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Estimation of tool wear of a gun drill using the signal curve pattern of feed force

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1. Introduction

Gundrilling is widely used, e.g. in automobile manufacture to machine deep holes in engine parts. When industrial drilling applications aim for maximum productivity within certain quality requirements, it also entails that work pieces should be machined at optimum cutting values with as few tool changes as possible. A tool is to be changed when it is worn out but before it is broken, as this often damages the work piece and may also damage the machine itself. If tools are changed frequently, profitability decreases and the costs related to changing and sharpening the tool increase.

Especially unmanned production requires tool wear monitoring. In real production, it is not possible to measure the wear of the drill repeatedly, but the process can be monitored during the drilling. It is generally known that there is a connection between cutting forces and tool wear; cutting forces increase as a function of tool wear. Therefore, it can be expected that tool wear can be estimated by monitoring the cutting forces during machining. According to Jantunen [1], Rao [2] and Rehorn et al. [3], many attempts have been made to determine the relationship between cutting forces and tool wear. For instance Lin and Ting [4] have proposed the utilization of force signals to monitor drill wear online. Cutting tests and statistical analysis indicated that tool wear can be properly estimated knowing the average thrust force and cutting parameters (feed, etc.), especially for large tool wear. It was also shown that thrust force increases as the flank wear increases.

Knowledge of the fact that tool wear affects, e.g. the mean feed force or that this leads to a change in the force curve does not relate exactly when the tool should be changed. For this, we need to know what certain changes in feed force (its intensity and curve) may tell about tool wear and the condition of the drill: whether the drill is new, worn, or worn out. In order to be able to change the tool in different industrial drilling conditions based on a feed force signal (e.g. the feed force value) at the optimal time, it is necessary to identify the connection between the tool wear and the feed force parameters and/or its curve-shaped function.

Tool wear can be measured directly from the tool for example when the workpiece is changed. This visual tool condition monitoring method is used especially during drilling tests in laboratory circumstances, for example when testing drills which have different geometries or coatings or when testing new cutting parameters. However, it is quite time consuming to measure all forms of tool wear and it is also more difficult to draw conclusions from the test results while monitoring several wear types. Moreover, it is difficult to decide how often the tool should be measured.

Flank wear is present in all cutting operations. It is relatively easy to measure. At least for a single-point turning tool, the width of the flank wear maximum is a suitable wear measure, and a predetermine value of the flank wear maximum is regarded as a good tool life criterion [5].

In many drilling tests, flank wear is used as an indicator of tool condition, and according to Jantunen [1] several attempts have been made to predict the flank wear, e.g. by drilling forces Liu and Anantharaman [6] used artificial neural networks for the online classification and estimation of the average flank wear of a drill. Thrust force and torque signals were used for obtaining the input vector of the neural network. Liu and Wu [7] used sensor fusion strategy in order to detect the extent of flank wear. They used indirect indexes: the percentage increase of the peak-to-peak amplitude of vertical acceleration and percentage increase of the trust force. A linear classifier was used to distinguish worn-out and functional drills. Also the pattern of the feed force signal has been used in prediction of the condition of the drill [8]. Subramanian and Cook [9] developed a mathematical model for drilling which combined thrust force, the Brinell hardness of the workpiece, feed, the radius at the cutting edge and average flank wear. The flank wear can be solved from that equation. Subramanian and Cook [9] concluded that through the influence of the work piece hardness on the torque and thrust force, those can be used as variables for drill wear sensing only when there is a close tolerance on the work piece hardness (± 5%).

Some researchers (e.g. Noori-Khajavi and Komanduri) [10] have proposed based on tests that drilling forces in the time domain do not correlate with tool wear. Nevertheless, also results favourable to drilling forces have been presented. Ramamurthi and Hough [11] built a reliably functional tool condition monitoring system which used thrust force, and the current of spindle and feed motor as input variables. According to Rehorn et al. [3] time domain signals in drilling have successfully been analyzed with statistical methods. Regardless of this conflict, according to Rehorn et al. [3] cutting forces in the time domain are the control methods applied during machining that have been studied the most and applied the most frequently in drill wear monitoring.

In this study the relationship between feed force and tool wear was studied in order to monitor the condition of the tool based of the feed force curve. The method used in drilling tests was gundrilling. The gundrilling process produces deep, one-pass, high quality holes. In gundrilling, the cutting speed is high and the feed rate is relatively low, but the penetration rate is higher than that of a twist drill. The method allows the tool to drill the full length of the deep hole without retraction. In the method, cutting fluid is injected with high pressure through the hollow shank. Once the fluid has lubricated the cutting edges of the tip, it escapes along the v-shaped flute of the shank, taking the chips out of the hole. [12]

During the years, many reports have been written concerning the wear of twist drills. Kanai and Kanda [13] investigated the physial and statistical characteristics of the wear at the twist drill point and drilling forces as the basis for developing standardized drill performance tests. They presented different wear types to be measured as a performance index in a standard test. The wear of a gun drill differs a bit from the wear of a twist drill [12] due to the special geometry of the gun drill tip and therefore the results of Kanai and Kanda cannot be directly used in the wear monitor of a gun drill. The wear of a gun drill has been less investigated. It has been presented, based on previous gundrilling tests [14] , that when drilling steel, the most suitable wear types for predicting the condition of a gun drill are flank wear in the drill tip, the average flank wear and the mean and maximum flank wear on the outside edge.

