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ABSTRACT

ANALYSIS OF SURFACE TEXTURE PARAMETERS AND CUTTING FORCES IN MILLING OPERATIONS.

by Preetesh U. Munshi

It has been known and understood that milling is quite a complicated process being a multi-point cutting tool operation. Each Surface texture is complex and requires different functions of forces to get the optimized Surface Texture. The challenge faced here is to devise any form of relation between the Surface Texture and the Milling Operating parameters (Spindle Speed, Feed rate, Depth of Cut), Cutting forces and the Milling Operating parameters and also between the Surface Texture and the Cutting Forces.

This Research study was conducted to determine the effect of the Operating Parameters on Surface Texture and Cutting forces and empirical relationships have been established between the Surface Texture and Operating parameters, The Cutting forces and Operating parameters and Surface Texture and Operating parameters.

Thus, the outcome of the research is to determine the optimal cutting conditions and by controlling the operating parameters, accordingly, better surface quality in milling operations can be attained.

ANALYSIS OF SURFACE TEXTURE PARAMETERS AND CUTTING FORCES IN MILLING OPERATIONS

by Preetesh U. Munshi

A Master's Thesis
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Industrial Engineering

Department of Industrial and Manufacturing Engineering

May 1997

APPROVAL PAGE

ANALYSIS OF SURFACE TEXTURE PARAMETERS AND CUTTING FORCES IN MILLING OPERATIONS

Preetesh U. Munshi

Dr. George Abdou, Thesis Advisor,	Date
Associate Professor of Industrial and Manufacturing Engineering, NJIT	
Du Carabar Das Coloritta Mambar	Doto
Dr. Sanchoy Das, Committee Member,	Date
Associate Professor of Industrial and Manufacturing Engineering, NJIT	
Dr. Carl Wolf, Committee Member,	, Date
Professor of Industrial and Manufacturing Engineering, NJIT	

BIOGRAPHICAL SKETCH

Author:

Preetesh U. Munshi

Degree:

Master of Science

Date:

May 1997

Undergraduate and Graduate Education:

- Master of Science in Industrial Engineering New Jersey Institute of Technology, Newark, NJ, 1997
- Bachelor of Science in Production Engineering
 K.J.Somaiya College of Engineering, Bombay University, India, 1995

Major:

Industrial Engineering

To my dear parents, brother and wife

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CHAPTER 1

INTRODUCTION

1.1 Background Information

It is well known that milling is quite a complicated process being a multi-point cutting tool operation. The process of cutting metals by milling operation develops stochastic cutting forces which ultimately result into variable surface roughness. In the machining industry it is of great importance to have the knowledge of Surface Texture or the Surface Finish that would be obtained by using a particular cutting operation.

Due to the stochastic nature of the cutting forces and Surface Texture it would be difficult to choose a machining operation for a particular component. This may result into unexpected and undesired tool failure which obviously needs to be avoided. In order to ensure system reliability and improve the productivity in an automated manufacturing environment it is necessary to implement sensing and corrective devices that can detect and correct the system malfunctions.

Over the last decade, researchers have put their efforts into on-line monitoring of the machining process, especially the recognition of tool breakage, because of the rapid development of computer integrated manufacturing systems and sensor based machining processes. One of the most important requirements is to obtain a relationship between the Surface Texture and Operating Parameters in the Milling operation. This would lead to developing a relationship between the cutting process parameters (spindle speed, feed rate,

depth of cut) and the Surface texture parameters. These relationships are important in developing analytical models for cutting process monitoring. At the same time this research also develops a relation between the Cutting Forces and Operating parameters and thereby determine the relationship between the Surface Texture and Cutting Forces.

CHAPTER 2

LITERATURE REVIEW

In the interest of maximizing the metal removal rate and preventing tool breakage L.K.Lauderbaugh and U.G.Ulsoy [1] have conducted Research work on Fixed Gain Feedback Controllers which manipulate the feed rate to maintain a constant cutting force. These process controllers have resulted in substantial improvements in the metal removal rate but may have poor performance when the process parameters deviate from the design conditions. They have also presented an empirical second order model of force response for a milling system to feed rate changes along with experimental results. These results show that the parameters of the model vary significantly with cutting conditions.

In their paper by Y Atlintas and Yelloley [4], the authors have shown that by force averaging over a tooth period and then differentiating twice, tool damage may be identified and normal transients may be ignored. The authors have shown that force averaging and normalized differencing form a suitable base for practical tool breakage detection algorithm.

In their paper L.K. Lauderbaugh and A.G. Ulsoy [8] describe the design and implementation of a model reference adaptive controller for force controlling in milling, the adaptive controller was found to be performing more effectively than the fixed gain controller but it is difficult to implement and tune because of the unmodelled dynamics or measurement noise resulting from runout on the milling cutter.

The researchers, Ismail and F. Albestawi [7] generated a mechanic model for Surface generation in peripheral milling that includes the effect of cutter runout and flank wear. The surface roughness parameters and characteristic features of the Surface Profile were examined by using Computer Simulation. The trend towards unattended manufacturing emphasized the need for sensing the variables in process that could affect the state of cutting force and Surface finish. The new trend brought the usage of Adaptive Control Technology and On -Line monitoring. The adaptive control denotes whereas the Numerical Control determines the proper speeds and/or the proper feed rates during the milling process as a function of , factors such as work material hardness, depth of cut, spindle speed. With increasing focus on the development of the sensing techniques many researchers demonstrated their findings by using sensing and adaptive control technology.

Bobe [10] employed a method which describes the method for determining the natural frequencies and vibration modes of milling machine's, the model combined a finite element model and an asymmetric stiffness matrix system.

According to Fussel and Srinivas [11], Varying machining conditions are encountered in adaptively controlled machining situations where operating conditions such as feed rate and spindle speed are adjusted continuously to achieve desired objectives. The authors have evaluated the adequacy of the models available of the milling process mechanics for many cases of varying machining conditions including the change of depth of cut and feed rate (axial

and radial) They have also evaluated the significance of dynamic effects in the milling process of effects such as run out for constraint type adaptive control system.

G.Chryssolouris and M.Guillot [12] presented an approach for the selection of a set of process parameters for use in machining control. The approach is aimed at providing a range of parameters within which machining operations can be optimized. Because of the complexity and somewhat unpredictable nature of the machining process the approach combines process modeling with rule based techniques. Modeling correlates process state variables such as surface roughness or chip merit mark to process parameters such as feed rate, cutting speed and tool rake angle. The modeling techniques considered in the paper include multiple regression analysis, group method of data handling and neural network. The authors concluded that a rule based system added the flexibility necessary to treat various cases of the machining process and considered the accuracy of the model. Even though this model has been developed with a particular intelligent controller scheme it is general enough to apply as a complement to other machining controllers (e.g. adaptive control constraint or optimization) or to standard machinability databases.

S.Smith and J.Tlusty [14] claim that it has been shown for many milling operations that it is desirable to set the tooth frequency equal to the natural frequency. At this spindle speed, the development of resonant forced vibration is actually inhibited by regeneration of waviness. The authors have presented an algorithm for automatically selecting the optimum spindle speed based on the

cutting force signal. It was concluded by the authors that the optimum spindle speed for a milling operation is that speed where the tooth frequency is equal to the natural frequency.

N.K.Jha [15] claims that the production planning of milling operations in an important problem. It has been observed that if discrete settings of speed and feed are taken into account, production planning becomes more complex. A procedure has been suggested in the paper for such cases. The approach suggested looks most promising for adaptive control optimization. The objective of the adaptive controller is to optimize the index of performance such as cost per piece, material removal rate by manipulating the speed or feed to maintain the measured variables at or below their constraint limit values. Especially sensors will be developed to a level at which true process performance can be measured on-line.

In conclusion a considerable amount of research has been done in the area of unattended machining, milling operations and a lot of means have been devised to get the desired cutting forces and Surface Finish on the Milled Products. During the course of the literature survey it was observed that there was no work that showed the optimal cutting conditions in which the desired cutting force and the desired Surface Texture could be obtained using typical combinations of speed, feed and depth of cut. There was hardly any work done to determine the values of spindle speed, feed rate, depth of cut using which a particular surface finish or a particular cutting force could be obtained.

Therefore, the main objective of the Research work is to improve the surface Quality of any component that is being machined on an automated Milling Machine. In order to improve the Surface quality of the machined component it would be of great benefit if the expected Surface Quality that could be obtained by the machine would be known prior to the machining operation. In an open machining system it is very difficult to improve the surface quality, and hence the need of a system which would give the feedback to the Milling machine. It is necessary to derive models that would establish empirical relations giving us the values of the expected Surface Quality. This expected value can then be compared with the actual surface quality value obtained and then depending on the need corrective measures could be incorporated to obtain the desired Surface Quality Results. As mentioned earlier in the introduction and the limitations of the literature review the interest and the focus of the research being done is to develop empirical relations between

- 1) Surface Texture and Operating parameters (spindle speed, feed rate and depth of cut)
- 2) Cutting Forces and Operating parameters (spindle speed, feed rate and depth of cut)
 - 3) Surface Texture Parameters and Cutting Force

By establishing these results it would be possible to predict the Surface Texture or the Cutting force that would be developed by using a particular combination of spindle speed, feed rate and depth of cut. Thus, we shall have the expected value of the Cutting Force and/or Surface Texture which could

serve as a reference for the actual values that would be obtained after the machining is done.

Hence, by knowing prior to machining the combination of spindle speed, feed rate and depth of cut it would be possible to set the machining system at those particular values and obtain a Surface Texture that would be desirable. in addition to that, it would also be possible to develop an Adaptive Control system which would be capable of detecting the Surface texture and the Cutting force during the process of operation and be capable of taking preventive and/or corrective measures.

This research work would greatly contribute towards improving the quality and the productivity of the components being machined using an automated milling machining and it can also be extended to other similar machining operations.

CHAPTER 3

PROPOSED METHOD AND METHODOLOGY

3.1 Methodology

In order to achieve the goals of the research Work it is necessary to conduct a number of experiments so that enough data can be collected to derive mathematical relations and models. It is necessary to conduct experiments on the milling machine so that data can be collected on the different milling operating parameters. After these experiments have been performed and data collected it would be possible to formulate mathematical models. The results obtained from these mathematical models would be then used to analyze the data collected and present the findings, give suggestions and improvements.

3.2 Variations in Cutting Forces and Surface Finish

Milling is a process in which the material is cut using a multi point cutting tool, thus ,making the milling process a complicated process. This complicated process is controlled by various operating parameters like spindle speed, feed rate and depth of cut. This complicated milling process results in stochastic forces, which also result in stochastic surface finish. The milling process can generate a wide range of shapes and obtain different surface texture results. It can also give a high material removal rate. All these properties of a milling process give rise to variations in the cutting forces which ultimately vary the final surface quality result. The problems mentioned above are critical to study the behavior of the milling process. There are also many other factors that affect the

cutting process. Hence, the surface finish, cutting forces and for that matter even tool wear are stochastic making it very difficult to predict the accuracy of these measures. Hence, the output of the cutting force varies from point to point and from one machine to another, even under the same operating conditions. It is of interest to examine the two applications that result from the stochastic milling process. One being, to identify the cutting conditions under different operating conditions and the other being able to examine the surface quality results due to the stochastic nature of the cutting force.

3.3 Design of Experiments

Experimental design is necessary to obtain reliable results. In this research, the validation of the models depends on the way the experiments were designed since the mathematical models of cutting force and Surface Texture will be formulated according to the experimental collected data.

In a milling process there are 3 control parameters that is the spindle speed, feed rate and depth of cut. These three variables can be selected to be the independent variables of the mathematical models of cutting force and surface roughness. A factorial design can be introduced for the formulation of the mathematical model. In a factorial design a fixed number of levels are selected for each of the number of variables and then experiments are run with all the possible combinations. If there are L1 variables for the first variable, L2 variables for the second variable, Lk variables for the Kth variable, the experimental run is called an L1 x L2 x x Lk factorial design. These designs

are of importance for a number of reasons. they require relatively few runs per factor studied and although they are unable to explore fully a wide region in the factor space, they can indicate major trends and so determine a promising direction for further experimentation. these designs and the corresponding fractional designs may be used as building blocks so that the degree of the complexity of the finally constructed design can match the sophistication of the problem. The interpretation of the observations produced by the design can proceed largely by using common sense and elementary arithmetic.

LEVEL	Cutting Speed	Feed rate	Depth of cut
High	S_h	F _h	D_h
Central	S_c	F _{c1} , F _{c2}	Dc
Low	Sı	Fı	Dı

The advantages of the factorial experimentation naturally depend on the purpose that is to investigate the effects of each factor over some pre assigned range that is covered by the levels of that factors which are used in the experiment. If all the factors are independent in their effect the factorial effect will save a considerable time and material devoted to the experiment. When the factors are not independent the purpose then is to still investigate each factor over the range represented by its levels. When the factors are not independent, the simple effects of a factor vary according to the particular combination of other factors with which these are produced.

3.4 Methods, Set Up and Procedures

It is necessary to come up with a method and the procedure in which the experiments would be conducted to obtain the desirable results. Explained as follows is the proposed procedure to obtain the desired models and results. First of all an appropriate workpiece has to be selected on which the experiments could be performed. The workpiece can be placed on the load cell and fixed with the aid of a vice. The data acquisition board is kept ready and all the necessary information is entered to a proper software. After that the amplifier is set up after a warm up of a fixed amount of time. The CNC milling machine and the NC part program are kept ready. The data acquisition program is then actuated and the process is performed. If there is no overload signal the data is saved. The Surface finish of the workpiece is measured by the necessary instrument and the collected data is transferred to the Surface Finish software.

The cutting force varies due to the stochastic nature of the process at each moment of time and thereby it leads to the variation in the surface roughness every time. Thus the cutting forces were also to be recorded at the same time. In this research, a transducer was used for converting the vibrations of the cutting force to analog signals. A transducer is a device that converts one type of physical quantity such as temperature, force, velocity into another type, commonly an electrical voltage. The reason for making this conversion is that the converted signal can be used or evaluated more conveniently. Basically, there are two types of transducers, analog and digital. The analog transducers produce a continuous analog signal for e.g. an electrical voltage. in the research

the transducer can be used to measure each separate component of the force at the same time. A force transducer will be used to measure the three orthogonal components of the cutting forces in arbitrary directions. The workpiece can be connected with 4 screws to the fixture and after every 4 experiments the workpiece can be changed to another one. The transducer has to be calibrated with the fixture as a perload.

A CNC machine can be used to perform the milling process. The machine that would be selected should have the three X, Y and Z axes and should be able to rotate in both the directions of rotation. A high speed processor would be required to increase the machine capability to use faster feedrates. These higher feedrates may be attained without emptying the machine buffer. There are also additional G and M code capabilities. The macro capabilities provides a programmer with full mathematical calculations within a program.

A mill can be used to perform the cutting operation. The cutters used should be constructed from a high speed steel matr. (HSS). First, the roughing operation is performed and then the finishing operation and the data has to be collected. For these experiments appropriate material of the workpiece should be selected so that it can be cut by the HSS cutter. Each experiment would consist of cutting in different directions. The total time for cutting should also be recorded for different combinations of the operating parameters which would help towards the analysis of all the data collected.

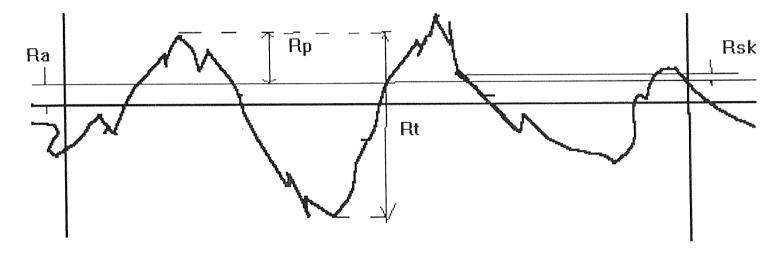
3.5 Data Collection

The most important part of the research work was the data collection. The data collection was divided into two parts. The first was the data collected for the different surface quality parameters and the second part was the data collected for the cutting forces.

The data that was collected for the Surface Quality had five different parameters: Rku, Ra, Rq, Rp and Rt. Fig. 3.1 shows the rough sketch of the profile of the Surface Quality parameters. The explanation of those parameters is as given below.

