Chapter 5

The Experiments

The machining process selected for use in this research was a NC turning machine. This selection was made for the following reasons. Turning has been used extensively as the basis for determination of tool life, and a well developed economic model exists for analysis of this process. Turning requires simple single point tools which are much less expensive than other tools such as milling cutters or drills. Finally, knowledge gained from studied turning, the simplest and most common single point tool operation, has been found by many complicated machining processes.

5.1 Experimental equipments

The experiment was conducted in a NC turning machine (Okuma LB10 CV-12; Fig. A.1 in Appendix A) using a spindle motor with a power consumption of 5.5 kW. The machine was equipped with a variable cutting speed and feed rate control so that the cutting speed and feed rate could be accurately set. Cutting speed and feed rate were set for accuracy and found to be accurated within ±1 m/min and ±0.0001 mm/rev respectively.

A microscope camera (VC820; Tokyo Electronic Industry CD.,LTD.) was used to measure the tool flank wear. The camera was installed near the tool turret of NC turning machine as shown in Fig. A.2 (Appendix A) and the flank wear measurement was measured by the scale of NC turning machine to be within ±0.001 mm.

In order to sufficiently control experiments involving the cutting processes, two sensors were used to simultaneously supervise. One was the Acoustic Emission Sensor (AE- sensor) which was mainly a piezo-electric ceramic formed from a titanium-circonium acid lead ($PbZr_x Ti_{1-x} O_3$) transducer. A specially designed tool shank had been developed to mount the sensor as close as possible to the cutting zone. The tool shank was shown in Fig. 5.1. The other was the Kistler table dynamometer utilized to measure forces three dimensionally with the help of three piezo-electric transdusers. A draft of the dynamometer was shown in Fig. 5.2. The AE-sensor, previously described, and its tool shank, were mounted on top of this table dynamometer which, itself, was fixed to the turret of the NC turning machine. This AE-force sensor tool holder system allows for simultaneous recording of all three machining forces together with the high frequency AE-signals. The experimental set up and the devices necessary to refine the sensor signals are displayed in Fig. 5.3. Two analyzing chains, one for the refined AE-signals and one for the refining of the force sensor signals were visible. The refined AE-signals and the three component force signals were fed together through a 12 bit 8 channel A/D- convector into the Hewlett Packard stand alone micro computer system for further analysis. The digitizing of the four cutting process related signals was done simultaneously with a fast assembler on-line monitoring loop. In Fig. 5.4, the software flow chart designed by Thomas Blum (17) was utilized in order to supervise the cutting processes, and the software flow chart was utilized in order to determine the optimum cutting conditions by means of the optimum gradient method during the experiment shown in Fig. 5.5.

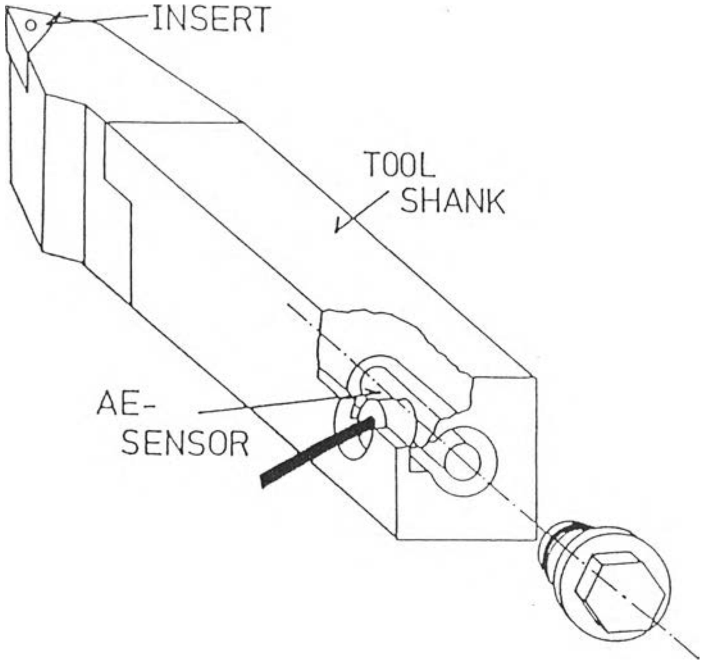


Fig. 5.1 Tool shank with the AE-sensor mounted inside (17)