In this study, the behavior of the feed force signal in gundrilling was studied especially in the situation where the feed was stopped just before guidance feed was replaced by actual drilling feed. Stopping the feed caused a new kind of behavior in the feed force pattern. This study examined whether the changes in this feed force pattern could be used in monitoring the extent of the drill wear. In the research, regression models were created in order to estimate the mean flank wear in the cutting edges, flank wear in the drill tip and longitudinal wear by the pattern of the feed force curve when cutting conditions remained constant.

2. Experimental equipment and tests

Gundrilling tests were carried out in the Horizontal Machine Center. Fig. 1 demonstrates the test arrangements. Stopping the feed refers in this study to the fact that the feed was stopped for a moment immediately before it was raised from feed f_1 to f_2. The feed was stopped by changing the NC program during the feed increase in question.

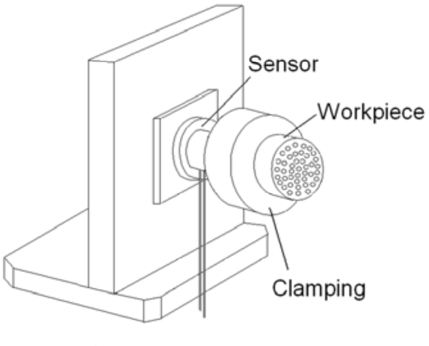


Fig. 1 Test arrangements [15]

2.1. Drills, the test material and cutting parameters

Single flute gun drills with a solid carbide tip (carbide type H15) were used as test drills. The geometry of the drills is presented in Fig. 2. The diameter of the drill was 8 mm and the total length 270 mm. Microalloyed steel, which is widely used in the automotive industry, was used as test material. The average Vickers hardness of the test material was 260 HV/30 (KV+20°C). Cylindrical billets (bars) were used as workpieces. The nominal diameter of the billet was 87 mm and the length was 187 mm. Holes were drilled through the bar to the cross-section. A total length of 7 meters was drilled into each bar (40 holes).

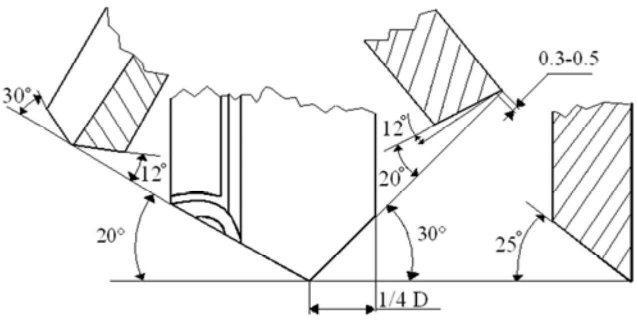


Fig. 2 Geometry of test drill [16]

2.2. Measurement methods

The feed force was monitored during the drilling of one hole after about 7 meters of drilling (the last hole drilled into to each billet). The force measuring system included a piezoelectric platform for feed force and a measuring program. The signal was post-processed (filtering and compression) after collection. The sampling frequency was 16 kHz. In sampling and post-processing, the measurement data was processed so that the final frequency was 20 Hz.

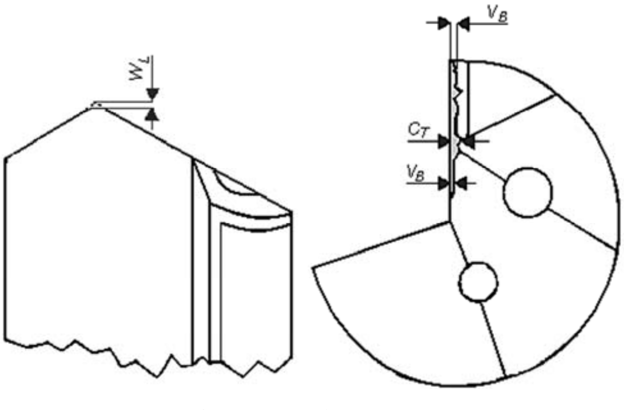


Fig. 3 Wear forms [15]

In this study flank wear value 0.3 mm was used as a tool life criterion, this means that the drilling continued with the same drill until the flank wear was 0.3 mm. Tool wear was measured with a microscope at intervals of 7 meters of drilling (after each billet was drilled). The drilling was stopped after each bar, and the drill was taken out of the machine for measurement of the tool wear. After measuring (if the tool was not worn out), the drilling continued with the same drill on a new work piece. Fig. 3 illustrates the forms of tool wear measured in these tests: the mean flank wear in the cutting edges V_B, flank wear in the drill tip C_T and longitudinal wear W_L.