- 1) Rku Kurtois provides a measure of the sharpness of the Surface Profile, a spiky surface has a high Rku and a bumpy surface has a low Rku value. Rsk which is the skew value cannot detect if the spikes on the profile are evenly distributed or not where as the Kurtois can, hence the Kurtois value is to be used.
 - Std K The standard deviation of the sharpness of the surface profile.

 S/N Rku This is the Signal to noise ratio for the Rku value.
- 2) Ra Ra is the parameter for roughness. It is the arithmetic mean of the departures of the roughness profile from the mean line.
- 3) Rq Rq is the RMS parameter corresponding to Ra.
- 4) Rp Rp is the maximum height of the profile above the mean line within the assessment length.
- 5) Rt Rt is the maximum peak to valley height of the profile in the assessment length.



Rq is the RMS value of Ra

Fig 3.1 Profile of the Surface Quality Parameters

Each of the above parameters have their standard deviations and Signal to Noise Ratios.

The second part that is the cutting forces were just in the form of values of the cutting forces. These cutting forces were directly imported into the excel spreadsheet. These values were in the form of data files and there is a special feature in the excel spreadsheet that allows the user to convert data files into Excel spreadsheets. The data that will be obtained from the CNC machine software will be in the form of thousands of numbers. This data needed to be organized so that mathematical models could be derived.

3.6 Statistical Techniques Using Microsoft Excel

There was a large amount of data collected in the form of Surface Texture parameters and also cutting forces by directly reading it from the CNC machine. This data was stored as data files and was imported into the Microsoft Excel Software for its analysis. The cutting was done in three directions, the X, XY, and the Y. For each of the axis the data was sorted in the ascending order of the speed, feed and the depth of cut. The average, maximum, and the minimum of each of the parameters of the Surface Texture and the Cutting Forces were found out by using the inbuilt Statistical Formulae. For eg. the maximum of a particular range was found by the formula = max (range), Similarly the minimum = min (range), and for the average = average (range). For the ease of use of Multiple Regression Analysis Technique the In values for each of the Operating parameters, Surface Texture Parameters and the Cutting forces were

found using In (number). Their log std. deviations was also calculated to see how much do they deviate from the average value. These calculations were done for both the Surface Texture Parameters and Cutting Forces. The Signal to noise ratios were also found out using the appropriate formula from the formulae mentioned earlier. A list of the formulae that could be used from Microsoft Excel are shown in table 3.1.

3.7 Mathematical Models

After all the data was collected and now organized there were 36 values for each operating parameter for cutting in each of the directions X, XY, and Y. This data was now to be converted into a Mathematical model giving relationship between the Surface Texture and the Operating parameters of speed, feed and depth of cut and also between the cutting force and the operating parameter of speed, feed and depth of cut. The Multiple Linear Regression Software written in QBASIC was used for this purpose. Then relationship was also established between the Surface Texture parameter and the Cutting Force and a more advanced software called the Table Curve Software was used for the same.

3.8 Multiple Linear Regression Analysis Technique

The Multi-Linear Regression analysis was selected as it was the most adequate statistical technique. This statistical technique was used to establish the relationship between

1) Surface Texture (Rku, Ra, Rq, Rp, Rt) and Milling Operating

Parameters (Spindle speed, feed rate, depth of cut).

2) Cutting Forces (Fmax, Favg) and Milling Operating Parameter (Spindle speed, feed rate, depth of cut).

An explanation as to why the above model was used is as follows.

In any statistical model there are dependent variables and independent variables. In the Surface Texture model, the Rku value for e.g. is the dependent variable and the operating parameters of speed, feed and depth of cut are the independent variables. In the Cutting Force model, the Fmax value for e.g. is the dependent variable and the operating parameters of speed, feed and depth of cut are the independent variables.

The relationship between the dependent and the independent variables can be mathematically represented as follows:

$$Y_i = X_0 * X_1^{n1} * X_2^{n2} * X_3^{n3}$$

This non-linear relationship can then be written linearly as:

$$\ln (Y_i) = \ln (X_0) + n1 * \ln (X_1) + n2 * \ln (X_2) + n3 * \ln (X_3)$$

Using the Multiple Regression technique it becomes possible to determine the values of X_0 , n1, n2, and n3. This is the statistical technique that is used to determine the equation of the line or the curve which minimizes the deviations between the observed data and the regression equation values. Since, there is more than one independent variable the Multiple Regression technique has been applied.

3.9 Analysis of Variances

After using the Multiple Regression Technique the models were established and the ANOVA i.e. Analysis of Variance has been performed to determine the adequacy of the models. The correlation coefficient and the F value are the main output of the ANOVA. The Correlation Coefficient is a measure of how well a specific regression equation explains the observed variation. Hence, Higher the R value better is the regression model, the F test is used to examine the adequacy of the model. The F value is the ratio of the regression sum of squares and the sum of squares error. Residual analysis is necessary to draw a conclusion about the regression model. Since all the above measures are based on the assumption of normality, the residual analysis is the tool to confirm this assumption. In this Research Standardized Residuals were calculated, the assumption of normality thus being confirmed. Thus using the above guidelines the model was developed and the relationships were established. It was now required to further establish a relationship between the Surface Texture and the Cutting Forces.

3.10 Curve Fitting Techniques

The table Curve software has been developed by Jandel Scientific. This software is ideally used when one has to determine the relation between two parameters, in which one is the dependent variable and the other is the independent variable. In the Research work this software has been used to develop relationship

between the Surface Texture parameters and the Cutting Force parameters for cutting in the 3 directions of X, XY and Y. This software has a File Menu which allows us to import data from Excel and Lotus spreadsheets. The data can be imported directly, it can be imported after digital filtration or it can also be imported from a Clipboard which has been previously saved. Next it has the Edit Menu. This software has an Ascii Editor and also a table editor in which we can directly type in the numbers to obtain the relations. This software has a Table and the Calculate Menu which calculates the integral, differential, Bessels function and various other desired mathematical and algebraic calculations. Next it has a Process menu in which the selected data gets processed and the software comes up with a graph listing the equations and the graph that was desired, it has a variety of options for the type of fit desired.

For this purpose the Table Curve Software was utilized. In this research work the software imports the data from the clipboard of a spread sheet, reads it, analyzes the same and comes up with a graph for Best Fit and also gives the Best Fit Equation. It calculates the Correlation Coefficient and thus we can determine the adequacy of the model. This software has a limitation that it can take just two variables and establish the relation between the two of them. This is the reason why this software was not used for determining the relation between the Surface Texture, Cutting Forces and the milling Operating Parameters. To use the table curve software the entire data was put on the spread sheet, then the table curve software was made to import the Surface Texture and the Cutting Force values, one at a time and the graphs and the relations were established

for each of the 36 values in each of the three directions for cutting (X, XY andY)

The data so transformed into mathematical models has to be analyzed and thereby conclusions can be made. With the help of the empirical relations obtained from these various softwares it would be possible to predict the nature of the cutting force and the value of the Surface Texture parameters before the cutting process would actually take place.

Table 3.1 List of formulae from Microsoft Excel

Statistical Functions

AVEDEV Returns the average of the absolute deviations of data points from their mean

AVERAGE Returns the average of its arguments

BETADIST Returns the cumulative beta probability density function

BETAINV Returns the inverse of the cumulative beta probability density function

BINOMDIST Returns the individual term binomial distribution probability

CHIDIST Returns the one-tailed probability of the chi-squared distribution

CHIINV Returns the inverse of the one-tailed probability of the chi-squared distribution

CHITEST Returns the test for independence

CONFIDENCEReturns the confidence interval for a population meanCORRELReturns the correlation coefficient between two data setsCOUNTCounts how many numbers are in the list of argumentsCOUNTACounts how many values are in the list of arguments

COVAR Returns covariance, the average of the products of paired deviations

CRITBINOM Returns the smallest value for which the cumulative binomial distribution is less than or equal to a

criterion value

 DEVSQ
 Returns the sum of squares of deviations

 EXPONDIST
 Returns the exponential distribution

 FDIST
 Returns the F probability distribution

Returns the inverse of the F probability distribution

FISHER Returns the Fisher transformation

FISHERINV Returns the inverse of the Fisher transformation

FORECAST Returns a value along a linear trend

FREQUENCY Returns a frequency distribution as a vertical array

FTEST Returns the result of an F-test

GAMMADIST Returns the gamma distribution

GEOMEAN Returns the geometric mean

GROWTH Returns values along an exponential trend

HARMEAN Returns the harmonic mean

HYPGEOMDIST Returns the hypergeometric distribution

INTERCEPT Returns the intercept of the linear regression line

KURT Returns the kurtosis of a data set

LARGE Returns the k-th largest value in a data set
LINEST Returns the parameters of a linear trend

 LOGEST
 Returns the parameters of an exponential trend

 LOGINV
 Returns the inverse of the lognormal distribution

 LOGNORMDIST
 Returns the cumulative lognormal distribution

 MAX
 Returns the maximum value in a list of arguments

MEDIAN Returns the median of the given numbers

 MIN
 Returns the minimum value in a list of arguments

 MODE
 Returns the most common value in a data set

 NEGBINOMDIST
 Returns the negative binomial distribution

Table 3.1 (Continued)

NORMDIST Returns the normal cumulative distribution

NORMINV Returns the inverse of the normal cumulative distribution

Returns the standard normal cumulative distribution

NORMSINV Returns the inverse of the standard normal cumulative distribution
PEARSON Returns the Pearson product moment correlation coefficient

PERCENTILE Returns the k-th percentile of values in a range
PERCENTRANK Returns the percentage rank of a value in a data set

PERMUT Returns the number of permutations for a given number of objects

POISSON Returns the Poisson distribution

PROB Returns the probability that values in a range are between two limits

QUARTILE Returns the quartile of a data set

Returns the rank of a number in a list of numbers

Returns the square of the Pearson product moment correlatin coefficient

SKEW Returns the skewness of a distribution

SLOPE Returns the slope of the linear regression line SMALL Returns the k-th smallest value in a data set

STANDARDIZE Returns a normalized value

STDEV Estimates standard deviation based on a sample

STDEVP Calculates standard deviation based on the entire population

<u>STEYX</u> Returns the standard error of the predicted y-value for each x in the regression

TDIST Returns the Student's t-distribution

TINV Returns the inverse of the Student's t-distribution

TREND Returns values along a linear trend

TRIMMEAN Returns the mean of the interior of a data set

TTEST Returns the probability associated with a Student's t-Test

VAR Estimates variance based on a sample

VARP Calculates variance based on the entire population

WEIBULL Returns the Weibull distribution

ZTEST Returns the two-tailed P-value of a z-test

CHAPTER 4

CASE STUDY AND RESULTS

4.1 Method of Experiment, Set Up and Procedure

The workpiece (3 in x 3 in) is placed on the load cell and it is fixed with the aid of a vice.

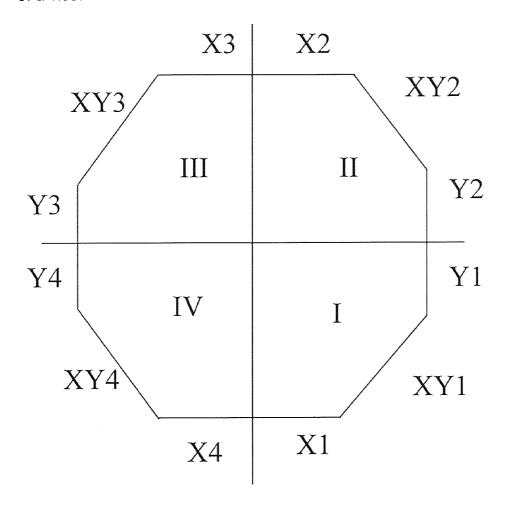


Fig 4.1 Workpiece and the feed rates in the order as the component was cut

The above figure represents the workpiece used in the experiments on the milling machine. The workpiece was made from the material Al 6060. The

cutter that was used for the milling operation was made out of high speed steel.

The workpiece was cut in the order as represented by the number in the figure.

The data acquisition board is kept ready and all the necessary information is entered to the UEI-Win 30. After that the amplifier is set up after a warm up of 1 hr. The CNC milling machine and the NC part program are kept ready. The data acquisition program is then actuated and the process is performed. If there is no overload signal the data is saved. The surface finish of the workpiece is measured by the Surtronic 3 + and the collected data is transferred to the Surface Finish software.

The cutting force varies due to the stochastic nature of the process at each moment of time and thereby it leads to the variation in the surface roughness every time. Thus the cutting forces were also to be recorded at the same time. In this research, a transducer was used for converting the vibrations of the cutting force to analog signals. The transducer measured each separate component of the force at the same time. A Kistler 9067 force transducer was used to measure the three orthogonal components of the cutting forces in arbitrary directions. The workpiece was an eight sided polygon that was connected with 4 screws to the fixture and after every 4 experiments the workpiece was changed to another one. The transducer was calibrated with the fixture as a perload.

The Fadal CNC machine was used to perform the milling process. The Fadal CNC machine is a 5 axis milling machine. It moves on the X,Y, and Z axis and rotates to both directions of rotations. The high speed processor increases

the machine capability to use faster feedrates. These higher feedrates may be attained without emptying the machine buffer. There are also additional G and M code capabilities. The macro capabilities provides a programmer with full mathematical calculations within a program.

Four 1/2 in. size flute side mills were used to perform the cutting operation. All the cutters were constructed from a high speed steel matr. (HSS). First, the roughing operation was performed and then the finishing operation was performed and the data was collected. For these experiments the workpiece was made from the AL 6060. Each experiment consisted of three different paths as follows X direction, XY direction and the Y direction under the same conditions.

4.2 Design of Experiments

In this research the factorial design of 2 ³ was adopted and the selected experimental points created the vertices of the cube. Based on the capacity of the milling machine used three levels (lower, central, and upper) were selected for each cutting condition. The table below shows the combination of the different parameters involved in the machining of the component.

 Table 4.1
 Operating Parameters and levels of cutting

SPEED	FEED	DEPTH OF CUT
1500 RPM	0.001 in/min	0.001 in
3000 RPM	0.005 in/min	0.02 in
4500 RPM	0.01 in/min	0.05 in
	0.02 in/min	

The above table shows the different operating parameters involved in the machining operation and the different levels of cutting. After the machining was carried out the data was collected and transferred to excel spreadsheet.

4.3 Total Time for 4 Experiments

There was a total of 4 experiments performed per combination of the operating parameters. These 4 experiments represent the cutting if the workpiece was divided into 4 quadrants. The milling process of each of the workpiece took as follows:

When the spindle speed = 1500 RPM, total time = 304.2 secs.

When the spindle speed = 3000 RPM, total time = 153.6 secs.

When the spindle speed = 4500 RPM, total time = 76.8 secs.

When the spindle speed was increased the milling process was shorter.

The total sampling rate that was collected is as follows:

For a total time of 307.2 secs. the signals per channel were 1024. For a total time of 153.6 secs. the signals per channel were 512 and when the total time was 76.8 secs. the signals per channel were 256.

There were 4 experiments performed on each workpiece. The workpiece was divided into 4 quadrants and each feedrate was used in each quadrant and the readings were recorded from the software. The Surface Quality results and the Cutting force results were all recorded from the software. Initially this data was in the form of .dat file from the software. It was imported into the Excel

Spreadsheet so that there could be ease of calculation. For this conversion a special feature in excel was used that allows us to convert each .dat file into a .xls format. Once the .xls format was obtained all the calculations could be performed like a normal excel spreadsheet. Given below are the results from the excel spreadsheet for the Surface Quality and Cutting Forces. The formulae that were described in the previous chapter were utilized to obtain the Signal to noise ratio for all the parameters.

4.4 Data Organization

The data that was obtained from the CNC machine software was in the form of thousands of numbers. This data needed to be organized so that mathematical models could be derived. The Surface texture data was first imported in the Excel Spreadsheet. It is to be noted that there were 3 spindle speeds, 4 feed rates and 3 depths of cut. Thus if we have a single value for a single combination for cutting in each direction we should end with 3 x 4 x 3 = 36 values for cutting in each direction. Thus each of the surface texture parameter was averaged or maximized or minimized to obtain the 36 values for cutting in each direction. Rku, Ra and Rq values were averaged as the average value would give optimum results. The Rp and Rt values which are the peak values were minimized because of the fact that minimum the distance between peaks the better it is. These values were calculated using the Excel spreadsheet. The cutting force data was split into the Fmax value and the Favg. value to obtain optimum results.

For this purpose also Excel spread sheet was used. Before performing these functions the data files had to be converted from the .dat format to the .xls format and this feature was available through a software in Excel.

