors that affect the every gear parameter is adjustment of manufacturing machine, the gear wheel, and the gear cutter.
- Ø Each corrective action affects results of all quality characteristics evaluation herewith the manufacturing machine capability. Therefore the action sequence is required.
- Ø In case of the F_r quality characteristic (circumferential flap deviation), reciprocal centring of the gear wheel and the gear cutter is of use, however the process is not affected positively enough. On the other hand it is achieved by side tooth line angle correction. This correction is of use not only for circumferential flap deviation but also for angular deviation *fHß.*
- Ø Machine capability index C_m (variability) for circumferential flap deviation (also roughness) is not evaluated because it does not contain the minus tolerance value.

Assessment of the manufacturing machine capability is evaluated on the basis of measured variables of selected quality characteristics. Thereby, effects of the manufacturing machine settings are important information for monitoring quality of manufacturing process, it need to be settled with interactions of corrective actions and their impact upon positive or negative results.

Improving quality and new approaches of monitoring and enhance the quality standards is not finished. There is always a space for optimalization of entering data, manufacturing process as well as the final product quality.

In chapter were used researches results within the frameworks of statutory researches VEGA 1/0576/09 (2009-2011) – "*The quality improvement of agricultural machines and production systems*"

REFERENCES

[1] HRUBEC, J. & VIRČÍKOVÁ, E. & et al. *Integrovaný manažérsky systém*. 2009, Nitra : SPU, 2009. 543 pp. ISBN 978-80-552-0231-0.

[2] FRIES, J. Analyse of together catching profiles of chainless haulage systems. *Sborník vědeckých prací Vysoké školy báňské - Technické univerzity Ostrava*, 2004, roč.49, p. 61-66. ISSN 1210-0471.

[3] Organization standards: Internal documentation (2008). Kechnec: Getrag, 2008.