2.3. Test conditions

Two different feed values were tested while the other cutting parameters remained the same. The total number of tested drills was 5, one in each series. Tables 1 and 2 present the cutting parameters and the test series used in the tests. The data of series 5 was used in validation.

The cutting fluid used in these tests was deep-hole drilling oil (as a base molecularly converted oil, 40 cSt/+20°C). The cutting fluid (oil) pressure was 60 bar. The guide hole's length in all series was 12 mm and the diameter 8 mm. As frequently done in gundrilling, a lower feed was used at the beginning of the drilling (starting feed, f_1), and the feed was raised (f_2) after the drill tip penetrated the material.

Table 1

Cutting parameters 1 and 2

Parameters	1	2
Cutting speed v	80 m/min	80 m/min
Starting feed f_1	0.025 mm/r	0.025 mm/r
Length drilled with f_1	38 mm	25 mm
Feed f_2	0.03 mm/r	0.037 mm/r
Length drilled with f_2	137 mm	150 mm

Table 2

Test series

Cutting parameters	Feed stopping: yes/no	Test series no.
1	no	1
1	yes	2
2	no	3
2	yes	4
1	yes	5 (repetition of the test no. 2)

3. Results

3.1. Tool wear and tool life

As mentioned above, this study applied the flank wear value 0.3 mm as the criterion for concluding drilling. In each test, one of the measured wear forms, the flank wear of the tip (C_T), the mean flank wear of the cutting edge (V_B) or the longitudinal wear (W_L) reached the 0.3 mm flank wear limit. In addition, these wear types were relatively easy to measure accurately, and for instance the built-up edge did not interfere with the measurement.

Flank wear on the tip of the drill (C_T) developed the most rapidly, and reached the 0.3 mm parameter before other types of flank wear in test series 1, 2 and 5. In test series 3 and 4, the flank wear on the drill tip alone was not a sufficient indicator of the actual condition of the drill. The problem in test series 3 and 4 was that the chips did not break off fully. This was most likely due partly to the fact that the feed level in tests 3 and 4 was excessively high.

Table 3 depicts the tool life in each test series. In test series 1, a total of 105 m was drilled, after which the flank wear on the tip of the drill (C_T) exceeded the 0.3 mm limit and the test was concluded. In test series two and its repetition (test series 5), a distance of 105 m was drilled. The feed in tests 3 and 4 was observed to be excessively high for the cutting conditions in question (in relation to the size of the drill, the work piece, the cutting speed, etc.). A worn drill could not break off chips in the desired fashion, making the chips overly long. In test series 3, a distance of 91 m was drilled without encountering any problems. In test series 4, a distance of 77 m was drilled nearly without difficulties. Nevertheless, the tip of the drill was worn significantly during the test, and finally, the drill could no longer break off the chips in the desired manner. After 77 m, the chips did not come off, but curled around the drill. Therefore, the test had to be concluded.

Table 3

Tool lives

Test number	Tool life, m	Billet drilled [number]
1	105	15
2	105	15
3	91	13
4	77	11
5	105	15

The wear of the tool did not differ significantly between cases in which the feed was not stopped during drilling (tests 1 and 3), and those in which the feed was stopped (tests 2, 4 and 5) before the feed level was raised to actual drilling feed (f_2). This can be stated for example by comparing the wear curves in Fig. 4 (feed not stopped) and Fig. 5 (feed stopped).

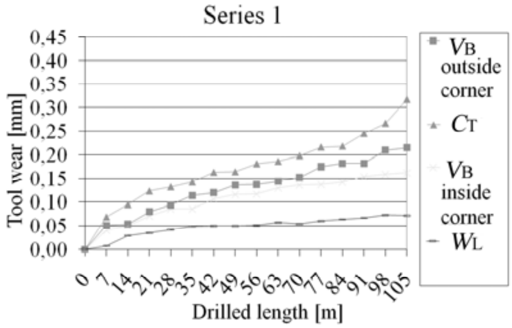


Fig. 4 Tool wear curves (series 1)