Taguchi's method was used to calculate the S/N Ratios. The following formulae are available and they were used according to the conditions.

a. When nominal is the best

$$(S/N) = 20 * log (Y/S)$$

where Y is the average of a number of readings = S

b. When small is the best (min function)

$$(S/N) = -10 * log (1/n (\Sigma Y^2))$$

where Y is the reading and n is the number of readings.

c. When big is the best (max. function)

$$(S/N) = -10 * log (1/n (\Sigma 1/Y^2))$$

where Y is the reading and n is the total number of readings.

Thus using the above formulae the Signal to noise ratios were calculated using either min. the better or max, the better.

Similar results were also obtained for the cutting forces. In this case there were only two parameters

Fmax - The maximum cutting force.

Favg - The average cutting force.

The standard deviations and the signal to noise ratios were calculated for the Fmax. in a similar manner as for the Surface texture Results. The cutting was carried out in three directions X, XY and the Y Directions. Therefore, a set of readings was obtained for each of the three directions.

There were thousands of numbers involved and to develop a mathematical model it was necessary that the data be organized so that sense could be made out of it after feeding it to the various softwares. Since there are three spindle speeds, four feed rates and three depths of cut 3 x 4 x 3 = 36 values of each operating parameter was obtained for cutting in each of the X, XY and the Y direction. The entire data which was consolidated and organized is shown in the tables 4.2, 4.3, 4.4, 4.5, 4.6, and 4.7. Tables 4.2, 4.3 and 4.4 show the surface quality parameter values of Rku, Ra, Rq, Rp and Rt, their In values, the standard deviations and the signal to noise ratios for cutting in each of the three directions X, XY and Y respectively. The tables 4.5, 4.6 and 4.7 show the maximum cutting force and the average cutting force, their In values, standard deviations and the signal to noise ratios for cutting in all the three directions X, XY and Y respectively.

The tables were created by using excel functions. On the Microsoft Excel screen there are lots of icons. There is an icon for "Function Wizard "which comes up with the numerous statistical formulae that can be used for mathematical and algebraic calculations. Not all of these functions were utilized during the course of the data organization.