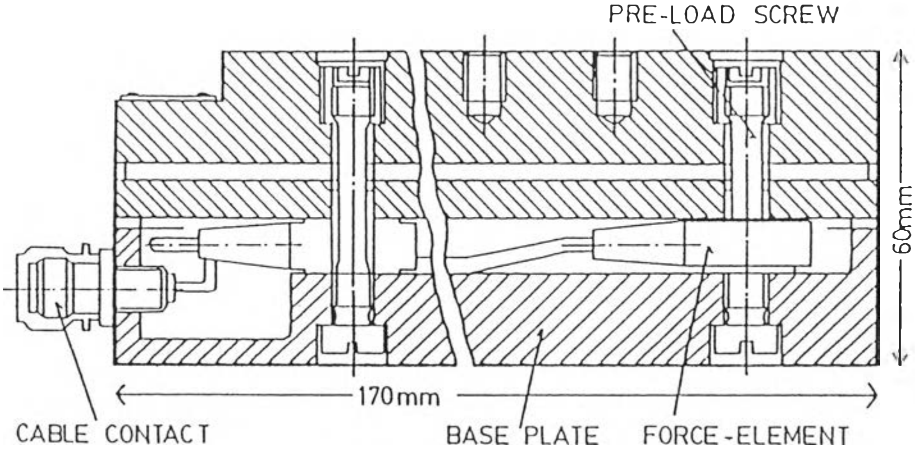


Fig. 5.2 Kistler table dynamometer utilized (17)