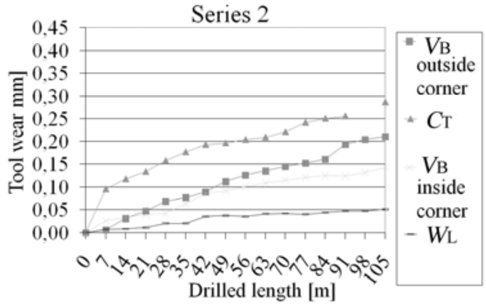
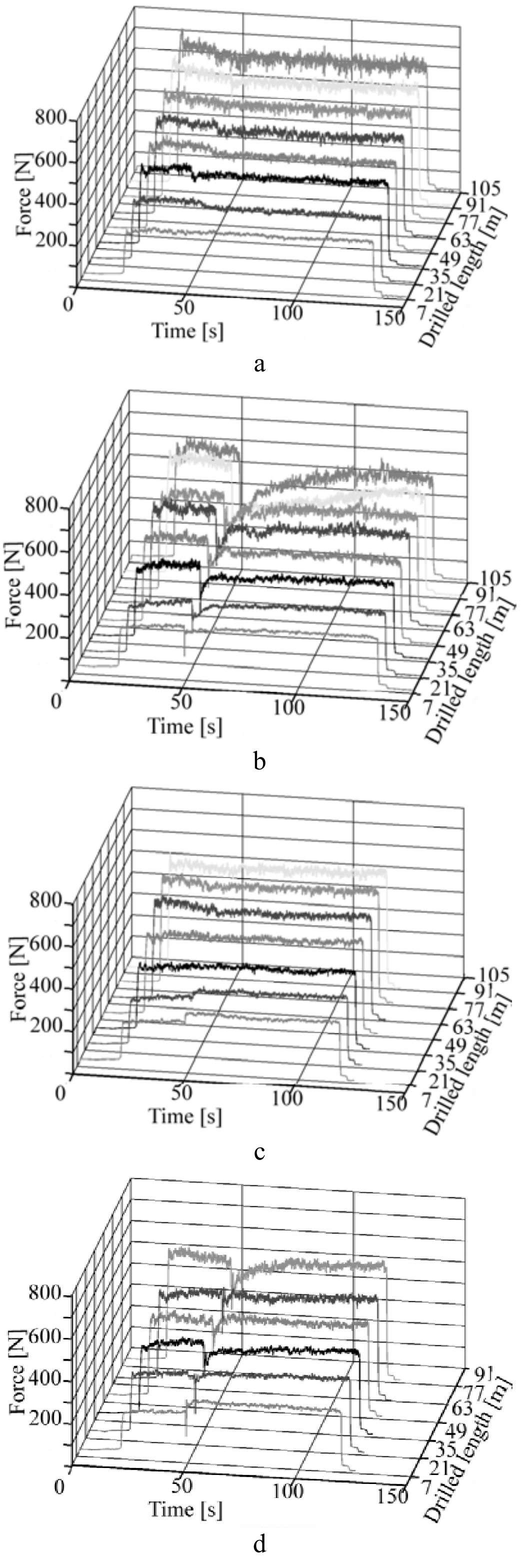


Fig. 5 Tool wear curves (series 2)

3.2. Pattern of the feed force when stopping the feed

Waterfall figures of feed force curves were created in order to recognize more easily the changes in the measured feed force. In Fig. 6, a-d the feed force curves during drilling one hole in series 1 - 4 are presented. The first force curve data of each figure was collected when drilling the last hole in the first bar when the tool was worn only slightly.



a

b

c

d

Fig. 6 Feed force curves in series a - 1, b -2, c -3 and d - 4. The curves are presented every 14 meters, not in every 7 meters, in order to show them clearly

The curves in Fig. 6, b and d show the change in the feed force curve after raising the feed (from f_1 to f_2) after 50 seconds of drilling. When the tool was worn, the force dropped quickly after the feed was stopped and then slowly raised again. The more the tool was worn (that is the more was drilled with the drill) the deeper and larger became the half of the canyon form in the feed force curve. Preciously described phenomenon cannot be seen from Fig. 6, a and c (curves from the drilling tests no. 1 and 3 in which the feed was not stopped).

4. Discussion

4.1. Analysing the pattern of the feed force curve and defining the sections of the curve

Initial tests [15, 16] had indicated that stopping the feed before the feed value was raised to f_2 changes the feed force curve. The feed force plunges momentarily. A new and interesting phenomenon can be observed in the feed force as the tool is worn: the force does not return to its so-called standard level as quickly as with a sharp tool after the feed value is raised (Figs. 7 and 8). The more the tool is worn, the longer it takes to regain the standard level of force. This change is examined below in more detail, and especially its potential for forecasting drill wear is discussed.

Usually when a cutting tool is worn, a greater force is needed to remove the material. In this study, however, the lowered force that was observed in connection with the increase in the feed value may be due, e.g. to vibrations caused by the worn tool. The feed came to nearly a complete stop, and when the feed was restarted, the tool vibrated. The more worn the drill was, the less stable the force was after the feed was increased. When the tool vibrates, the force needed for cutting may decrease. Vibration has apparently been used to assist in a number of cutting processes, and one such technology is ultrasonic vibration cutting, in which the tool vibrates elliptically, thus decreasing, e.g. the cutting forces. This has been studied by Moriwaki and Shamoto [17] and also by Klocke and Rübenach [18].

Figs. 9 and 10 illustrate the vertical vibration and acoustic emission measured during the drilling of test series 2 both when the drill was new and when it was worn.