Table 4.2 Cutting in X Direction

speed	In speed	feed	in feed	depth	In depth	Rest	avo)	Łn Rku	std k	logstd k	S/N Rku	1	Avg Ra	In Ra	std Ra	logstd Ra	Ş/N Ra
									i								L
1500 1500		0.001				2.96		1.087439						2.817403			
1500		0.001				3.46		1.335001 1.243194						3.217542			
1500	7 31322	0.005	-5.29832	0,001		5.66	6667	1,734601	3.894012				21.73333	3.078847	14.23388	1,153323	-27 8348
1500			-5.29832				5.7	1.740466	2,946184	0.46926	-15,8293		14.93333	2.703596	3.098925	0.491211	-23 6061
1500 1500			-5 29832 -4 60517				6667 6667		0.5					2.77467 3.158418			
1500			-4.60517							-0.53959				3.319023			
1500	7 3 1 3 2 2	0.01	-4 60517	0.05		2.00		0,993252			-8,65499		32 26667	3.474035	3.385754	0.529655	-30.2068
1500								1.173514	1.877054	0.273477	-11 0732		37 73333	3 630544	5.508478	0 741032	-31 5958
1500 1500	7 31322	0 02				2 16	6667 2.1	0.77319	0 305505 0.43589	-0.51498 -0.36062			44.7	3.799974			
3000		0 001				4 03		1.394593	0.378594	-0.36062				2 854553	7.108446		
3000	8 006368	0.001	-6 90776	0 02	-3 91202	4 93	3333	1.596015	1 674316	0 223837	-14 1841		16.83333	2.823361	3.092464	0.490305	-24 62
	8.006368		-6 90776					1 575536			-14.101			2.879198			-25 7533
	8 006368 8 006368		-5 29832 -5 29832			3.13		1 142097			-9.99421 -10.4676			2.509599 2.382628			-21 8263 -20 74
3000	8 006368	0 005	-5 29832			3.53				0.032852		<u> </u>		2.24071		0.113943	
	8 006368		-4.60517	0.001						-0.07033				2.762117	3.855299	0 586058	-24 1598
	8.006368 8.006368	0.01								0.254153				2.60269			
	8.006368						6667	1.716796 0.77319	0.208167		-14.916 -6.73021	 		3.015535 3.584444			
	8 006368	0.02					3333		0.152755			İ	55.3	4.012773	3.740321	0.572909	-34 8677
	8.006368	0.02								0.022661			33 3	3 505557	5.940539	0 773826	-30 5401
	8 411833 8 411833		-6.90776 -6.90776					1.223775		-0.30103 0.699519	-10.6917 -19.0117	 	15.7	2.753661 2.961831	3.109662	0.492713	-24 0301
	8 411833							1.290151			-11 3704	 	13.66667	2.61496	3.354599	0 525641	-27 1469
4500	8 411833	0.005	-5.29832	0.001	-6 90776			1.163151			-10 162			2 742988			
	8 411833	0 005		0.02				1.410987			-12 3696		13 13333	2.575154	1.93477	0.286629	-22 4299
	8 411833 8 411833	0.005		0.05	-2 99573 -6 90776			1.252763	0.1	0.494056			12.16667		2.050203		
4500			-4.60517	0.02		-		1.386294			-14.2711 -12.5543			3.052428 3.212187			
4500	8 411833	0.01	-4.60517	0.05	-2.99573		3333	1.369487	1.882374	0.274706	-12.5123		17.96667	2 888518	0.70946	-0 14907	-25 0939
	8.411833	0.02	-3.91202			2.73		1.005522			-8.73514		29.43333	3.382128	1.955335	0.291221	
4500 4500	8.411833 8.411833	0.02		0.02		2 03:		1.568616			-14.9276 -6.18048			3.815512			-33 584
			13,51202	0.03	-2.00013		33331	0,709676	0.132733	-0.81601	-0.10040		34 /000/	4.003082	2.050203	0311/8/	-34 7744
		In Rq		logstd Rq		Avg 8		0,709676 In Rp		logstd Rp			Avg Rt	4 003082		logstd Rt	
	Avg Rq	In Rq	Std Rq	logstd Rq	S/N Rq	Avg	Rр	In Rp	Std Rp	logstd Rp	S/N Rp		Avg Rt	In Ri	Sid Ri	logstd Rt	S/N Rt
	Avg Rq 20 86667	In Rq 3,038153	Std Rq 2.750152	logstd Rq 0 439357	S/N Rq -26.4391	Avg I	Rp.	in Rp 4.184591	Std Rp 8,621678	logstd Rp 0.935592	S/N Rp -36.3965		Avg Rt	In Ri 4,770685	Std Rt 18 35756	logstd Rt 1.263815	S/N Rt -41 5072
	Avg Rq 20 86667 32 63333 28 83333	In Rq 3,038153 3,485334 3,361532	Std Rq 2.750152 10.73421 3.917057	logstd Rq 0.439357 1.03077 0.59296	S/N Rq -26.4391 -30.5757 -29.251	Avg 8 65.60 101.	Rp 5667 3333 88	In Rp 4.184591 4.618415 4.477337	Std Rp 8,621678 45,54485	0.935592 1.658439 1 113943	S/N Rp -36.3965 -40.6638 -38.9524		Avg Rt 118 194 174.3333	In Rt 4,770685 5,267858 5 160969	Std Rt 18 35756 56 02678 20 84067	1 263815 1 748396 1 318912	S/N Rt -41 5072 -45 991 -44 8688
	Avg Rq 20 86667 32.63333 28.83333 30 26667	In Rq 3.038153 3.485334 3.361532 3.410047	Std Rq 2.750152 10.73421 3.917057 22.45135	logstd Rq 0 439357 1.03077 0 59296 1.351243	S/N Rq -26.4391 -30.5757 -29.251 -30.9764	Avg 8 65.66 101.	Rp 3667 3333 88 3333	In Rp 4.184591 4.618415 4.477337 4.907741	Std Rp 8.621678 45.54485 13 142.4792	0.935592 1.658439 1.113943 2.153752	S/N Rp -36.3965 -40.6638 -38.9524 -45.0309		Avg Rt 118 194 174.3333 216.3333	In Rt 4,770685 5,267858 5 160968 5 37682	Std Rt 18 35756 56 02678 20 84067 183 3939	1.263815 1.748396 1.318912 2.263385	S/N Rt -41 5072 -45 991 -44 8688 -48 4025
	Avg Rq 20 86667 32 63333 28 83333 30 26667 21	In Rq 3.038153 3.485334 3.361532 3.410047	Std Rq 2.750152 10.73421 3.917067 22.45135 6.656576	0 439357 1.03077 0 59296 1.351243 0.823251	S/N Rq -26.4391 -30.5757 -29.251 -30.9764 -26.726	Avg 8 65.66 101.	Rp 5667 3333 88 3333 3333	In Rp 4.184591 4.618415 4.477337 4.907741 4.321923	Std Rp 8.621678 45.54485 13 142.4792 47.07795	0.935592 1.658439 1.113943 2.153752 1.672818	S/N Rp -36.3965 -40,6638 -38.9524 -45.0309 -38.5447		Avg Rt 118 194 174.3333	In Rt 4,770685 5,267858 5 160969 5 37682 4 946393	Std Rt 18 35756 56 02678 20 84067 183 3939 64 04165	1.263815 1.748396 1.318912 2.263385 1.806463	S/N Rt -41 5072 -45 991 -44 8688 -48 4025 -43 5259
	Avg Rq 20 86667 32 63333 28 83333 30 26667 21 20.5 29 53333	In Rq 3.038153 3.485334 3.361532 3.410047 3.044522 3.020425 3.38552	Std Rq 2.750152 10.73421 3.917057 22.45135 6.656576 1.4 2.542309	0 439357 1.03077 0 59296 1.351243 0.823251 0.146128 0.405228	5/N Rq -26.4391 -30.5757 -29.251 -30.9764 -26.726 -26.2486 -29.4277	Avg (65.64 101.) 135.: 76.3:	Rp 3667 3333 88 3333 63 3333	In Rp 4.184591 4.618415 4.477337 4.907741 4.321923 4.143135 4.525405	Std Rp 8.621678 45.54485 13 142.4792 47.07795 5.567764 9.291573	0.935592 1.658439 1 113943 2 153752 1 672818 0 745681 0 968089	S/N Rp -36.3965 -40.6638 -38.9524 -45.0309 -38.5447 -36.0094 -39.3364		118 194 174.3333 216.3333 140.6667	In Rt 4,770685 5,267858 5 160969 5 37682 4 946393 4 859812	Std Rt 18 35756 56 02678 20 84067 183 3939	logstd Rt 1.263815 1.748396 1.318912 2.263385 1.806463 1.318244	S/N Rt -41 5072 -45 991 -44 8688 -48 4025 -43 5259 -42 2865
	Avg Rq 20 86667 32 63333 28 83333 30 26667 21 20 5 29 53333 34 46667	In Rq 3.038153 3.485334 3.361532 3.410047 3.044522 3.020425 3.38552 3.539993	Std Rq 2.750152 10.73421 3.917057 22.45135 6.656576 1.4 2.542309 7.600877	0 439357 1.03077 0 59296 1 351243 0 823251 0 146128 0 405228 0 880864	S/N Rq -26.4391 -30.5757 -29.251 -30.9764 -26.726 -26.2486 -29.4277 -30.8866	Avg ! 65.66 101. 135. 76.3: 92.3: 89.66	Rp 3333 88 3333 3333 63 3333 6667	In Rp 4.184591 4.618415 4.477337 4.907741 4.321923 4.143135 4.525405 4.496099	Std Rp 8.621678 45.54485 13 142.4792 47.07795 5.567764 9.291573 14.57166	0.935592 1.658439 1 113943 2 153752 1 672818 0 745681 0 968089 1 163509	S/N Rp -36.3965 -40.6638 -38.9524 -45.0309 -38.5447 -36.0094 -39.3364 -39.1284		Avg Rt 118 194 174,3333 216,3333 140,6667 129 163 180,6667	In Rt 4,770685 5,267858 5,160969 5,37682 4,946393 4,859812 5,09375 5,198654	Std Rt 18 35756 56.02678 20 84067 183 3938 64 04165 20 80865 6 557439 27 46513	1,263815 1,748396 1,318912 2,263385 1,606463 1,318244 0,816734 1,438782	S/N Rt -41 5072 -45 991 -44 6688 -48 4025 -43 6259 -42 2865 -44 2484 -45 204
	Avg Rq 20 86667 32 63333 28 83333 30 26667 21 20 5 29 53333 34 46667 39 7	In Rq 3.038153 3.485334 3.361532 3.410047 3.044522 3.020425 3.38552 3.539993 3.681351	Std Rq 2.750152 10.73421 3.917057 22.45135 6.656576 1.4 2.542309 7.600877 10.95628	0 439357 1.03077 0 59296 1.351243 0.823251 0.146128 0.405228 0.880864 1.039663	S/N Rq -26.4391 -30.5757 -29.251 -30.9764 -26.726 -26.2486 -29.4277 -30.8866 -32.009	Avg 1 65.6 101. 135. 75.3 92.3 89.6 101.	Rp 5667 3333 88 3333 3333 63 3333 667 5667	In Rp 4.184591 4.618415 4.477337 4.907741 4.321923 4.143135 4.525405 4.496099 4.621699	Std Rp 8.621678 45.54485 13 142.4792 47.07795 5.567764 9.291573 14.57166 18.00926	0.935592 1.658439 1 113943 2 153752 1 672818 0 745681 0 968089 1 163509 1 255496	S/N Rp -36.3965 -40.6638 -38.9524 -45.0309 -38.5447 -36.0094 -39.3364 -39.1284 -40.2335		Avg Rt 118 194 174,3333 216,3333 140,6667 129 163 180,5667 197,6667	In Rt 4.770685 5.267858 5.160969 5.37682 4.946393 4.859812 5.09375 5.196654 5.286582	Std Rt 18 35756 56.02678 20.84067 183.3939 64.04165 20.80865 6.557439 27 46513 23 35237	1 263815 1 748396 1 318912 2 263385 1 806463 1 318244 0 816734 1 438782 1 368331	S/N Rt -41 5072 -45 991 -44 6688 -48 4025 -43 6259 -42 2865 -44 2484 -45 204 -45 9589
	Avg Rq 20 86667 32 63333 32 68637 21 20.5 29 53333 34 46667 39 7 45 7	In Rq 3.038153 3.485334 3.361532 3.410047 3.044522 3.020425 3.38552 3.539993 3.681351 3.822098	Std Rq 2.750152 10.73421 3.917057 22.45135 6.656576 1.4 2.542309 7.600877	0 439357 1.03077 0 59296 1.351243 0.823251 0.146128 0.405228 0.880864 1.039663 0.966617	5/N Rq -26.4391 -30.5757 -29.251 -30.9764 -26.726 -26.2486 -29.4277 -30.8866 -32.009 -33.3156	Avg 1 65.64 101. 135. 75.3: 92.3: 89.64 101. 171.	Rp 5667 3333 88 3333 63 3333 63 3333 5667 5667	In Rp 4.184591 4.618415 4.477337 4.907741 4.321923 4.143135 4.525405 4.496099 5.143611	Std Rp 8.621678 45.54485 13 142.4792 47.07795 5.567764 9.291573 14.57166 18.00926 108.8592	0.935592 1.658439 1.113943 2.153752 1.672818 0.745881 0.968089 1.163509 1.255496 2.036865	S/N Rp -36.3965 -40.6638 -38.9524 -45.0309 -38.5447 -36.0094 -39.3364 -39.1284 -40.2335 -45.7119		118 194 174,3333 216,3333 140,6667 129 163 180,6667 253,3333	In Rt 4,770685 5,267858 5 160969 5,37682 4,946393 4,859812 5,09375 5,196654 5,286582 5,534706	Std Rt 18 35756 56 02678 20 84067 183 3939 64 04165 20 80865 6 557439 27 46513 23 35237 130 6688	1,263815 1,748396 1,318912 2,263385 1,806463 1,318244 0,816734 1,438782 1,368331 2,116172	S/N Rt -41 5072 -45 991 -44 8688 -48 4025 -43 5259 -42 2865 -44 2484 -45 204 -45 9589 -48 783
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	Avg Rq 20 86667 32 63333 38 83333 30 26667 21 205 29 53333 34 46667 23 16667 23 16667 25 16667 26 16667 27 17 38667 28 76667 29 17 38667 29 17 38667 20 11 30 63333 19 73333 19 73333 17 46667 20 11 65.5 28 33333 19 23333	In Rq 3.038153 3.485334 3.61532 3.410047 3.044522 3.38552 3.38552 3.53993 3.681351 3.822098 3.948033 3.931826 3.107572 3.142714 3.220208 2.734588 2.617396 2.47092 2.982309 2.86253 3.59217 3.740048 4.156753 3.59222 2.992393 3.280224 2.992393 3.280224 3.34038 3.34038	Std Rq 2.750152 10.73421 3.917057 22.45135 6.656576 4.2542309 7.600877 10.95528 9.26013 6.115826 9.26013 6.115826 13.37174 1.509867 1.868154 2.013289 1.876866 4.728636 3.73229 9.176237 4.784349 26.73955 4.891148 20.23199 3.098925 2.6885144 2.923199 3.098925	logstd Rq 0 439357 1.03077 0.59296 1.351243 0.823251 0.823251 0.8268617 0.7868617 0.786815 0.858461 0.587224 0.739612 1.126188 0.47366 0.688319 0.674736 0.791413 0.674736 0.791413 0.674736 0.791413 0.674736 0.791413 0.674736 0.791413	S/N Rq 26. 4391 30.5757 29.251 30.9764 26.726 26.2246 26.2246 29.4277 30.8866 -29.4277 30.8866 -32.009 33.3156 33.3156 33.43323 34.209 27.0777 27.4571 -28.7266 23.7782 -21.5452 -22.27879 -21.5452 -22.27879 -21.5452 -23.2782 -24.8145 -29.2113 -32.522 -36.063 -32.2676 -26.2249 -31.5078 -26.2249 -31.5078 -26.2249 -31.5078 -26.2249 -31.5078 -26.2249 -31.5078 -26.2249 -31.5078 -26.2249 -31.5078 -26.2249 -31.5078 -26.2249 -31.5078 -26.2249 -26.23295 -26.2339	Avg 1 65 64 101. 135. 75 3: 92 3: 89 64 101. 128. 87 64 87 64 88 64 49 3: 128. 139. 159 3: 104 65 111.6	Rp 56667 3333 3333 63 6567 6667 3333 3333	In Rp 4.184591 4.618415 4.477337 4.907741 4.321923 4.143135 4.525406 4.96099 5.143611 4.864631 4.804021 4.473542 4.473542 4.473542 4.473542 4.473543 4.87463 3.69368 3.97469 4.983171 4.715518 4.730333 4.650781 4.730333 4.650781 4.74387 5.030438 4.083171 4.715318 4.730438 4.73048 4.	8.621678 8.521678 8.521678 8.521678 8.521678 8.521678 8.521678 112 4792 9.791573 14.57166 11.80922 9.36551 14.57166 11.35732 8.521678 9.291573 14.57166 11.35732	logstd Rp 0.935592 1.658439 1.113943 2.153752 6.72918 0.745581 0.968089 1.63509 1.255496 0.963428 1.67535 0.963428 1.67535 0.963428 1.67535 0.963685 1.67535 0.963689 1.65295 1.574147 0.968537 1.380713 0.968089 1.3496792 1.635098 1.3496792 1.635098 1.350629 1.3792219 1.392219 1.392219 1.392219 1.392219 1.392219 1.392219 1.392219 1.392219 1.392219 1.392219 1.392219 1.392219 1.392219 1.392219 1.392219 1.392219 1.392219 1.392219 1.3928219	S/N Rp 36 3865 40,6638 38 9524 45 0309 38 5447 39 036 0994 40 2335 45 7119 42 1942 41 7356 39 2128 43 92128 43 738 711 33 9504 32 927 33 8504 41 0905 41 1066 42 7284 41 0042 36 55964 35 1963 35 1968 36 6546 33 1868 36 6546 33 1868		Avg Rt 118 194 174,3333 140,6667 163 180,6667 197,6667 162,3333 216,6667 162,3333 163,6667 169,667 199,16667 199,16667 199,1667 191,16667 191,16667 191,16667 191,16667 191,16667 191,16667 191,16667 191,16667 191,16667 191,16667 191,16667 191,16667 191,16667 191,16667 191,16667 191,16667 191,16667 191,16667 191,16667	In Rt 4.770-885 5.267 958 5.160-969 5.37682 4.94-6393 4.859812 5.09375 5.396852 5.367582 5.367785 5.367852 5.367785 5.367852 5.367785 5.367785 5.367785 5.367785 5.367785 5.367785 5.3677858 5.367785 5.367785 5.367785 5.367785 5.367785 5.367785 5.3677858 5.367785 5.367785 5.367785 5.367785 5.367785 5.367785 5.3677858 5.367785 5.3678785 5.367785 5.367785 5.367785 5.367785 5.367785 5.367785 5.3678785 5.367785 5.367785 5.367785 5.367785 5.367785 5.367785 5.3678785 5.367785 5.367785 5.367785 5.367785 5.367785 5.367785 5.367785 5.367785 5.367785 5.367785 5.367785 5.367785 5.367785 5.36778	Std Rt 18.35756 56.02678 20.84067 183.3939 64.04165 20.80656 6.557439 27.46513 23.35237 130.6688 16.77299 32.39241 54.19717 87.75154 97.6586 16.27299 16.16581 9.291573 12.01388 63.37961 40.73082 43.58899 16.16581 9.291573 12.01388 63.37961 40.50103 206.7519 42.35957 15.94783 92.557994 15.885 99.71459	logstd Rt 1,263815 1,748396 1,318912 2,263385 1,608-63 3,1382-4 0,5167,34 1,436782 1,368331 2,116172 1,295716 1,224611 1,295716 1,224611 1,255716 1,224611 1,255926 1,325539 1,609923 0,60923 0,60923 0,60923 0,60923 1,079823 1,80195 1,507466 2,315449 1,626952 1,4079 1,20987 1,20987 1,20987 1,20987 1,20987 1,20987 1,998759	SN Rt 41 5072 45 991 44 8088 48 4026 43 6259 44 2484 45 2596 44 72 2866 44 2484 45 9599 46 743 46 743 46 743 47 391 48 512 39 1148 38 4611 37 389 42 7352 49 0887 45 6577 45 6577 45 697 45 949 47 19940 41 6191 39 7536 45 11694
	Avg Rq 20.86867 32.63333 28.83333 30.26867 21.20.5 29.53333 34.46867 51.83333 17.36867 28.76867 28.76867 29.73333 17.36867 28.76867 29.13333 17.36867 28.76867 29.13333 17.36867 28.76867 29.13333 17.36867 28.76867 29.13333	In Rq 3.038153 3.485334 3.61532 3.410047 3.044522 3.020425 3.38552 3.539993 3.681351 3.822098 3.142714 3.220208 2.47092 2.47092 2.47092 2.854553 3.698004 3.00072 3.422086 3.155753 3.698004 3.00072 3.422086 2.87222 2.992393 3.860294 2.74084 3.342086	2.750152 10.73421 3.917057 22.45135 6.656576 1.4 2.542309 9.26013 6.115826 7.218726 3.865661 5.115826 7.218726 13.37174 1.509967 1.868154 2.013289 9.76227 4.784369 4.728636 7.218726 4.728636 7.218726 4.728636 7.218726 4.728636 7.2287 9.73279 9.76237 4.784349 9.76237 4.784349 9.78237 9.	0 439357 0 439357 0 59296 1 351243 0 823251 0 140128 0 860864 1 039663 0 986617 0 7884155 0 858461 1 03963 0 161454 0 587224 0 739812 1 126188 0 178967 0 271413 0 303996 0 571976 0 571976 0 962655 0 679823 1 427154 0 689411 0 428568 0 6953849 1 0 1,28858 0 953849 1 0 1,28858 0 953849 1 0 1,28858 0 953849 1 0 1,28858 0 953849 1 1 0 1,28858	SAN Rq 26. 4391 20. 4391 20. 5157 29.251 20. 9764 26. 726 26. 24867 20. 29. 4277 20. 8866 32. 009 33. 3156 33. 209 27. 0777 28. 7266 23. 7782 27. 4571 28. 7266 23. 7782 22. 7879 21. 5452 22. 26. 0775 24. 8145 29. 213. 32. 522 29. 213. 32. 522 29. 213. 32. 522 29. 213. 32. 522 29. 213. 32. 522 29. 213. 32. 522 29. 213. 32. 522 29. 213. 32. 522 29. 213. 32. 522 29. 213. 32. 523 29. 213. 32. 523 29. 213. 32. 523 29. 213. 32. 523 29. 213. 32. 523 29. 213. 5278 29. 213. 22. 523 29. 213. 5278	Avg 1 65 64 101. 135. 75 3: 92 3: 89 64 101. 128. 87 64 87 64 88 64 49 3: 128. 139. 159 3: 104 65 111.6	Rp 56667 3333 3333 3333 3333 3333 3333 333	In Rp 4.184591 4.618415 4.477337 4.907741 4.321923 4.143135 4.525405 4.96099 4.96099 5.143611 4.804021 4.473542 4.48484 3.6936 3.753418 3.697586 4.394489 4.083171 4.715518 4.79542 4.473542 4.473542 4.473542 4.473542 4.473542 4.473543 4.79543	Std Rp 8.621678 45.54485 13 142.47922 47 07795 5.567764 9.291573 14 57166 18.09926 108.8592 12.50333 9.192388 31.39002 29.38551 47.35528 8.521678 4.57166 11.35782 37.51 14.57166 11.35782 11.5782 14.57166 11.35782 11.5782	logstd Rp. 1.658439 1.658439 1.113943 2.153752 1.672818 0.745881 0.745881 0.745881 1.65509 1.15509 1.255496 0.963428 1.496792 1.467838 1.467635 0.935592 1.63509 1.055295 1.574147 0.606537 1.380713 0.968089 1.184917 0.606537 1.380713 0.968089 1.184917 0.935592 1.132219 2.236795 1.310242 0.937531 1.305662 1.034093 1.30242 0.937531 1.305662 1.034093 1.1911835 1.631818	S/N Rp 36.3965 40.6638 38.9524 45.0309 48.5447 36.0094 39.1284 40.2335 45.7119 42.1942 41.7356 39.2129 39.7112 39.7112 39.7112 39.7112 39.7112 39.7112 31.8690 31.7944 41.0905 41.1066 42.7284 41.0905 41.1066 42.7284 41.0905 41.1066 42.7284 41.0905 41.1066 42.7284 41.0905 41.1066 42.7284 41.0905 41.1066 42.7284 41.0905 43.7963 35.1838 36.6546 33.7693 35.1838 36.6546 42.528 42.2438		Avg Rt 118 194 174,3333 140,6667 129 180,6667 197,6667 253,3333 216,6667 153,6667 162,3333 161,6667 162,3333 772 112 188,6667 191,6667 193,333 115,6667 194,13333 115,6667 196,767 110,6667 110,6667 110,6667 110,6667 110,6667 110,6667 110,6667 110,6667 110,6667 110,6667 110,6667 110,6667 110,6667 110,6667 110,6667 110,6667 1110,6667 1110,6667	In Rt 4,770685 5,267958 5,169969 5,37682 4,946393 4,859812 5,96587 5,196654 5,26592 5,34766 5,34766 5,34766 5,34766 4,276666 4,276666 4,276666 5,241747 4,798542 5,5758 5,70866 5,241747 4,795542 5,76712 4,706523 4,776316 4,56714 5,1647916	Std Rt 18.35756 56.02678 20.84067 183.3939 64.04165 20.80865 6.557439 27.46513 23.35237 130.6688 16.77299 32.39341 54.19717 87.75154 19717 87.75154 19716 16.16581 10.73089 10.73082 10	logstd Rt 1.263815 1.748396 1.318912 2.263385 1.606463 1.318244 0.516734 1.436782 1.368331 2.116172 1.96716 1.224611 1.510457 1.94256 0.99214 1.775928 1.325639 1.609923 1.609923 1.801951 1.501466 1.20457 1.94766 1.202097 1.202097 1.202097 1.202097 1.202097 1.202097 1.202097 1.202097 1.202097 1.202097 1.202097 1.2020987	5N R 41 9072 45 991 44 6898 48 4026 43 5259 42 2865 44 2846 45 5299 48 783 46 6463 39 1148 38 4611 37 3892 49 783 49 783
	Avg Rq 20.86867 32.63333 30.26867 21.205 29.53333 34.46867 39.7 23.16867 23.36867 23.36867 24.11 83333 19.73333 17.48687 20.13 30.63333 17.46867 20.13 30.63333 17.46867 20.13 30.63333 17.46867 20.13 30.63333 17.46867 20.13 30.63333 31.636667 20.13 30.63333 31.646667 20.13 30.653333 31.656667 20.13 30.653333 31.6566667 20.13 30.653333 31.656667 20.13 30.653333 31.656667 20.13 30.653333 31.656667 20.13 30.653333 31.656667 20.13 30.656667	In Rq 3,038153 3,485334 3,861532 3,410047 3,044522 3,020425 3,38552 3,539993 3,822098 3,142714 3,220208 2,617396 2,47092 2,982309 2,854553 3,740048 4,155753 3,698004 3,42089 2,892222 2,992393 2,860294 2,74088 3,44039 3,50964 3,14039 3,50964 3,14039 3,50964 3,14039 3,50964	Std Rq 2.750152 10.73421 3.917057 22.45135 6.656576 4.2542309 7.600877 10.95528 9.26013 6.115826 9.26013 6.115826 13.37174 1.509867 1.868154 2.013289 1.876866 4.728636 3.73229 9.176237 4.784349 26.73955 4.891148 20.23199 3.098925 2.6885144 2.923199 3.098925	0 439357 0 439357 0 59296 1 1551243 0 823251 0 146128 0 405228 0 880864 1 039663 0 986617 0 587224 0 739612 1 126188 0 161454 0 587224 0 173961 0 161454 0 58725 0 571976 0 71976 0 71	SAN Rq 26. 4391 30. 5757 29. 251 30. 9764 26. 726 26. 2486 26. 2486 29. 4277 30. 8866 32. 009 33. 3156 32. 009 27. 0777 28. 7266 23. 7762 27. 4577 28. 7266 23. 7762 22. 7879 24. 5145 25. 26. 0715 36. 1063 32. 2096 25. 2076 26. 2249 36. 1063 32. 2676 26. 2249 31. 5072 26. 2729 27. 2727 27. 2757 28. 7266 29. 211 32. 527 29. 211 32. 527 29. 211 32. 527 29. 211 32. 527 29. 213 32. 527 29. 213 32. 527 29. 213 32. 527 29. 213 32. 527 29. 213 32. 527 29. 213 32. 527 29. 213 32. 527 29. 213 32. 527 29. 213 32. 527 29. 213 32. 527 29. 213 32. 527 29. 213 32. 527 29. 213 32. 528 33. 5076 32. 508 32. 508 32. 508 33. 508 33. 508 33. 508 33. 508 33. 108	Avg 1 65 64 101. 135. 75 3: 92 3: 89 64 101. 128. 87 64 87 64 88 64 49 3: 128. 139. 159 3: 104 65 111.6	Rp 6667 3333 3333 3333 3333 322 33333 3333 322 33333 3333 322 33333 3333	In Rp 4.184591 4.618415 4.477337 4.907741 4.321923 4.143135 4.525405 4.96099 5.143611 4.854631 4.804021 4.473542 4.473542 4.473542 4.473542 4.73543 4.915103 4.95473 4	8.621678 45.54485 13 142.4792 47 07795 5 567764 9 291573 14 57:66 108.8592 11 250333 9.192388 31.39002 9.38551 14.57:66 14.57:66 15.5022 24.02776 9.291573 15.30795 14.57:68 11.35782 24.02776 9.291573 15.30795 16.81665 81.6272 67.85207 10.81665 81.6272 67.85207 4.932883	logstd Rp. 1.658439 1.658439 1.113943 2.153752 1.672818 0.745881 0.745881 0.745881 1.65509 1.15509 1.255496 0.963428 1.496792 1.467838 1.467635 0.935592 1.63509 1.055295 1.574147 0.606537 1.380713 0.968089 1.184917 0.606537 1.380713 0.968089 1.184917 0.935592 1.132219 2.236795 1.310242 0.937531 1.305662 1.034093 1.30242 0.937531 1.305662 1.034093 1.1911835 1.631818	S/N Rp 38 3865 40,6638 38 9524 45 0309 38 5447 39 1284 40 2335 45 7119 42 1942 41 7356 39 2128 43 92128 43 93 17 39 7112 33 9504 32 927 31 8469 38 75 31 8469 41 10965 41 10965 41 10965 43 35 6548 44 10923 45 396 35 1838 35 1838 36 6548 42 2343 36 65801 42 2388		Avg Rt 118 194 174,3333 140,6667 129 163 180,6667 197,6667 197,6667 162,3333 216,6667 162,3333 161,6667 162,3333 172,125 188,6667 199,189,189,189,189 121,3333 241,3333 175 110,6667 110,667	In Rt 4,770685 5,267958 5,169969 5,37682 4,946393 4,859812 5,96587 5,196654 5,26592 5,34766 5,34766 5,34766 5,34766 4,276666 4,276666 4,276666 5,241747 4,798542 5,5758 5,70866 5,241747 4,795542 5,76712 4,706523 4,776316 4,56714 5,1647916	Std Rt 18.35758 56.02678 20.84667 183.3939 64.04165 20.80865 6.557439 27.46513 130.6688 16.77299 32.39231 130.6688 16.77299 32.39241 54.19717 87.75154 18.87679 21.16601 40.73082 4.358879 12.01388 63.3798.1 40.50103 206.7519 42.35957 15.94783 25.57994 15.685 99.71457 19.69772	logstd Rt 1.263815 1.748396 1.318912 2.263385 1.606463 1.318244 0.816734 1.438782 1.16172 1.295716 1.224611 1.510457 1.733977 1.943255 0.96214 1.275928 1.325593 1.009823	5/N Rt -11 5072 -45 991 -44 8058 -48 4025 -43 5259 -42 2865 -42 2865 -42 2865 -45 793 -46 733 -46 743 -46 743 -47 3554 -48 194 -48 194 -49 194 -49 198 -48 735 -48 735 -48 735 -48 735 -49 7