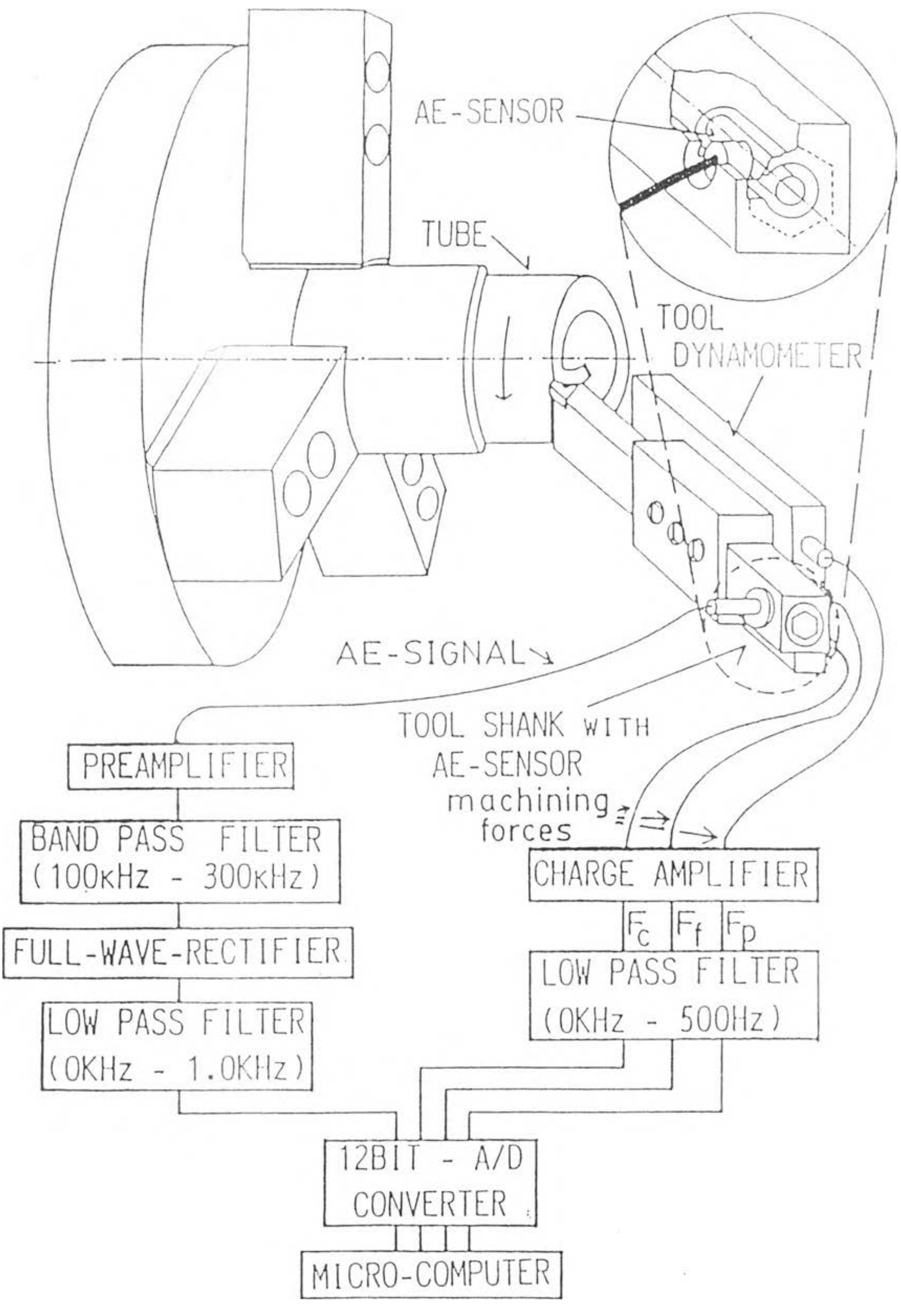


Fig. 5.3 Experimental set-up (17)