The sensors for measuring the vibration and

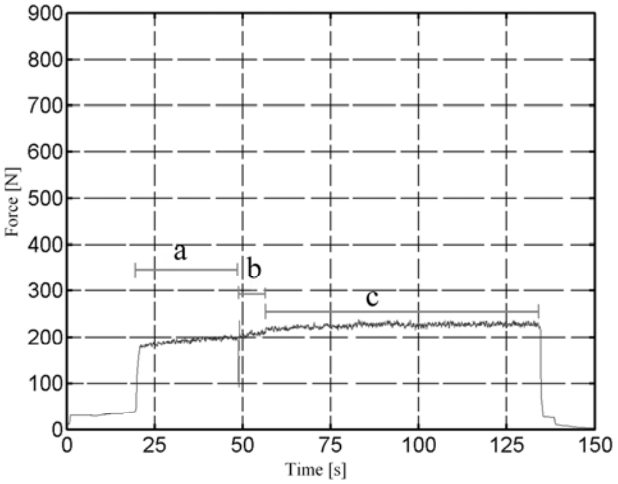


Fig. 7 The feed force curve when the feed is stopped immediately before its level is raised. 7 meters was drilled with the drill. The initial feed in section *a* was f_1, and in sections *b* and *c* it was f_2. Section *b* describes how the feed force returns to the standard level (section *c*) after the feed stop

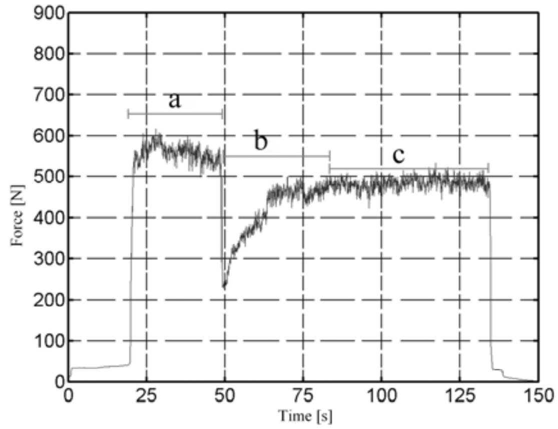


Fig. 8 The feed force curve when the feed is stopped immediately before its level is raised. 105 meters was drilled with the drill

acoustic emission were placed on the clamping of the work piece. The figures show a significant peak in vibration and acoustic emission when the feed was lowered close to zero and then raised (just before the drilling had lasted 50 seconds). The greater the tool wear, the higher the AE and vibration peaks.

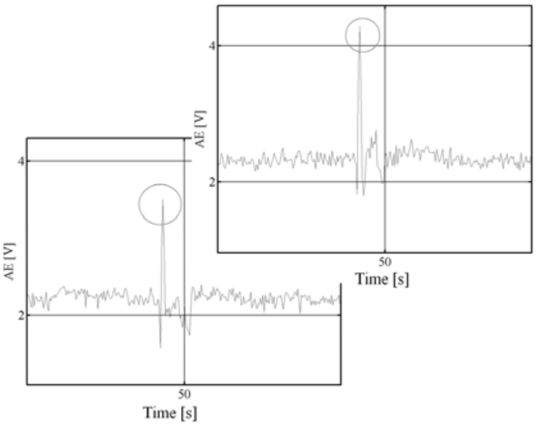


Fig. 9 Acoustic emission values during drilling when 7 m (lower figure) and 105 m (higher figure) were drilled

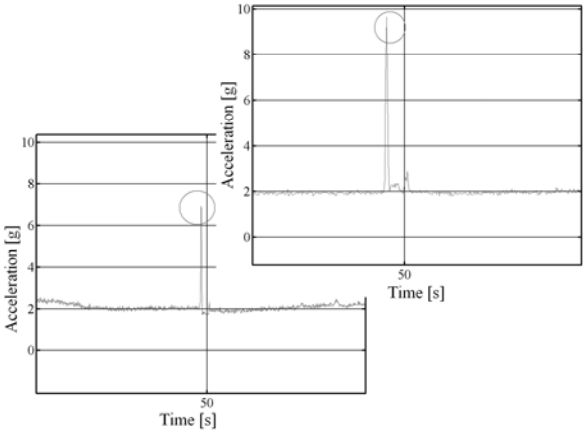


Fig. 10 Vibration values during drilling when 7 m (lower figure) and 105 m (higher figure) were drilled

4.1. Fitted equation

In order to examine the patterns of feed force curves and their changes, curve fitting was defined for the feed force curve after the feed increase in test series 2 and 4 (i.e. tests in which the feed was stopped before it was increased to f_2). The equation thus obtained is

$$F\left(x\right) = a + bx + ce^{-dx} \tag{1}$$

where a, b, c and d are constants to be solved, x is the measurement point, and e is the Euler number (≈ 2.718). The curves could have been fitted also as a function of time, but in this study a measuring point was used to simplify the movement of the zero point and facilitate the analysis (one measuring point – 0.05 seconds).