Table 4.3 Cutting in XY Direction

st	eed	In speed	feed	In feed	depth	In depth	Rk	ı İn	Rku st	1 Rio	logstd RI	S/N R	ku .	Ra	In Ra	std Ra	logstd Ra	SANR
	1500	7.31322	0.001	-6.90776	0.001	-6.90776	···	2.7 0.993	252	0.3	-0 52288	-8.66287		14.7	2.687847	3.551056	0 550358	-23.5121
-	1500		0.001			-3.91202			858 2.68		0.428968			29.5			1.328638	
	1500							3 1.098	612	0.1	.1	-9.54564					0,415935	
	1500		0.005						398 3,614								0.608874	
	1500		0.005						662 0,416								0.729772	
	1500						 		241 3.740 952 3.55								0.373706	
	1500					-3.91202	5.233		048 2.700								0.423478	
	1500						3 566	67 1.271	631 1.069	268	0.029086	-11.298					0.851732	
	1500				0.001		2.433	33 0.889	262 0,305	505	-0.51498	-7.76943		30 26667	3.410047	0.85049	-0.07033	-29.6216
1.	1500		0.02					67 1.017	643 0.907	377	-0.04221	-9,1399			3.664416		1 053305	
	1500		0.02						532 0,665								0 135145	
		8 006368		-6.90776 -6.90776		-6,90776 -3 91202	4 066	67 1,402	824 2.193 487 1.069	931	0.341223			15 13333	3.025291	0.152753	1 027096	
1		8 006368					3.933	133 1 369	242 0.32	455	.0.49788	-12.1041 -10.9876					-0.81601 -0.02205	
- "		8 006368			0.001	-6.90776	6.066	67 1.802	809 4 712	041	0.673209	-17.1271					0 877988	
		8 006368			0.02	-3 91202	6.066	67 1,802	809 4.101	626	0.612956	-16.8142		15 86667	2,76422	4,808673	0 682025	-24.2678
1.		8 006368		-5.29832	0,05	-2.99573		3.8 1.335	001 1.571	623	0.196348	-12.0647		112	2.415914	0.6245	-0.20447	-20.9934
		8 006368				-6,90776	2 933	33 1.076	139 0.35	188	-0.45446	-9.38853					0.211896	
		8 006368							194 0.723								0,292918	
1		8 006368 8 006368							926 2.193 686 0.152								0.226914	
1		8 006368						1.8 0.587		0.1		-5.11438					0.377663	
1		8 006368							246 0.404	145	-0.39346	-5.85085		40.73333	3.707047	6 013596	0.779134	-32.2616
1	4500	8 411833	0 001	-8.90776	0.001	-6,90776	3 133	33 1,142	097 0.208	167	-0.68159	-9.93289		14 16667	2.650892	0.763763	-0.11704	-23.0338
İ		8 411833					5 833	33 1.763	589 3.013	857	0 479123	-16.0296		12.96667	2.562382	2.993883	0 476235	-22,4082
1		8.411833					5.933	33 1,780	586 4.128	357	0.615777	-16,6808	L	14 63333	2.683302	5.390114	0 731598 0 301763 0 438782	-23 5829
					0,001			3 8 1,335	001 1.014				ļi	16 46667	2.801338	2.003331	0.301753	-24,3748
1		8 411833	0.005			-3 91202 -2 99573		67 1 352 33 1,005			-0.10972 -0.59918	-11.862 -8.75833	¥	19 06667	2 94/942	2.746513	0.438782	-25 6652
1		8 411833			0.001	-6.90776		33 1 076			-0.59918						0.312141	
-		8 411833			0.02	-3.91202			139 0,152		-0.81601			23 96667	3.176664	5.749203	0 759608	-27 7556
		8.411833	0,01	-4.60517	0.05	-2.99573		8 1.029			-0.39794			21.36667	3 06 1832	2.569695	0.409882	-26.6364
		8 411833	0.02		0,001				511 0.173		-0,76144			30 26667	3.410047	1.101514	0.04199	-29,6231
ļ.,		8.411833	0.02		0.02	-3.91202	3.866	67 1.352	393 2.494	681 (0.397012						0.997759	
-	4500	8 411833	0.02	-3 91202	0.05	-2.99573	1.8666	67 0.624	154 0.11	547	-0.93753	-5,4324	ļi	53.83333	3.985893	5,787343	0.762479	-34.6544
-		Rq	In Rq	etd Ro	logstd Rq	S/N Ro	Rp	ln.	20 81/	Rp	logsto R	S/N R	ļi	Rt	In Rt	std Rt	logstd Rt	S/N Rt
	:	214		310 119	TOMOTO THE	- OFFICE			, D	111	CONSTRUCTION OF THE PARTY OF TH		f			Big I'v	1036910.13	30.5
1		18 06667		4 135618	0.61654	-22,8998		52 3.951	244 12.12	436	1.083659	-34.4747		93	4.532599	19	1.278754	-39,4889
		41 96667			1 523525			84 5 214	936 178.			-47.4095			5 600888			
					0.510457			33 4.179			1.180234				4 836282		1.241437	-42.0625
		33 16667	3 501545	10.37368	1.015933 0.835879	-29.5836		34 4.89	784 97.8	928	1.990751	-43.864	ļi				2.234793	
	•	35 46667	3 568593	8 451233	0.835879	-20,0047	75 666	67 4 910	338 35,10 201 97,04	205	1.545364	-38 1604			5.556828		1.672818 2.21569	
	;				1.484482		196.66		151 200.8								2.414505	-51 4497
	- 1				0.827633				729 69,63								1.775053	
L					1.091853				733 30.34	798	1,48213	-38.055		180 3333	5 194807		1.94907	
1 -					0.243097				048 6.557					177 6667			1 185762	
1.					1 072899		119 66		471 35.07				ļ ļ	217 6667			1,447527	
		46.1 28 63333	3 830813		-0.04576 1.254711				734 6.082 174 116.3		0.784101 2.065938	-43.2325 -43.5643		256 6667	5.547778		1.341674 2.177745	
	- ‡	20 03333			0.024609			65 4.174			0.90309			187 134	4.89784		1.418794	
1	- 1		2 305913	1.305118	0.11565	-18,3969	· · · · · · · · · · · · · · · · · · ·	32 3.465			0.89967	-30.2776					1.034093	
1	j	31 93333	3,46365	17.32234	1 238606	-30.0707		33 5.077	255 165.4	882 2	2.218767	-46 431		236	5 463832	198.0227	2 296715	-49.1296
	1				1 101956				203 128.0			-44,3632			5.351858	181.4277	2.258704	-48 2259
					-0.57745				72 4.582		0.66111				4 462069		1.04199	-38 8036
1					0 363092				112 10.21		1.009212				4 742029		1.392071	
1					0 663986 0 556526	-24.041 -24.9616	78.686		522 27,30 393 34.87		1.436175						1.46926 1.707598	
	,				0.432354		100 22		181 5.686			-31 2425 -39.9514					0.948814	
1	•	71 96667	4 276203	5.918051	0.772179	-35.6037			393 3.21		0.50712	-42.9653				10.69268		-49.0501
1		46 33333	3.835862	6.921223	0.840183	-31.0395	1	71 4 26	268 11.26	943	1 051902	-37,0975		170 6667	5,139712	28.29016	1.451635	-44 7218
		17 93333	2 886661	1.137248	0.055855	-23.0013	54 333	33 3,995	3.785	939 0	0.578174	-34.7154		101	4.615121	5.291503	0 723579	-40 0944
1		18.5	2 917771	6.579514	0.818194	-21 6369			511 55.41						4.859812		1.765484	
1		22.3	3.104587	12.85146	1.108952	-27.4322		33 4.773			2.045205			193			2 234019	
	-+		3.049273	∠.986637	0.475182			76 4 220	449 29.71 733 15.71	522	1.47298	-38,5429 -37,7384		142 6667	4.885324	37,42103	1 573116 1.34613	-42.6589 -43.1550
		21 1	3 213528	4 105622				1014.030	UU 1U,11	- to!	1. 13004G			142.0007	-1,0000 T T	44. 100391	1.34013	
		24 86667	3.213528				-	59 4.077	5371	11	O.	-35 4179	1 1	115 6667	4.750712	9 609024	0.982679	-41 2841
		24 86667 21 36667	3.213528 3.061832	1.70098	0.622797 0.230699 0.353074	-25,1733		59 4.077		1 2	0.30103	-35.4179 -37.2686		115.6667	4,750712	9.609024	0.982679	-41,2841 -41,7082
	-	24 86667 21 36667 22 93333 29.63333	3.213528 3.061832 3.132591 3.3889	1,70098 2,254625 6,815668	0.230699 0.353074 0.833508	-25,1733 -25,4587 -26,6289	87.666	59 4,077 73 4,290 67 4.473	159 342 13.05	118	0.30103 1.11565	-37.2686 -38.9204		121 6667	4.801285	9.609024 4.932883 30.56687	0.982679 0.693101	-41,2841 -41,7082 -43,8263
	-	24 86667 21 36667 22 93333 29.63333 26 1	3.213528 3.061832 3.132591 3.3889 3.261935	1.70098 2.254625 6.815668 3.1241	0.230699 0.353074 0.833508 0.494725	-25,1733 -25,4587 -26,6289 -27,1514	87.666 80.333	59 4,077 73 4,290 67 4.473 33 4,386	159 542 13.05 185 11.06	118 044 1	0.30103 1.11565 1.043772	-37.2686 -38.9204 -38.1525		121 6667 153 3333 133	4.801285 5.032614 4.890349	9.609024 4.932883 30.56687 18.52026	0 982679 0 693101 1 485251 1 267647	-41.7082 -43.8263 -42.5328
		24 86667 21 36667 22 93333 29.63333 26 1 37 03333	3.213528 3.061832 3.132591 3.3889 3.261935 3.611818	1.70098 2.254625 6.815668 3.1241 1.41892	0.230699 0.353074 0.833508 0.494725 0.151958	-25,1733 -25,4587 -26,6289 -27,1514 -29,5859	87.666 80.333 110.66	59 4,077 73 4,290 67 4,473 33 4,386 67 4,706	159 542 13.05 185 11.06 523 5.686	118 044 1 241 0	0.30103 1.11565 1.043772 0.754825	-37.2686 -38.9204 -38.1525 -40.888		121 6667 153 3333 133 192 6667	4.801285 5.032614 4.890349 5.260962	9.609024 4 932883 30 56687 18.52026 15.885	0 982679 0 693101 1 485251 1 267647 1 200987	-41.7082 -43.8263 -42.5328 -45.7158
		24 86667 21 36667 22 93333 29.63333 26 1 37 03333 47 63333	3.213528 3.061832 3.132591 3.3889 3.261935 3.611818 3.863533	1,70098 2,254625 6,815668 3,1241 1,41892 9,407621	0.230699 0.353074 0.833508 0.494725	-25,1733 -25,4587 -26,6289 -27,1514 -29,5859 -32,2973	87.666 80.333 110.66 136.33	59 4,077 73 4,290 67 4.473 33 4,386 67 4.706 33 4.915	159 542 13.05 185 11.06	118 044 1 241 0 714 1	0.30103 1.11565 1.043772 0.754825 1.676027	-37.2686 -38.9204 -38.1525 -40.888 -43.029		121 6667 153 3333 133 192 6667 250 6667	4.801285 5.032614 4.890349 5.260962 5.524124	9.609024 4 932883 30 56687 18.52026 15.885 51 3939	0 982679 0 693101 1 485251 1 267647	-41.7082 -43.8263 -42.5328 -45.7158 -48.102