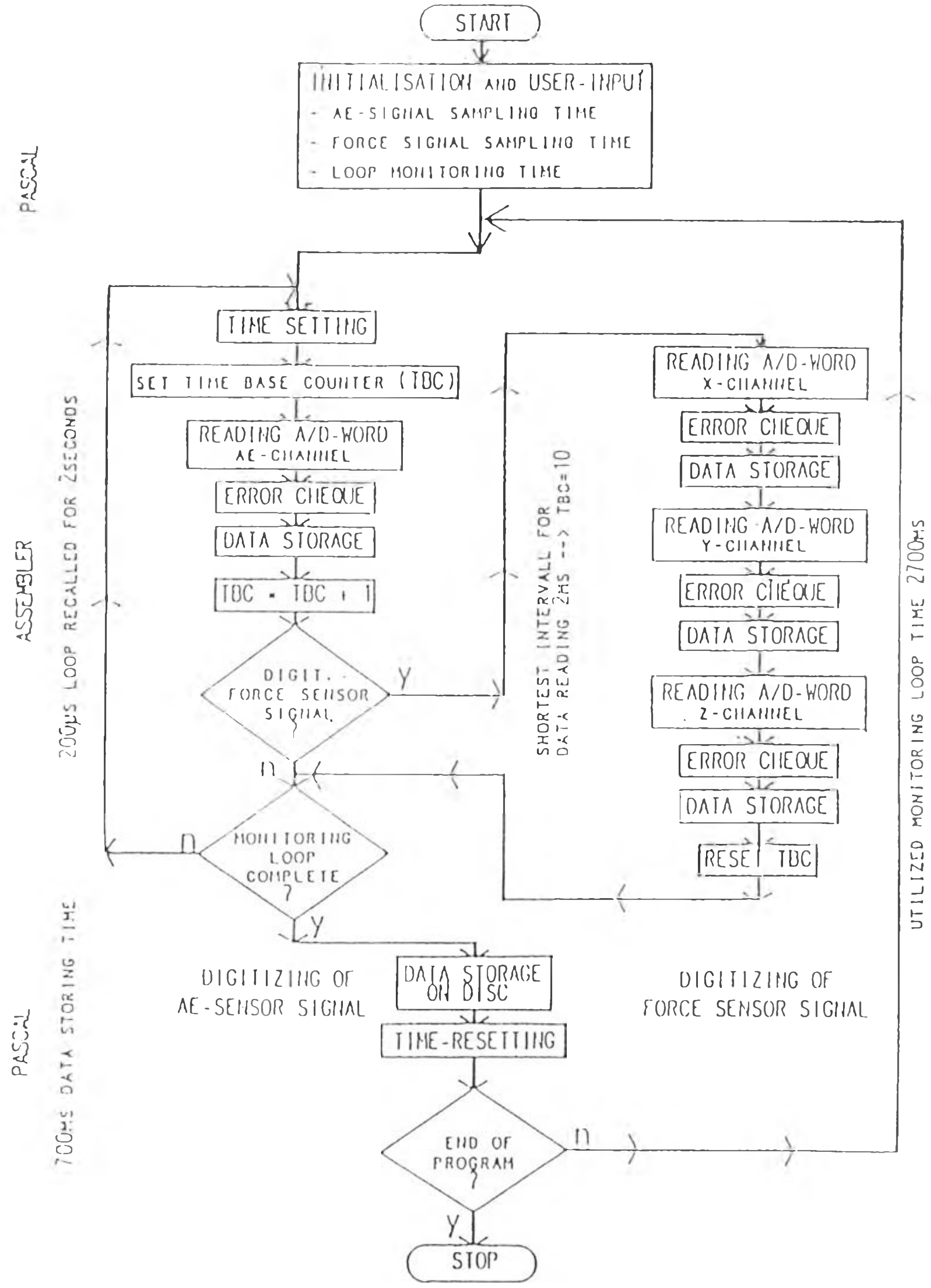


Fig. 5.4 Flow chart of the utilized software (17)

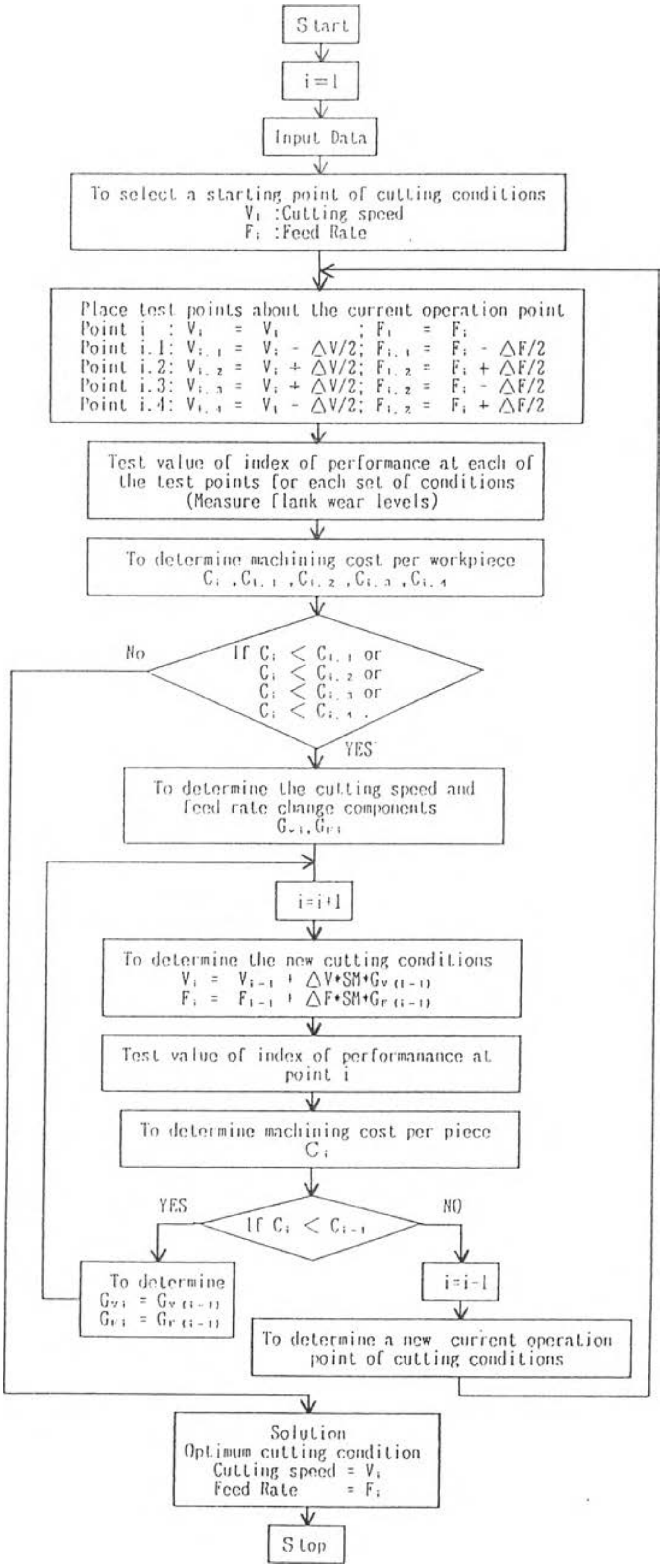


Fig. 5.5 Flow chart of the optimum gradient method

Two tool materials were selected to machine the steel AISI 1045, a carbide tool (TNMG 160404-R/LC, TiC-TiN-TaC-WC) and a coated tool (TNMG 160404-27, TiC-Al(ON)$_x$ 8μm coated) of the Toshiba Tungalog. The insert was mounted on a tool holder which had a clearance of 6 degrees.