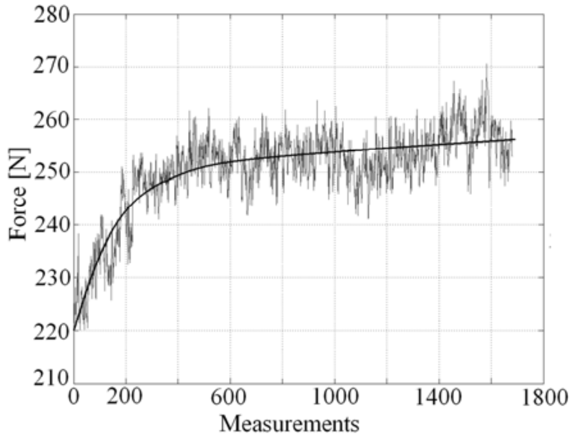


Fig. 11 Feed force in test series 2 after 7 meters of drilling. The vertical axis represents the force [N] and the horizontal axis the measurement points (time points 0.05 s). Feed section f_2, i.e. sections *b* and *c* in Fig. 8. The drilling depth at the zero point on the horizontal axis is approximately 50 mm (12 mm guide hole + 38 mm of gun drilled hole)

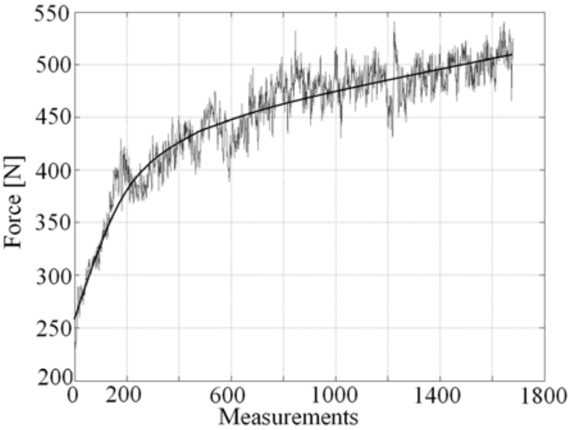


Fig. 12 Feed force in test series 2 after 105 meters of drilling. The vertical axis represents the force, N and the horizontal axis the measurement points (time points 0.05 s). Feed section f_2, i.e. sections *b* and *c* in Fig. 8. The drilling depth at the zero point on the horizontal axis is approximately 50 mm

Figs. 11 and 12 show a stretch of the feed force curve after approximately 50 seconds from the start of the drilling (cutting depth 50 mm) to the end of the drilling (187 mm). The curve was fitted into this section. This is the section where the feed is f_2 (from Fig. 8 areas called b and c). When the constants *a, b, c* and *d* of equation (1) are solved, then the value of a given point on the force curve can be defined at the each measurement point. The constants were solved numerically with the MATLAB software. The curves in Figs. 11 and 12 present the fitted function.

4.2. Definition of wear based on the pattern of the feed force curve

This study investigated whether the pattern of the force curve after the increase in feed explains the extent of different types of wear. At each feed force measurement point (x), values given by the exponential function (1) are solved. These values explained the flank wear of the outside and inside edge (C_T) and longitudinal wear (W_L) in the PLS regression analysis (Partial Least Square Regression), which was carried out on MATLAB.

The PLS regression equations are formulated as follows: when the constants *a, b, c* and *d* have been solved, the force values are determined at each measurement point (x) on the curves of exponential functions (1) at 7 meter drilling distances. The results compose a matrix : force values after 7 meters of drilling y_{11}, y_{12}, y_{13}, …, force values after 14 meters of drilling y_{21}, y_{22}, y_{23}, … and force values after X meters of drilling (when the tool is worn out) y_{z1}, y_{z2}, y_{z3}, …(the number of tool wear measurements z when the tool is worn out). The PLS regression allows calculating the coefficients b_0, b_1, b_2, etc. for the regression Eqs. (2). There are as many values of b_n as there are measuring points. The wear values forecasted on the basis of actual forces are obtained with the following kind of equations

$$\left.\begin{aligned} W_{predicted,7m} &= b_0 + b_1\,y_{11} + b_2\,y_{12} + b_3\,y_{13} + \dots \\ W_{predicted,14m} &= b_0 + b_1\,y_{21} + b_2\,y_{22} + b_3\,y_{33} + \dots \\ &\dots \\ W_{predicted,Xm} &= b_0 + b_1\,y_{z1} + b_2\,y_{z2} + b_3\,y_{z3} + \dots \end{aligned}\right\}. \quad (2)$$

4.3. Validation

The applicability of the regression Eqs. (2) formulated was tested with the help of validation material (test series 5), and the results are presented in Table 4. The estimated (according to the Eq. (2)) and measured, i.e. actual flank wear curves for the drill are presented in Figs. 13, 14 and 15 show the actual and estimated curves for longitudinal and flank wear.