Table 4.4 Cutting in Y Direction

spee	ed It	n speed	leed	in feed	depth	in depth	Rku	In Rku	std k	log std k	S/N RKu	Ra	In Ra	sto Ra	log std Ra	S/N Ra
1	I .	7 31322	0.001	-6 90776	<u> </u>	-6 90776	2 666667	1 299283	0.833666	0.07053	-11.4322	15.5	2 74084	3.214032	0.50705	-23 0204
	500	7 31322		-6 90776	0.02			1.955389					2.835172			
	500	7.31322	0.001		0.05		4	1.386294	1.479865	0.170222	-12.4204		2,738687			-23 8996
	500	7 31322	0.005		0.001		3,433333	1.233532	1.101514 0.1	0.04199	-11.0026 -9.2514		3.066501		0.34302	-26 557 -26 57 14
	500	7 31322	0.005		0.05		2.966667	1.087439	0.11547			21 2333.	3.152736	0.173205	-0.76144	-27.3845
15	500	7 31322	0.01	-4.60517	0 001	-6 90776	3 466667	1.243194	0.665833	-0.17663	-10.9038	17.83333	2.881069	5.085601	0.706342	-25 2539
	500	7 31322 7 31322	0.01	-4 60517 -4 60517	0.02			1.098612		-0.46041			2.643808		0,44863	
	500	7 31322	0.02		0.001			0.980829					3.478158			-30 235
	500	7 31322	0.02	-3.91202	0.02	-3,91202	2.6	0.955511	0.87178	-0.05959	-8.61335	39,7	3.681351	13.81774	1.140437	-32,3131
	500	7 31322 8 006368	0 02		0.001			0.861482			-7.5868 -9.6708		2.787067		0.748188	-33 147 -24 5097
		8 006368	0.001	-6.90776	0.001			1,109662	7 43931	0.49288			2.562382			
		8 006368	0.001	-6.90776	0.05	-2.99573		1.317301				5 933333	1 780586	0 757188	-0.1208	-15 5129
		8 006368	0 005	-5 29832	0.001			1.223775					2.549445			-22 1976
		8 006368 8 006368	0.005		0.02	-3.91202 -2.99573		1.661398					2,908721		0.592488	-26 4055 -22 4703
		8 006368	0.01		0.001		2.633333		0.208167		-8.42817		2.910537			-25 3279
		8.006368	0.01		0.02			2.147879					3,025291		0.3674	-26.3142
		8 006368 8 006368	0.01		0.001			0.929536					2.835172 3.316607			-25 1616 -28 8435
30	200	8 006368	0.02		0.001			1.029619					4.142076			-35 9845
30	000	8 006368	0.02	-3 91202	0.05	-2.99573	1.833333	0.606136	0.251661	-0.59918	-5.31904	38,43333	3,648925	4 966219	0.696026	-31 7422
		8 411833	0.001	-6.90776	0 001	-6.90776		1.629241		0.505785			2.780588			-24 312
		8 411833 8 411833	0,001	-6.90776 -6.90776	0.02 0.05		3 133333	1,728701	0.251661	0.183988 -0.59918			2 487681			-21 1597 -21 8747
45	000	8 411833	0 005		0 001	-6 90776	2 933333	1.076139	0 152753	-0.81601	-9 35507	16,86567	2.825339	3 415162	0.533411	-24 6577
		8 411833	0 005		0.02			2.128232					3,042934			-26.768
		8 411833 8 411833	0 005		0 05			0.993252	0.750555				2.951432 3.162658			-26 0062 -27 5682
		8 411833	0 01		0 02			1,299283					3.00072			-26 1059
45	500 8	8 411833	0.01	-4.60517	0.05		37	1.308333	1 389244	0.142779	-11 7542	23.7	3,165475	11.63228	1 065665	-28 1418
		8 411833 8 411833	0.02	-3 91202 -3 91202	0.001			0.955511		-0.46041 -0.3459			3.604592		1 036774	-31 5557 -33 9161
												49.00007	3.05310	3 1002 17		
	000:0	8 41 1833	0.02	3 9 1 2 0 2	0.05	-2 99573	1 2666667	1 0.980829	1.501111	0.176413	9.35171	56,96667	4.042466	9 000741	0 954278	-35 1841
	0001	8 411833	0,02	-3.91202	0.05				1.501111					9 000741		
	00: 0	8 411833 Rq	In Rq		0 05 log std Rq	-2 99573 S/N Rq	2 666667 Rp	0.980829 In Rp	1.501111 std Rp	0 176413 logstd	-9 35171 S/N Rp	\$6,96667 Rt	4 042466 In Rt		0 954278 log std Rt	-35 1841 S/N Rt
		Rq		std Rq	log std Rq	S/N Rq	Rp				S/N Rp	Rt		std Rt	log sta Rt	S/N Rt
		Rq 19 26667 27 46667	In Rq 2.958376 3.312973	std Rq 3.527511 25.06199	log std Rq 1.181844 1.130334	S/N Rq -25.7921 -30.6935	Rp 52	In Rp 3.951244 4.969813	std Rp 5 178 4461	logstd 0 69897 2 251507	S/N Rp -34 3468 -46 2288	Rt 105,6667 201,6667	In Rt 4.560289 5.306616	std Rt 17,50238 209,0223	log std Rt 1 243097 2 320193	5/N Rt -40 5575 -48 4383
-		Rq 19 26667 27 46667 20 43333	In Rq 2.958376 3.312973 3.017168	std Rq 3.527511 25.06199 5.378042	1,181844 1,130334 1,416641	5/N Rq -25.7921 -30.6935 -26.4029	Rp. 52 144 70	In Rp 3.951244 4.969813 4.248495	std Rp 5 178 4461 35 36948	logstd 0.69897 2.251507 1.548629	S/N Rp -34.3468 -46.2288 -37.5846	Rt 105.6667 201.6667 128	In Rt 4.660289 5.306616 4.85203	std Rt 17,50238 209,0223 44,91102	log std Rt 1 243097 2 320193 1 652353	S/N Rt -40 5575 -48 4383 -42 4868
		Rq 19 26667 27 46667 20 43333 27 13333	In Rq 2.958376 3.312973 3.017168 3.300763	std Rq 3.527511 25.06199 5.378042 1.497776	1.181844 1.130334 1.416641 1.426511	5/N Rq -25.7921 -30.6935 -26.4029	Fp. 52 144 70 91.33333	In Rp 3.951244 4.969813	std Rp 5 178 4461 35 36948 22 47962	0.69897 2.251507 1.548629 1.351789	S/N Rp -34 3468 -46 2288 -37 5846 -39 3845	Rt 105.6667 201.6667 128 157.3333	In Rt 4.560289 5.306616	std R1 17.50238 209.0223 44.91102 21.38535	1 243097 2 320193 1 652353 1 330116	5/N Rt -40 5575 -48 4383
45		Rq 19 26667 27 46667 20 43333 27 13333 26 66667 29 46667	In Rq 2.958376 3.312973 3.017168 3.300763 3.283414 3.38326	std Rq 3.527511 25.06199 5.378042 1.497776 2.800595 0.650641	1.181844 1.130334 1.416641 1.426511 1.469822 1.469822	5/N Rq -25.7921 -30.6935 -26.4029 -28.6789 -28.5512 -29.388	Rp 52 144 70 91.3333 74.66667 84.3333	3.951244 4.969813 4.248495 4.514516 4.313034 4.434777	std Rp 5 178 4461 35 36948 22 47962 10.59874 2 886751	logstd 0.69897 2.251507 1.548629 1.351789 1.025254 0.460409	S/N Rp -34 3468 -46 2288 -37 5846 -39 3845 -37,5205 -38 5234	Rt 105.6667 201.6667 128 157.3333 156.63333	In Rt 4.660289 5.306616 4.85203 5.058367 5.010635 5.113994	std Rt 17.50238 209.0223 44.91102 21.38535 16.46208 3.785939	log std Rt 1 243097 2 320193 1 652353 1 330116 1 216485 0 578174	S/N Rt -40 5575 -48 4383 -42 4868 -43 9896 -43 5566 -44 4211
45		Rq 19 26667 27 46667 20 43333 27 13333 26 66567 29 46667 22 36667	In Rq 2.958376 3.312973 3.017168 3.300763 3.283414 3.38326 3.107572	std Rq 3.527511 25.06199 5.378042 1.497776 2.800595 0.650641 6.185736	1.181844 1.130334 1.416641 1.426511 1.469822 1.469822 1.184691	-25.7921 -30.6935 -26.4029 -28.6789 -28.5512 -29.388 -27.208	8p 52 144 70 91,3333 74,66667 84,3333 788	In Rp 3.951244 4.969813 4.248495 4.514516 4.313034 4.434777 4.356709	std Rp 5 178 4461 35 36948 22 47962 10 59874 2 886751 33 18132	0 69897 2 251507 1 548629 1 351789 1 025254 0 460409 1 520894	S/N Rp -34 3468 -46 2288 -37 5846 -39 3845 -37,5205 -38 5234 -38,3366	Rt 105.6667 201.6567 128 157 3333 156.3333 136.3333	In Rt 4.660289 5.306616 4.85203 5.010635 5.010635 5.113994 4.915103	stg Rt 17.50238 209.0223 44.91102 21.38535 16.46208 3.785939 47.07795	1 243097 2 320193 1 652353 1 330116 1 216485 0 578174 1 672818	S/N Rt -40 5575 -48 4383 -42 4868 -43 9896 -43 5566 -44 4211 -43 0242
4:		Rq 19 26667 27 46667 20 43333 27 13333 26 66667 29 46667 22 36667 17 66667	In Rq 2.958376 3.312973 3.017168 3.300763 3.283414 3.38326 3.107572 2.87168	3.527511 25.06199 5.378042 1.497776 2.800595 0.650641 6.185736 3.652853	1.181844 1.130334 1.416641 1.426511 1.469822 1.469822 1.184691 1.330414	-25.7921 -30.6935 -26.4029 -28.6789 -28.5512 -29.388 -27.208 -25.0651	52 144 70 91.3333 74.66667 84.3333 78 552	3.951244 4.969813 4.248495 4.514516 4.313034 4.434777	5 178 4461 35 36948 22 47962 10 59874 2 886751 33 18132 7 81025	0 69897 2 251507 1 548629 1 351789 1 025254 0 460409 1 520894 0 892665	S/N Rp -34 3468 -46 2288 -37 5846 -39 3845 -37.5205 -38 5234 -38 3366 -34 3849	Rt 105.6667 201.6667 128 157.3333 156.3333 136.3333 101.6667	In Rt 4.660289 5.306616 4.85203 5.058367 5.010635 5.113994	std R1 17.50238 209.0223 44.91102 21.38535 16.46208 3.785939 47.07795 17.89786	1 243097 2 320193 1 652353 1 330116 1 216485 0 578174 1,672818 1 252801	S/N Rt -40 5575 -46 4383 -42 4868 -43 9896 -43 5566 -43 6242 -43 0242 -40 2324
93		Rq 19 26667 27 46667 20 43333 27 13333 27 13333 26 66667 29 46667 22 36667 17 66667 27 63333 39 03333	In Rq 2.958376 3.312973 3.017168 3.300763 3.283414 3.38326 3.107572 2.87168 3.319023 3.664416	std Rq 3.527511 25.06199 5.378042 1.497776 2.800595 0.650641 6.185736 3.652853 6.860272 3.435598	1.181844 1.130334 1.416641 1.426511 1.426511 1.469822 1.184691 1.330414 1.322219 1.568202	5/N Rq -25.7921 -30.6935 -26.4029 -28.6789 -28.5512 -29.388 -27.208 -27.208 -25.0651 -29.0035 -31.8511	Rp 52 144 70 91 33333 74 66667 84 33333 78 52 104 112 3333	In Rp 3.951244 4.969813 4.248495 4.514516 4.313034 4.434777 4.356709 3.951244 4.644391 4.721471	5178 4461 35.36948 22.47962 10.59874 2.886751 33.18132 7.81025 74.10128	logstd 0 69897 2 251507 1 548629 1 351789 1 025254 0 460409 1 520894 0 892665 1 869826 1 067301	S/N Rp -34 3468 -46 2288 -37 5846 -39 3845 -37 5205 -38 5234 -38 3366 -34 3849 -41,6067 -41,0413	Rt 105 6687 201 6667 128 157 3333 156 3333 101 666 3333 101 666 204 204 6667 204 6667	In Rt 4.660289 5.306616 4.85203 5.058367 5.010635 5.113994 4.915103 4.621699 5.31812 5.321383	std Rt 17.50238 209 0223 44.91102 21 38535 16.46208 3.785939 47.07795 17.69786 62.63776 34.07834	1 243097 2 320193 1 652353 1 330116 1 216485 0 578174 1 672818 1 252801 1 917179 1 532478	S/N Rt -40 5575 -48 4383 -42 4868 -43 9896 -43 5566 -44 4211 -43 0242 -40 2324 -46-6435 -46 3005
43.		Rq 19 26667 27 46667 20 43333 27 13333 26 66667 29 46667 22 36667 17 66667 27 63333 39 03333 47 16667	In Rq 2.958376 3.312973 3.017168 3.300763 3.283414 3.38326 3.107572 2.87168 3.319023 3.664416 3.853687	std Rq 3.527511 25.06199 5.378042 1.497776 2.800595 0.650641 6.185736 3.652853 3.652853 3.435598 14.37231	1.181844 1.181844 1.130334 1.416641 1.426511 1.469822 1.184691 1.330414 1.322219 1.568202 1.737193	5/N Rq -25.7921 -30.6935 -26.4029 -28.6789 -28.5512 -29.388 -27.208 -25.0651 -29.0035 -31.8511 -33.7335	Rp 52 144 770 91 3333 74 66667 84 33333 112 3333 116 3333	In Rp 3.951244 4.969813 4.248495 4.514516 4.313034 4.334777 4.356709 3.951244 4.644391 4.721471 4.75646	5178 4461 35 36948 22 47962 10 59874 2 886751 33 18132 7 8 1025 74 10128 11 67619 37 58102	logstd 0 69897 2 251507 1.548629 1.351789 1 025254 0 460409 1.520894 0 892665 1 869826 1 067301 1.574969	S/N Rp -34 3468 -46 2288 -37 5846 -39 3845 -37 5205 -38 5234 -38 3366 -34 3849 -41 0667 -41 0413 -41 6062	Rt 105.6867 201.6667 172 157.3333 156.3333 101.6667 204.6667 204.6667 212.6667 212.6667	In Rt 4.660269 5.306616 4.85203 5.058367 5.010635 5.113994 4.915103 4.621699 5.321383 5.321383 5.359726	std Rt 17,50238 209,0223 44,91102 21,38535 16,46208 3,785939 47,07795 17,69786 82,63776 34,07834 40,45162	1 243097 2 320193 1 652353 1 330116 1 216485 0 578174 1,672818 1 252801 1 917179 1 532476 1 606936	S/N Rt -40 5575 -48 4383 -42 4868 -43 9896 -43 5566 -44 4211 -43 0242 -40 2324 -46 6435 -46 3005 -46 6575
43		Rq 19 26667 27 46667 20 43333 27 13333 26 66667 29 46667 17 66667 17 66667 27 63333 39 03333 47 16667 53 96667	In Rq 2.958376 3.312973 3.017168 3.300763 3.283414 3.38326 3.107572 2.87168 3.319023 3.664416	std Rq 3.527511 25.06199 5.378042 1.497776 2.800595 0.650641 6.185736 3.652853 6.860272 3.435598 14.37231 4.921721	log std Rq 1.181844 1.130334 1.416641 1.426511 1.469822 1.184691 1.330414 1.322219 1.568202 1.737193 1.773055	5/N Rq -25 7921 -30 6935 -26 4029 -28 6789 -28 5512 -29 388 -27 208 -25 0651 -29 0035 -31 8511 -33 7335 -34 8665	Rp 52 144 70 91.33333 74.66667 84.33333 78 52 104 112.3333 116.3333 116.3333	In Rp. 3.951244 4.969813 4.248495 4.514516 4.313034 4.434777 4.356709 3.951244 4.644391 4.721471	std Rp 5 178 4461 35 36948 22 47962 10.59874 2 886751 33 18132 7 81025 74 10128 11 67619 37 58102 14 73092	logstd 0 69897 2 251507 1 548629 1 351789 1 025254 0 460409 1 520894 0 892665 1 869826 1 869826 1 1 667301 1 574969	SIN Rp -34 3468 -46 2288 -37 5846 -39 3845 -37.5205 -38 5234 -38 3366 -34 3849 -41.0413 -41.0462 -43.0768	Rt 105.6667 201.6667 128 157.3333 136.3333 130.6667 224.6667 212.6667 212.6667 237.6667 237.6667	In Rt 4.660289 5.306616 4.85203 5.058367 5.010635 5.113994 4.915103 4.621699 5.31812 5.321383	stg Rt 17.50238 209.0223 44.91102 21.38535 16.46208 3.785939 47.07795 17.69786 82.63776 34.07834 00.7834 00.7834 00.7834	1 243097 2 320193 1 652353 1 330116 1 216485 0 578174 1 672818 1 252801 1 917179 1 532478 1 606936 1 368331	\$#N Rt 40 5575 48 4383 42 4868 43 9896 43 5566 44 4211 43 0242 40 2324 46-6435 46 6575 47 5472
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		Rq 19 26667 27 46567 20 43333 26 66567 29 46667 27 63333 39 03333 47 16667 27 63333 20 76667 20 83333 22 76667 766 16 13333	In Rq 2.958376 3.012973 3.017168 3.300763 3.283414 3.38326 3.107572 2.87168 3.319023 3.664416 3.853687 3.036554 3.125297 2.028148 2.780888	std Rq 3.527511 25.06199 5.378042 1.497776 2.800594 6.185736 3.652853 6.850841 6.185736 3.435598 14.37231 14.37231 18.64688 0.953939 2.064784	log std Rq 1.181844 1.30334 1.416641 1.426511 1.469622 1.84691 1.330414 1.322219 1.586202 1.737193 1.773055 1.113943 1.082785 0.875061	5/N Rq -25 7921 -30 6935 -26 4029 -28 6789 -28 5512 -29 388 -27 208 -27 208 -29 0035 -31 8511 -33 7335 -34 6665 -26 7412 -28 7516 -17 6616 -17 6616 -24 2016	Rp 52 144 70 91 33333 74 66667 84 33333 116 3333 116 3333 138 3333 24 5 59	In Rp 3.951244 4.959813 4.268495 4.514516 4.313034 4.35477 4.356709 3.951244 4.75447 4.75646 4.955827 4.099885 4.099885 4.099885 4.099885 4.099887	std Rp 5 178 4461 35 36948 22 47982 10.59874 2.886751 33.18132 7.81025 74.10128 11.67619 37.58102 14.73092 16.04161 174.6492 20.07486	logstd 0.69897 2.251507 1.548629 1.351789 1.025254 0.692065 1.520894 0.892665 1.669301 1.74969 1.16823 1.205248 2.242167 0.845098	S/N Rp -34 3468 46 2288 -37 5846 -37 5846 -37 5205 -38 5234 -38 3358 -41 6067 -41 0413 -41 6062 -43 0768 -35 8111 -45 9628 -37 5438 -35 7388 -35 7388	Rt 105.6667 201.6667 128 157.3333 15.5 15.5 16.5 3333 10.6667 204.6667 212.6667 212.6667 214.6667 115 224.6667 69.3333	in Rt 4.680(28) 5.306616 4.85(20) 5.006315 5.010635 5.113994 4.915103 4.621699 5.21833 5.3591726 5.21833 5.3591726 3.740839 4.744932 5.411646 3.905334	std Rt 17.50238 209.0223 44.91102 21.38535 16.46208 3.785393 47.07795 17.89786 82.63776 34.07834 40.45162 23.35237 33.371943 251.2449 11.37248 27.27244	1 243097 2 320193 1 652353 1 330116 1 216485 0 576174 1,672816 1 252801 1 917179 1 532476 1 606936 1 368331 1 52788 2 400097 1 055855	\$\text{SN Rt}\$ 40.5575 48.4383 42.4866 43.9896 44.4211 43.0254 40.2324 46.6435 46.3005 46.6501 47.5472 41.456 49.6501 34.0705 34.0705 39.9000
		Rq 19 26667 27 46567 27 46567 20 43333 27 13333 26 66667 29 46667 27 63333 39 03333 47 16667 53 96667 20 83333 22 76667 7 6 16 13333 17 26667	In Rq 2.958376 3.312973 3.00763 3.203414 3.38326 3.107572 2.87168 3.319023 3.654416 3.85367 3.036554 3.195297 2.028148 2.760888 3.378725 2.848778	std Rq 3 527511 25 06199 5 378042 1 497776 2 80059 0,650641 6 .185736 3 .652853 6 860272 3 .435598 14 37231 4 921721 7 .5855932 18.64868 0 953393 2 .064784 25 41069 7 050059	log std Rq 1.181844 1.30341 1.416641 1.426511 1.469822 1.184691 1.302414 1.302419 1.588202 1.737193 1.773055 1.113943 0.875061 1.167317 1.033424 1.3033424	S/N Rq -25 7921 -30 6935 -26 4029 -28 6789 -28 5512 -29 3938 -27 208 -27 208 -27 208 -27 31 8511 -33 7335 -34 6665 -26 7412 -28 7516 -17 6616 -24 2016 -31 109 -25 2019	Rp 52 144 70 91.3333 74.66667 84.33333 110.3333 110.3333 142.3333 138.3333 1438.3333 24 55 53.66667	In Rp 3.951244 4.969813 4.248495 4.514516 4.313034 4.434777 4.356709 3.951244 4.721471 4.7546 4.955827 4.099885 4.929666 3.178054 4.077537 5.023881	std Rp 5 178 4461 55 36948 22 47962 10.59874 2866751 33.18132 7 81025 74.10128 11.67619 37 58102 14.73092 16.04161 174 6492 7 20.07486	logstd 0 69697 2 551507 1 548629 1 351789 1 025254 0 .892656 1 087301 1 574969 1 1,68233 1 205248 2 242167 0 845098 1 302653 2 231252	S/N Rp -34 3468 -46 2288 -37 5846 -39 3845 -37,5205 -38,3368 -34,3849 -41,6062 -41,0413 -41,6062 -43,0768 -35,8111 -45,9628 -36,7399 -46,278 -35,3813	Rt 105 6867 201 6667 122 157 3333 156 3333 136 3333 136 335 244 6866 124 4866667 151 151 151 151 151 151 151 151 151 15	In Rt 4.660298 4.650293 5.0563967 5.5016635 5.113994 4.915103 4.621699 5.31612 5.321383 5.359726 5.4704699 4.744932 5.411846 3.905334 4.567814 5.499897	std RI 17.50238 209.0223 44 91102 21 38535 16.46208 3.785939 47.07795 17.69786 62.63776 34.07834 40.45162 23.35237 33.71943 251.2449 11.37248 27.22744 253.2594 58.07753	1 243097 2 320193 1 652353 1 652353 1 330116 1 216485 0 578174 1,672818 1 252801 1 917179 1 532478 1 606936 1 368331 1 52788 2 400097 1 055855 1 435007 2 403566	9/N Rt 40 5575 46 4383 42 4866 43 9896 43 9896 44 4211 43 0242 40 2324 46 4305 46 3005 46 6575 47 5472 41 456 49 6501 39 9009 50 1124 41 3655