5.2 Experimental procedures

5.2.1 A starting point was selected based on recommended cutting conditions for the cutting tool, workpiece material, depth of cut, and so on.

5.2.2 Place test points around the current operating on a square pattern shown in Fig. 5.6. These points represent a set of exploratory moves to determine which direction will improve the index of performance (machining cost per workpiece).

5.2.3 Determine the value of the machining cost per workpiece at each of the test points. This is accomplished by performing machining operations at each of the cutting speed and feed rate combinations represented by the points. For each

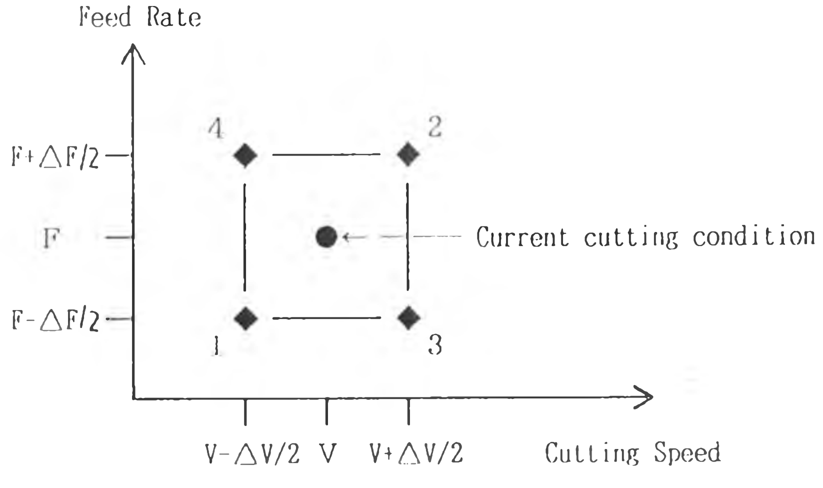


Fig. 5.6 Fortorial experiments of cutting speed and feed rate to estimate the gradient

set of cutting conditions, data for job specifications and cost factors must be acquired to determine the machining cost per workpiece. A worksheet for organizing the data and making the calculations for machining cost per workpiece is shown in Table 5.1.

5.2.4 Determine the cutting speed and feed rate change components. Table 5.2 shows the procedure.

5.2.5 Make a move of prescribed length in the direction indicated by the gradient components. This will define a new cutting condition which should be superior to the previous cutting conditions.

5.2.6 The machining cost per workpiece is determined at the new cutting condition. If the machining cost per workpiece at the new cutting condition is less than the machining cost per workpiece at the previous cutting condition, the following step move in the direction of the previous gradient is taken.

5.2.7 Repeat in step 5.2.6 until there is no further improvement in the machining cost per workpiece. If the current machining cost per workpiece is greater than previous machining cost per workpiece, determine the new gradient at the previous cutting conditions. Go to step 5.2.2 in the procedure until an optimum cutting condition, based on the stopping criteria, has been reached.

5.3 Validation

To prove that the proposed method can determine the optimum cutting conditions, the conventional tool life tests are performed. The two tested groups of each cutting tools at the optimum cutting conditions are repeated and the results are analyzed by the statistic method (18). The following statistic method are used:

5.3.1 Regression: The relationships between the cutting time and the flank wear of each cutting tools are determined by using the linear model (2).

5.3.2 Lack of fit: The test of the goodness of fit of regression model is confirmed whether the order of the model is correct.

5.3.3 Hypothesis testing: The wear rate and initial wear level are tested to confirm whether the tool life in the determination of the optimum cutting conditions is correct.