Coefficients of determination (Table 4) are good, especially when estimating wear in the drill tip (C_T) and inside corner wear (V_B). But even though the coefficients of determination are high, they do not explicitly define the validity of the models, as they do in traditional regression analysis. It should be taken into account that the RMS values are quite high in relation to the extent of the wear. The validity of the models can be assessed by examining the difference between the actual and estimated wear values (Figs. 13, 14 and 15). Note that especially the extent of the wear can be relatively reliably estimated based on the pattern of the feed force curve. The flank and longitudinal wear values estimated for cutting edges are slightly lower than the actual measured wear values (Figs. 14 and 15). The actual measured values for flank wear of the drill tip are, however, lower than the estimated wear values

Table 4
Coefficients of determination from validation, and the root mean square error (RMS)

Wear type	Coefficient of determination, %	RMS
V_B outside corner	74	0.0227
V_B inside corner	88	0.0120
C_T	96	0.0119
W_L	81	0.0071

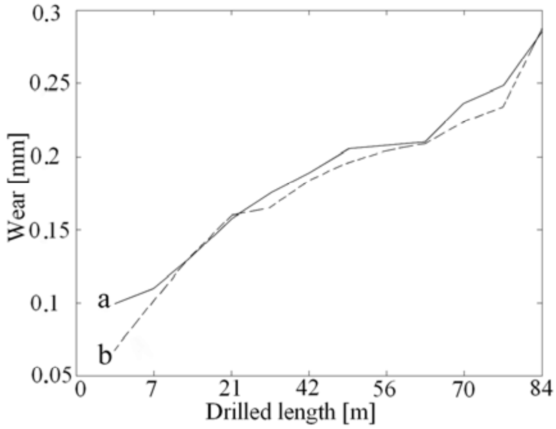


Fig. 13 Estimated $W_{predicted}$ (a) and measured values (b) for the wear in drill tip C_T (series 5)

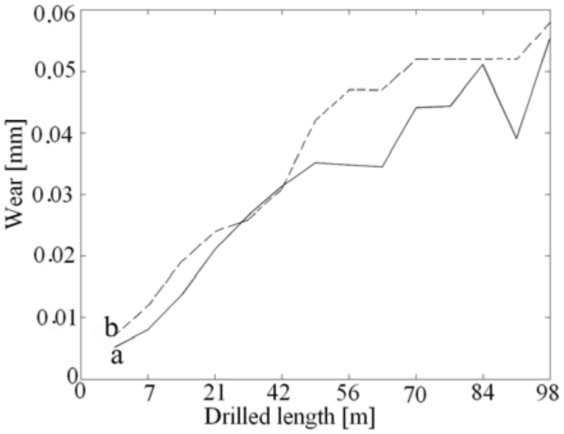


Fig. 14 Estimated $W_{predicted}$ (a) and measured values (b) for the longitudinal W_L (series 5)

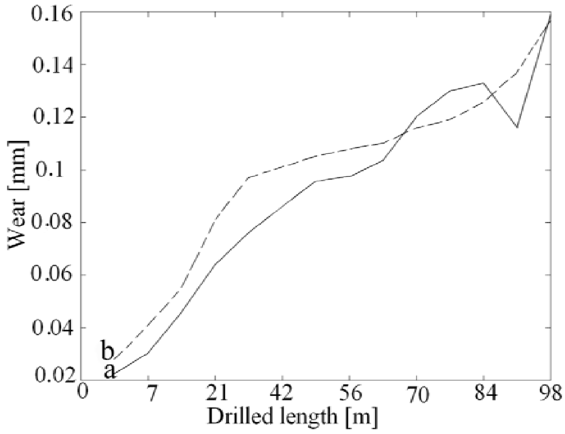


Fig. 15 Estimated $W_{predicted}$ (a) and measured values (b) for the flank wear in inside corner V_B (series 5)

(Fig. 13). Even though there are differences between the actual and estimated wear values, they are still rather small, especially in the case when monitoring the condition of the tool not a single wear value.

Based on the results, the wear can be estimated according to the form of the feed force curve modified by stopping the feed. In this way, it is possible to monitor the condition of the tool (operable or worn out) during drilling.

The regression equations formulated on the basis of test series 2 (feed 0.03 mm/r) did not match with test series 4 (feed 0.037 mm/r). Models did not explain the change in wear in test series 4. Neither did the equations formulated on the basis of test series 4 match with the test series 2. When the cutting values changed, tool wear could not be forecasted with the models created before with different cutting parameters. Changes in cutting values should, therefore, be accounted for in the equations.

4.4. Determination of wear with coefficients in an equation fitted to the feed force curve

Also the use of constants (*a, b, c* and *d*) of equation (1) as independent variables is quite sufficient in the forecasting of wear (mean flank wear of outside and inside edges, longitudinal wear and flank wear of the drill tip). With linear regression, for example the following regression equation was obtained for estimating the mean flank wear of the outside edge

$$VB = -0.5603\,a - 0.00024900\,b + 2.0034\,c + \\ + 0.0005830\,d - 0.1458 \tag{3}$$

When this model was used in the validation data, the coefficient of determination was 68%, leading to an RMS value of 0.026. Although the coefficients of determination here were high, as well, one should still take into account that the RMS values were rather high in relation to the extent of the wear. The maximum errors in the estimations are quite large. Comparing the forecasting of wear with the help of constants to forecasting based on the pattern of a curve fitted to the feed force curve, the latter solution is the better choice. Its RMS values, i.e. errors, are smaller.