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		Rq 19 26667 27 46667 27 46667 27 46667 28 46667 29 46667 22 36667 27 36667 28 6667 29 6667 20 83333 27 16667 26 13333 29 76667 20 33333 21 76667 22 234 76667	In Rq 2,958376 3,312973 3,017168 3,300763 3,300763 3,303767 2,87164 3,38326 3,107572 2,87168 3,319023 3,664416 3,853687 3,988367 3,988367 2,028148 2,780888 3,10252 2,848778 3,030554 3,030554 3,030554 3,030554 3,030554 3,030554 3,030554 3,030554 3,030554	std Rq 3 527511 25 06199 5 378042 1 497776 2 800595 0 650641 6,185736 3,435598 14,37231 4,921721 7,565932 14,87231 2,04784 22,541069 7 050059 7 050059 9,011844	log std Rq 1.181844 1.130334 1.436511 1.426511 1.426512 1.69822 1.68822 1.68822 1.737193 1.7737193	S/N Rq -25 7921 -30 6935 -26 4029 -28 6789 -28 5512 -29 308 -27 208 -29 0035 -31 8511 -31 6665 -26 7412 -28 7516 -17 6616 -24 2016 -31 1099 -25 2019 -26 958 -31 0136	Rp 52 144 70 91 33333 74 66667 84 33333 78 652 104 112 3333 116 33333 138 33333 24 59 152 53 66667 64 216 3333	n Rp 3.951243 4.969813 4.248495 4.514516 4.313034 4.434777 4.356709 3.951247 4.75466 4.955827 4.099885 3.178054 4.077537 5.023881 3.982792 4.158883 5.386279	std Rp 5 178 4461 35 36948 22 47962 10.59874 2 886751 33.18132 7 81025 74.10128 11 67619 37 58102 14.73092 16.04161 174 6492 7 20.07486 170.3174 29.29733 3	logstd 0 69897 2 251507 1 548629 1.351789 1.025254 0.460409 1.520894 0.69265 1.667301 1.16823 1.205248 2.242167 0.845098 1.302653 2.231259 1.458628 0.477121	S/N Rp 34 3468 46 2288 37 5846 39 3845 37,5846 38,3368 34,3869 34,3669 41,0413 41,6067 41,0413 41,6067 42,0768 35,8111 45,9628 27,8438 35,7399 46,278 35,811 36,13 47,474	Rt 105.6867 201.6667 172 201.6667 172 201.6667 17333 195.333 196.3333 196.6667 204.6667 212.6667 212.6667 196.6667 197.333 244.6667 197.344,667 197.344,67 197.344,67 197.344,67 197.344,67 197.344,67 197.344,67 197.344,67 197.344,67 197.344,67 197.344,67 197.3	In Rt 4.660289 5.306616 4.85203 5.058367 5.010635 5.113994 4.915103 4.021699 5.31812 5.321833 5.359726 5.470869 4.744932 5.411646 3.905334 4.567814 5.459897 4.672829 4.736198 5.85698	std Rt 17,50238 209,0223 44,91102 21,38535 16,46208 3,785939 47,07795 17,69786 62,63776 34,07834 40,45162 23,35237 33,71943 251,2449 11,37246 27,22744 253,2594 58,07753 10,76167 11,07246 16,7753	1243097 2 320193 1 652353 1 330116 1 216485 0 578174 1.672818 1 252801 1 917179 1 532478 1 608936 1 368331 1 52788 2 400097 1 055855 1 435007 2 403566 7 64008	9/N Rt 40 5575, 48 4383, 42 4866, 43 9896, 43 5566, 44 4211, 43 0242, 40 2324, 46 4435, 46 8575, 47 5472, 41 456, 49 6501, 39 9009, 50 1124, 41 3665, 41 1893, 51 1893,
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		Rq	In Rq 2.958376 3.312973 3.017168 3.300763 3.283414 3.38326 3.107572 2.87768 3.319023 3.684416 3.986367 3.986367 3.986367 3.986367 3.986367 3.986367 3.986367 3.036554 3.03655	std Rq 3.527511 25.06199 5.378.042 1.497776 2.800595 0.650641 6.185736 3.652853 6.860272 3.435598 14.37231 4.921721 7.5655932 18.64868 0.953393 2.064784 25.41069 7.050059 0.011844 11.38083 3.559494 6.197849	log std Rq 1,181844 1,190334 1,416641 1,426511 1,469822 1,469822 1,469822 1,469822 1,320219 1,320219 1,320219 1,32031 1,32031 1,082785 1,113943 1,082785 1,113943 1,082785 1,113943 1,082785 1,113943 1,082785 1,113943 1,082785 1,113943 1,11394 1,113943 1,113943 1,113943 1,113943 1,113943 1,113943 1,113943 1,113943 1,113943 1,113943 1,113943 1,113943 1,113943 1,11394	5/N Rq -25 7921 -30 6935 -26 4029 -28 6789 -28 56789 -27 208 -25 0651 -29 0035 -31 8511 -37 7335 -34 6665 -24 2016 -31 109 -26 958 -31 0136 -27 4491 -30 3777 -37 2339	Rp 52 144 70 91.3333 74.66667 84.33333 78 52 104 112.3333 116.3333 124 60.33333 24 559 55.366667 64 218.3333 27,66667	In Rp 3.951244 4.969813 4.248495 4.514516 4.313034 4.434777 4.356709 3.551244 4.644391 4.7546 4.955827 4.05985 5.023891 3.178054 4.077537 5.023891 3.982792 4.15883 5.386023 4.276686 4.58156 5.241747	std Rp 178 4461 35 36948 22 47982 10.59874 2 886751 33 18132 74 10128 11 67619 37 58102 14,73092 16,04161 174 6492 720 07486 170 3174 29 29733 108 7949 53 11309 4 163332 98 77247	0 69897 2 251507 1 548629 1 351789 1 025254 0 480409 1 1520894 0 89265 1 869826 1 1067301 1 1623 1 1623 1 1623 2 242167 0 445098 1 302653 2 231259 1 46862 0 477121 2 036609 1 725202 0 619441 1 199463	S/N Rp -34 3468 -46 2288 -37 5846 -39 3845 -37 5826 -38 5324 -41 6067 -41 0413 -41 6062 -43 0768 -35 38134 -45 9628 -36 336 336 -37 399 -46 276 -38 4909 -39 8002 -46 2557	Rt 105.6887 201.6687 1728 157.3333 15.5333 136.3333 101.6867 204.6867 212.6867 237.6867 115 244.88667 109 114 349.6867 123.6867 123.6867 124.68667 123.6867	In Rt 4.6807289 5.306516 4.85203 5.058367 5.010635 5.113994 4.915103 4.621599 5.31812 5.321383 5.359726 5.470859 4.744932 5.411646 5.499897 4.74592 4.736198 5.85534 4.5567814 5.499897 4.5567815 5.599886 5.85598	std Rt 17.50238 209.0223 44.91102 21.38535 16.46208 3.78539 47.07795 17.89786 82.633776 34.07834 40.45162 23.35237 33.71943 253.2594 58.07753 10.078184 64.08527 7.81025 7.81025	1 243097 2 320193 1 652353 1 330116 1 216485 0.578174 1,672818 1 252801 1 917179 1 532478 1 608936 1 368331 1 52788 2 400097 1 055855 1 435007 2 403566 1 7764008 1 1224834 1 192472 0 892655	S/N Rt 40 5575 48 4383 42 4868 43 9896 44 35566 44 4321 40 2324 46 6435 46 3006 46 8575 47 5475 49 6501 39 9000 50 1124 41 1365 41 1603 51 1935 51 1935 51 1935 51 9026
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		Rq 119 26667 27 46667 20 43333 26 68667 22 36667 17 63633 39 03333 47 16667 7 6 13333 22 76667 16 13333 22 76667 17 26667 21 26667 21 66667 32 9 72 46667 32 9 72 46667 31 9 72 46667 32 9 73 9 72 46667 31 9 72 26333 31 15 23333 31 52 3333 31 52 3333	In Rq 2.958376 3.312973 3.017168 3.283414 3.38326 3.107572 2.87168 3.919023 3.664416 3.919023 3.664416 3.125297 2.028148 2.780883 3.78725 2.8848778 3.100992 3.76585 3.092556 2.80336 2.723486 3.092556 2.80336 2.723486 3.092556 2.80336 2.723486 3.092556 2.80336 2.723486 3.092556 2.80336	std Rq 3 527511 25 06199 5 378042 1 497776 2 800595 0,650641 6 185736 3,652853 6 860272 3,435598 14 37731 4,921721 7,565932 18,64888 0,953939 2,3 9,011844 11,38083 3,55944 6,197849 5,628665 7,97849 4,160529 4,1	log std Rq 1.181844 1.130334 1.416641 1.426511	5/N Rq -25 7921 -30 6935 -26 4029 -28 65192 -28 65512 -29 3988 -27 208 -25 2053 -31 8511 -34 8665 -26 7412 -28 7516 -17 6616 -31 109 -26 958 -31 1019 -26 958 -31 0136 -37 2323 -38 8543 -27 237 -24 4518 -26 4441 -27 44518 -28 5516 -27 42016 -28 5516 -29 52019 -29 52019 -20 520	Rp	In Rp 3 951244 4 969613 4 248495 4 313034 4 34877 4 356709 3 95124 4 4 344777 4 356709 3 95124 4 75646 4 95985 4 929666 3 178054 4 077537 5 023881 3 382792 4 158883 5 281747 4 30917 4 481118 4 153661 3 159061 5 189246 4 58156 5 241747 6 30917 6 4 38156 6 241747 6 30917 6 4 38156 6 241747 6 30917 6 4 38156 6 3 189246 6 4 58156 6 5 241747 6 3 189246 6 4 58156 6 5 241747 6 3 189246 6 5 189246 6 4 58156 6 5 241747 6 3 189246 6 4 58156 6 5 241747 6 3 189246 6 5 189246 6 4 58156 6 5 241747 6 3 189246 6 5 189246 6 4 58156 6 5 241747 6 5 189246 6 5 189	std Rp 5 178 4461 35 36948 22 47982 10.59874 21.59874 21.59874 21.67619 33.18132 78.1025 77.4 10128 77.4 10128 77.4 10128 77.4 10128 77.2007486 170.3174 20.07486 170.3174 20.07486 31.309 4.163332 98.77247 31.19295 63.79316 11.01514 11.7745 11.7745 120.1764 23.89561 120.1764 23.89561 26.2742 25.82413	legatd 0.69897 2.251507 1.548629 1.548629 1.52084 0.892665 1.667301 1.574869 1.16823 1.16823 1.205246 2.242187 0.845098 1.16823 2.231259 1.16823 1.468628 0.477121 2.036609 1.75202 0.619441 1.51598 2.24187 1.29418	S/N Rp -34.3468 -46.2288 -37.5846 -37.5205 -38.3368 -34.3849 -41.6067 -41.0413 -41.6062 -43.0768 -35.7399 -46.278 -36.33	Rt 105.6867 201.6667 122 157.3333 156.3333 101.6667 2204.6667 237.6867 115 224.46667 116 244.6667 123.6867 123.6867 123.6867 123.6867 123.6867 123.6867 124.6867 124.68687 125.6867 126.6867 127.6867 127.6867 128.6867 129.6867 149.6867 149.6867 149.6867	In Rt 4.6807289 5.306616 4.85203 5.058367 5.010635 5.113994 4.915103 4.621699 5.31912 5.32183 5.359126 5.470869 4.744932 5.411646 3.90534 4.652761 4.56296 5.85698 4.81759 5.009886 5.821072 5.162686 5.821072 5.162686 5.921072 5.162686 5.921072 5.162686 5.921072 5.162686 5.921072 5.162686 5.921072 5.162686 5.921072 5.162686 5.921072 5.008681 5.921072 5.008681	std R1 17.50238 209.0223 44.91102 21.38535 16.46208 3.785399 47.07795 34.07834 40.45162 23.35237 34.07834 251.2440 11.37248 257.22744 253.2594 58.07753 17.80233 299.885557 122.7694 41.25934 98.89557 12.27694 41.25934 98.89557 12.27694 41.25934 98.89557 12.27694 41.25934 98.89557 12.27694 41.25934 98.89557 12.27694 41.25934 98.89557 12.27694 41.25934 98.89557 12.27694 41.25934 98.89557 12.27694 12.27694 12.27694 12.27694 13.27694 13.27694 14.25934 15.27694 15.27694 16.50374 16	log std Rt. 1 243097 2 320193 1 652353 1 652353 1 330116 1 216485 0 578174 1,672818 1 252801 1 917179 1 532478 1 606936 1 368331 1 362838 2 400097 1 055855 1 435007 2 403566 1 764008 1 72472 0 89265 1 764008 1 615522 1 989517 1 495002 1 417009 1 417009 1 615522 1 989517 1 49602 1 417009 1 4	S/N Rt 40 5575 48 4383 42 4856 43 9896 43 5586 44 4211 46-6435 46-6435 47 5472 47 5472 41 456 49 6551 39 9059 41 1603 50 1124 41 3655 41 1603 51 1935 43 9116 44 9651 41 9656 41 1936 39 9752 41 9866 44 8641 41 9866 44 8641 41 9858 43 9458 43 9458 44 8641 41 9858 43 9458 44 9448 43 9448 44 9448 44 9448 44 9448 44 9448
		Rq 19 26667 27 46667 20 43333 26 66667 29 46667 17 66667 17 66667 20 3333 39 03333 47 7 16667 20 83333 20 3333 17 26667 22 26667 22 26667 22 26667 22 26667 22 26667 23 29 24 76667 22 26667 24 66667 25 26 26 26 26 26 26 26 26 26 26 26 26 26	In Rq 2.958376 3.312973 3.017168 3.302763 3.283414 3.38326 3.107572 2.87168 3.389237 3.8684416 3.385267 3.986367	std Rq 3 527511 25 06 199 5 378042 1 497776 2 800595 0 .850841 6 .185736 3 .455285 6 860772 3 .435598 14 .37231 4 .921721 7 .565932 18 .64868 0 953939 7 050059 3 0.01844 1138083 3 559494 6 197849 5 828685 7 957596 3 148015 4 65009 14 17021 4 915282 17 3208 11 17721 4 915282 7 264296	1,181844 1,18054 1,180641 1,130334 1,416641 1,426511 1,426511 1,426511 1,426511 1,322219 1,588202 1,737193 1,77793 1,77793 1,77793 1,77793 1,77793 1,77793 1,77793 1,167317 1,03342 1,167317 1,3654 1,37819 1,465383 1,46538 1,465	25 7921 30 6935 26 4029 28 6789 28 5512 29 938 25 0651 27 208 31 8511 31 8511 31 8665 26 7412 28 7516 17 6616 24 2016 31 1036 27 24 2016 32 20 3777 30 3777 30 3777 31 2239 32 8543 32 4528 31 058 25 26 4348 31 058 25 26 4348 31 058 22 2217 24 25 2019 32 25 2019 31 30 3777 32 25 2019 32 25 2019 32 25 2019 32 25 2019 33 25 25 26 27 4491 34 25 26 27 4491 35 26 25 26 27 4491 36 27 4491 37 22 23 27 24 25 28 29 21 27 28 29 21 27 28 29 21 27 28 29 21 27 28 29 21 21 21 21 21 21 21 21 21 21 21 21 21	Rp	In Rp 3.951244 4.969813 4.28495 4.514516 4.313034 4.434777 4.55666 4.955827 4.079885 4.76266 4.955827 4.079587 5.023881 3.982792 4.07537 5.023881 3.982792 4.158883 5.386023 4.76666 4.58156 5.241747 4.40817 4.48118 4.153651 3.850148 4.174397 5.189246 4.158893 5.189246 4.587269	std Rp 5178 4461 35 36948 22 47982 10.59874 2 886751 33,18132 7 8 1025 7 4 10128 11 67619 37 58102 14,73092 16,04161 174 6492 7 20 07486 170 3174 29 29733 108 7849 53 11309 4 163332 898 77247 31 19295 63 79916 11,01514 1774 130,1704 23 89561 130,1704 25 82413 47,12041	legatd 0 69897 2 251507 1 548629 1 025254 0 460409 1 1520894 0 892665 1 067301 1 16823 1 205246 2 242167 0 845098 1 16823 2 231259 1 486826 0 677121 2 036609 1 14804 1 1994636 1 804815 1 04199 1 1378318 1 419529 1 178822	S/N Rp -34 3468 -46 2288 -37 5846 -37,5205 -38 5234 -38,5326 -34,3849 -41,6067 -41,0413 -41,6062 -42,0768 -35,8111 -47,4476 -35,8111 -36,134 -47,4476 -36,816	Rt 105.6667 201.6667 128 157.3333 155. 166.3333 136.3333 101.6667 204.66667 212.6667 212.6667 212.6667 115 224 49.66667 109.33333 244.66667 109.33333 174.3333 175.3333 174.3333 175.3333 176.3333 177.3333	In Rt 4.660289 5.306616 4.85203 5.068367 5.010635 5.01394 4.915103 4.921599 5.31812 5.321383 5.359726 5.470869 4.744932 5.411646 3.905334 4.567814 5.498997 4.672829 5.60969 5.45573 4.509697 4.7567989 5.60969 5.45573 4.50968	std R1 17,59238 209,0223 44,91102 21,38535 16,46208 3,785939 47,07795 34,07834 40,45162 23,35237 33,71943 251,2248 11,37248 27,22744 253,2594 58,07753 167,916,418 48,08557 7,81025 122,7694 41,25934 98,8557 31,2623 29,51271 22,11334 165,0374 75,79798 35,01908 88,11545	log std Rt 1 243097 2 320193 1 652353 3 30016 1 216485 0 578174 1,672818 1 252801 1 917179 1 532478 606936 1 368331 1 52788 2 400097 2 403566 1 764008 1 764008 1 7240097 1 92472 0 892655 2 08908 6 15522 1 995177 1 470009 1 3446504 2 217562 1 194652 2 1 194652 2 1 194652 2 1 194652 2 1 194652 2 1 194652 2 1 194652 2 1 194652	5/N Rt 40 5575 48 4383 42 4856 43 9566 44 421 40 2324 46 6375 46 3005 46 6575 47 5472 41 456 41 1860 50 1124 41 1860 51 1935 44 3034 50 9287 44 9034 44 6641 41 1935 44 304 50 9287 44 9666 44 6641 41 967 44 1957 44 1958 44 1967 44 1968 44 1967 44 1968 44 1968
		Rq 119 26667 27 46667 20 43333 26 66667 22 36667 22 36667 27 63333 39 03333 47 16667 26 3333 22 76667 26 16 13333 22 76667 21 66667 22 34 76667 21 21 66667 22 23 42 6667 21 6667 21 6667 21 22 23 43 6667 21 6667 22 23 45 6667 23 29 31 76667 24 25 32 77 25 26 77 25 26 77 25 26 77 25 26 77 25 26 77 25 27 26 77 26 77 27 28 77 27 28 77 28 77 28 77 28 77 28 77 28 77 28 77 29 77 29 77 20	In Rq 2.958376 3.312973 3.017168 3.283414 3.38326 3.107572 2.87168 3.919023 3.664416 3.919023 3.664416 3.125297 2.028148 2.780883 3.78725 2.8848778 3.100992 3.76585 3.092556 2.80336 2.723486 3.092556 2.80336 2.723486 3.092556 2.80336 2.723486 3.092556 2.80336 2.723486 3.092556 2.80336	std Rq 3 527511 25 06199 5 378042 1 497776 2 000595 0 ,650641 6 ,185736 3 .652853 6 860272 3 .435598 14 37231 4 921721 7,585932 18 ,64868 0 953939 2 3 4921721 7,585932 18 ,64868 0 953939 3 ,148015 4 6 197849 5 828865 7 957596 3 ,148015 4 65009 1 7 3208 1 1 17721 4 9 15282 7 7 264296 2 0 63104 3 1 9482	log stid Rq 1.181844 1.130334 1.416641 1.426511 1.469822 1.184691 1.330414 1.326219 1.568202 1.737193 1.773055 1.113943 1.082785 0.875061 1.13943 1.46533 1.40554 1.537819 1.46533 1.81844 1.235528 1.283301 1.283301 1.283301 1.283301 1.283301 1.283301 1.283301 1.283301 1.283301	25 7921 30 6935 26 4029 28 6789 28 6512 29 398 27 208 25 0651 29 398 27 208 31 8511 34 8665 26 7412 28 7516 17 6616 24 2016 31 109 26 958 31 1036 27 4491 30 3777 37 2239 32 8543 37 235 27 237 24 4518 27 228 28 538 29 2217 28 538 29 2217 28 738 28 538 28 31 31 31 31 31 31 31 31 31 31 31 31 3	Rp	In Rp 3 951244 4 969613 4 248495 4 313034 4 34877 4 356709 3 95124 4 4 344777 4 356709 3 95124 4 75646 4 95985 4 929666 3 178054 4 077537 5 023881 3 382792 4 158883 5 281747 4 30917 4 481118 4 153661 3 159061 5 189246 4 58156 5 241747 6 30917 6 4 38156 6 241747 6 30917 6 4 38156 6 241747 6 30917 6 4 38156 6 3 189246 6 4 58156 6 5 241747 6 3 189246 6 4 58156 6 5 241747 6 3 189246 6 5 189246 6 4 58156 6 5 241747 6 3 189246 6 4 58156 6 5 241747 6 3 189246 6 5 189246 6 4 58156 6 5 241747 6 3 189246 6 5 189246 6 4 58156 6 5 241747 6 5 189246 6 5 189	std Rp 5 178 4461 35 36948 22 47962 10.59674 21.69674 21	legatd 0 69897 2 251507 1 548629 1 025254 0 460409 1 1520894 0 892665 1 067301 1 16823 1 205246 2 242167 0 845098 1 16823 2 231259 1 486826 0 677121 2 036609 1 14804 1 1994636 1 804815 1 04199 1 1378318 1 419529 1 178822	S/N Rp -34 3468 -46 2288 -37 5846 -37,5205 -38 5234 -38,5326 -34,3849 -41,6067 -41,0413 -41,6062 -42,0768 -35,8111 -47,4476 -35,8111 -36,134 -47,4476 -36,816	Rt 105.6867 201.6667 1728 157.3333 156.3333 101.6667 204.6667 204.6667 212.6667 212.6667 115 224.6667 115 244.6667 107 114.33333 174.3333 174.3333 175.3333 172.33333 174.3333 175.3333 174.3333 175.3333 174.3333 175.3333 174.3333 175.3333 176.3333 177.3333	In Rt 4.6807289 5.306616 4.85203 5.058367 5.010635 5.113994 4.915103 4.621699 5.31912 5.32183 5.359126 5.470869 4.744932 5.411646 3.90534 4.652761 4.56296 5.85698 4.81759 5.009886 5.821072 5.162686 5.821072 5.162686 5.921072 5.162686 5.921072 5.162686 5.921072 5.162686 5.921072 5.162686 5.921072 5.162686 5.921072 5.162686 5.921072 5.008681 5.921072 5.008681	std R1 17.50238 209.0223 44.91102 21.38535 16.46208 3.785939 47.07795 17.89786 62.63776 34.07834 40.45162 23.35237 33.71943 251.2449 11.37248 42.53.2594 58.07753 10.167.8164 44.08527 7.81025 122.7694 41.25934 98.89557 12.2633 29.51271 22.11334 165.0374 75.79798 35.01904 88.11545 154.1817 57.68882	log std Rt	S/N Rt 40 5575 48 4383 42 4856 43 9896 43 5586 44 4211 46-6435 46-6435 47 5472 47 5472 41 456 49 6551 39 9059 41 1603 50 1124 41 3655 41 1603 51 1935 43 9116 44 9651 41 9656 41 1936 39 9752 41 9866 44 8641 41 9866 44 8641 41 9858 43 9458 43 9458 44 8641 41 9858 43 9458 44 9448 43 9448 44 9448 44 9448 44 9448 44 9448