Table 5.1 Machining cost calculation

Cutting Condition Optimization

Calculation Procedure: Machining cost per workpiece
Depth of cut: ____ mm
Cutting tool used: ________
Model: MCPW = MR * (TTFT+WCT) + (MR*TCT + TC)/N

1. Known Information
   Price of insert (baht) P = ______
   Total cutting edges on tool insert (edges) E = ______
   Machine operation rate (baht/min) MR = ______
   Tool changing time (min/cutting edge) TCT = ______
   Work changing time (min/workpiece) WCT = ______
   Tool cost per cutting edge (TC;baht) = P/E TC = ______

2. Total tool feed time (TTFT)
   Cutting speed (m/min) V = ______
   Feed rate (mm/rev) F = ______
   Workpiece length (mm) L = ______
   Before and after cut length (mm) L_1 = ______
   Workpiece diameter (mm) D = ______
   Actual machining time (min)
   MT = 3.142*D*L/1000*F*V MT = ______
   Total tool feed time (min)
   TTFT = 3.142*D*(L+L_1)/1000*F*V TTFT = ______

3. Number of workpiece per cutting edge (N)
   First cut wear (mm) W_1 = ______
   Second cut wear (mm) W_2 = ______
   Wear rate per workpiece (mm) = $W_2 - W_1$ WR = ______
   Wear level at tool failure (mm) WF = ______
   Number of workpiece per cutting tool (pieces)
   N = (WF − W_2)/WR + 2 N = ______

4. Tool life (TF;min) = N*MT TF = ______

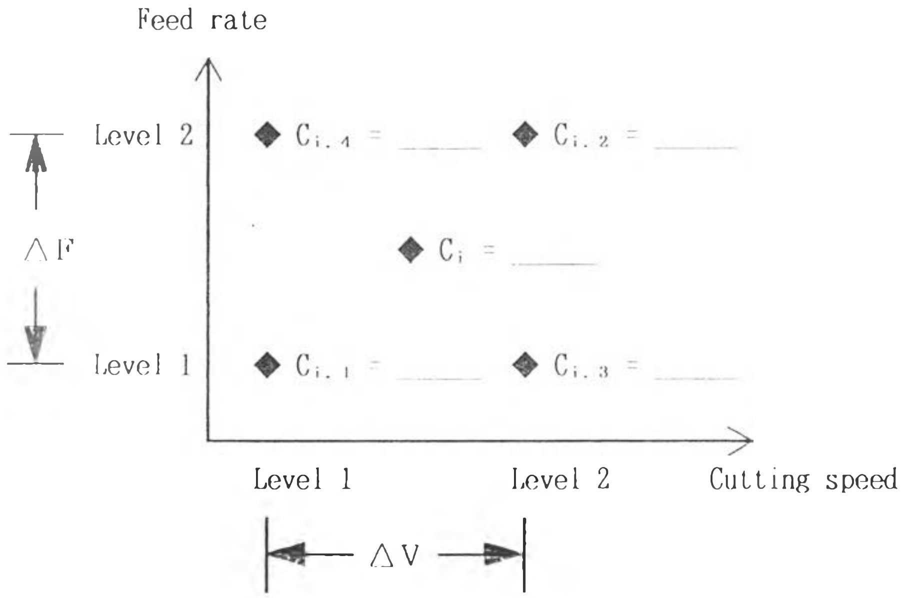
5. Machining cost per workpiece (MCPW;baht) **MCPW** = ______

Table 5.2 Gradient calculation

Gradient Calculation

Cutting speed and feed rate change analysis: Turning operation

1. Current operating condition:
   Cutting speed (m/min) = ______
   Feed rate (mm/rev) = ______
2. Test conditions:
   Cutting speed: Level 1 = ______ Level 2 = ______
   Feed rate: Level 1 = ______ Level 2 = ______
3. Observed results: Machining cost per workpiece (baht)



4. Gradient calculation:
   Different cutting speed: ΔV = ______
   Different feed rate: ΔF = ______
   Step move: SM = ______
   Cutting speed gradient:
   $G_{Vi} = (C_{i,1} + C_{i,4} - C_{i,2} - C_{i,3})/2$ = ______
   Feed rate gradient:
   $G_{Fi} = (C_{i,1} + C_{i,3} - C_{i,2} - C_{i,4})/2$ = ______
   Magnitude gradient:
   $M_p = [G_{Vi}^2 + G_{Fi}^2]^{1/2}$ = ______
5. New cutting condition:
   new $V = \text{old } V + \Delta V * SM * G_{Vi}/M_p$ = ______
   new $F = \text{old } F + \Delta F * SM * G_{Fi}/M_p$ = ______