4. Conclusions

The tests suggested that stopping the feed had no significant effect on tool wear. Therefore stopping the feed could be used for the purpose of facilitating tool condition monitoring. Based on the test results, it can be concluded that from the pattern of the feed force monitored in time domain and modified by stopping the feed, it is possible to predict tool wear. The exponential function fitted to the pattern of the feed force curve helped to estimate the flank wear of cutting edges, the flank wear of the drill tip, and longitudinal wear. The use of constants of feed force curve as independent variables is not sufficient in forecasting wear.

When the cutting values remain the same (as those usually do when drilling large volumes of a same product in mass production industry), the equations formulated in this study can forecast the tool wear. It has to be noticed that the same equations can not be used when the cutting values are changed. Therefore in the future the changes in cutting values should be accounted for in the equations so that the same equations could be used also when the cutting parameters are changed.

The models based on feed force patterns introduced in this study are only indicative, and should be modified to obtain more accurate estimations. Based on this research, however, it can be stated that stopping the feed allows monitoring tool wear with the help of a feed force pattern in time domain. Even better-suited models for forecasting wear could be found with ensemble methods, which model possible noise in data by adding it to data used for education purposes (applied if there are more variables than there are forecasted samples). Moreover, more recent regression analysis methods could be applied, and more material collected or pre-processed before the regression analysis.

In order for the results to be applied to practice and validated, further tests must be performed on other work piece materials, a range of cutting parameters and gun drill geometries. The results of this study can be applied to further research that focuses on developing a system for monitoring tool condition. At its simplest, a tool wear monitoring system may estimate the extent of the wear. The wear types are given predetermined maximum values. For example, the value for flank wear on the outside edge and drill tip may be 0.3 mm. Drills can be divided into two classes based on their condition: operable and worn out. When the flank wear of the tip and/or outer edge estimated on the basis of feed force exceeds 0.3 mm, the system signals that the tool is worn out.

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I. Sihvo, J. Varis

ŠAUTUVŲ GRĄŽTO DILIMO ĮVERTINIMAS PAGAL PASTŪMŲ JĖGOS SIGNALŲ KREIVĘ

Reziumė

Straipsnyje nagrinėjama galimybė šautuvų grąžto gręžimo proceso ir atitinkamos pastūmos jėgos signalo sąveika, laikui bėgant, panaudoti grąžto dilimui kontroliuoti. Pastūmos jėgos savybės studijuotos normalioje šautuvų grąžto gręžimo procedūroje, taip pat išjungus pastūmą tuoj pat prieš jos pakeitimą kita gręžimo pastūma. Išjungus pastūmą keičiasi grąžto pastūmos jėgos kreivės vaizdas, kuris gali būti panaudotas grąžto dilimo eigai kontroliuoti. Regresiniai modeliai buvo sukurti grąžto pjovimo briaunos vertei, briaunos dilimui grąžto viršūnėje bei grąžto ilgio dilimui pagal pastūmos jėgos kreivę apskaičiuoti, kai išlaikomos pastovios pjovimo sąlygos. Remiantis bandymo rezultatais buvo padaryta išvada, jog šautuvų grąžto dilimo eigą galima prognozuoti, naudojant gręžimo ir atitinkamos pastūmos jėgos signalo kreivę.

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ESTİMATİON OF TOOL WEAR OF A GUN DRİLL USİNG THE SİGNAL CURVE PATTERN OF FEED FORCE

Summary

This study concentrates on gundrilling and the related feed force signal in time domain, and possibilities of using this signal in drill wear monitoring. The behavior of the feed force was studied in a normal gundrilling procedure, and also in a situation where the feed was stopped just before guidance feed was replaced by actual drilling feed. Stopping the feed caused a new kind of behavior in the pattern of the feed force curve, which could be used in monitoring the extent of drill wear. Regression models were created in order to estimate the mean flank wear in the cutting edges, flank wear in the drill tip, and longitudinal wear based on the pattern of the feed force curve when cutting conditions remain constant. Based on the test results, it was concluded that from the pattern of the feed force curve monitored in time domain and modified by stopping the feed, it is possible to predict the extent of the wear of the gun drill.

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ОЦЕНКА ИЗНОСА ПУШЕЧНОГО СВЕРЛА, ИСПОЛЬЗУЯ ОБРАЗЕЦ СИГНАЛЬНОЙ КРИВОЙ СИЛЫ ПОДАЧИ

Резюме

В публикации представлена оценка износа пушечного сверла по сигналу измеренной силы подачи. Измерение силы подачи исследовано в нормальном процессе сверления пушечным сверлом, а также при прекращении подачи при изменении ее величины. Выключение подачи изменяет вид кривой, которая может быть использована для контроля процесса износа сверла. Модели регрессии разработаны для расчета величины износа режущей кромки и длины сверла по временной зависимости силы подачи, когда выдержаны постоянные условия резания. Используя результаты эксперимента, сделан вывод, что можно прогнозировать износ сверла величиной силы подачи.

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