Table 4.5 Cutting in X Direction

speed	feed	depth	Fmax	In speed	In feed	In depth	In Fmax	In Favg	stdev	logstdev	S/N Ratio	Favg
1500	0.001	0.001	64.11	7.31	-6.91	-6.91	4.16	2.93	8.933	0.950997	-26.355	18.78
3000	0.001	0.001	64.96	8.01	-6.91	-6.91	4.17	3.38	10.07	1.003029	-29.82	29.31
4500	0.001	0.001	80.22	8.41	-6.91	-6.91	4.38	3.55	14.06	1.147985	-31.44	34.65
1500	0.001	0.02	93.34	7.31	-6.91	-3.91	4.54	3.59	20.67	1.31534	-32.42	36.34
3000	0.001	0.02	177.01	8.01	-6.91	-3.91	5.18	4.10	26.41	1.421768	-36.36	60.34
4500	0.001	0.02	122.45	8.41	-6.91	-3.91	4.81	4.65	5.7	0.755875	-40.38	104.37
1500	0.001	0.05	71.6	7.31	-6.91	-3.00	4.27	3.36	8.15	0.911158	-29.49	28.71
3000	0.001	0.05	36.76	8.01	-6.91	-3.00	3.60	3.16	9.62	0.983175	-28.09	23.5
4500	0.001	0.05	23.36	8.41	-6.91	-3.00	3.15	2.69	2.13	0.32838	-23.46	14.75
1500	0.005	0.001	108.39	7.31	-5.30	-6.91	4.69	4.32	8.94	0.951338	-37.62	75.51
3000	0.005	0.001	138.46	8.01	-5.30	-6.91	4.93	4.33	16.6	1.220108	-37.84	76.22
4500	0.005	0.001	118.94	8.41	-5.30	-6.91	4.78	4.52	11.25	1.051153	-39.33	91.97
1500	0.005	0.02	84.46	7.31	-5.30	-3.91	4.44	3.67	16.81	1.225568	-32.6	39.31
3000	0.005	0.02	134.87	8.01	-5.30	-3.91	4.90	4.45	23.66	1.374015	-38.98	85.77
4500	0.005	0.02	149.6	8.41	-5.30	-3.91	5.01	4.71	8.82	0.945469	-40.96	111.5
1500	0.005	0.05	70.18	7.31	-5.30	-3.00	4.25	3.68	8.16	0.91169	-32.12	39.55
3000	0.005	0.05	68.57	8.01	-5.30	-3.00	4.23	3.31	13.89	1.142702	-29.76	27.49
4500	0.005	0.05	31.84	8.41	-5.30	-3.00	3.46	2.71	6.89	0.838219	-24.36	15.06
1500	0.01	0.001	110.92	7.31	-4.61	-6.91	4.71	4.34	8.61	0.935003	-37.71	76.38
3000	0.01	0.001	130.12	8.01	-4.61	-6.91	4.87	4.37	17.47	1.242293	-38.14	78.91
4500	0.01	0.001	109.57	8.41	-4.61	-6.91	4.70	4.55	9.88	0.994757	-39.6	95.01
1500	0.01	0.02	90.97	7.31	-4.61	-3.91	4.51	3.78	18.16	1.259116	-33.48	43.62
3000	0.01	0.02	129.25	8.01	-4.61	-3.91	4.86	4.46	24.07	1.381476	-39.08	86.77
4500	0.01	0.02	133.06	8.41	-4.61	-3.91	4.89	4.70	5.22	0.717671	-40.87	110.48
1500	0.01	0.05	71.45	7.31	-4.61	-3.00	4.27	3.71	8.67	0.938019	-32.45	41.04
3000	0.01	0.05	64.64	8.01	-4.61	-3.00	4.17	3.36	12.21	1.086716	-29.92	28.9
4500	0.01	0.05	43.47	8.41	-4.61	-3.00	3.77	2.63	7.95	0.900367	-24.04	13.85
1500	0.02	0.001	75.07	7.31	-3.91	-6.91	4.32	4.23	5.385	0.731186	-36.8	68.57
3000	0.02	0.001	95.45	8.01	-3.91	-6.91	4.56	4.33	16.09	1.206556	-37.8	75.98
4500	0.02	0.001	134.85	8.41	-3.91	-6.91	4.90	4.66	10.34	1.014521	-40.5	105.45
1500	0.02	0.02	61.22	7.31	-3.91	-3.91	4.11	3.74	22.06	1.343606	-33.55	42.23
3000	0.02	0.02	90.57	8.01	-3.91	-3.91	4.51	4.21	25.32	1.403464	-37.17	67.65
4500	0.02	0.02	129.39	8.41	-3.91	-3.91	4.86	4.57	8.2	0.913814	-39.7	96.33
1500	0.02	0.05	22.56	7.31	-3.91	-3.00	·	4	1.21	0.082785	A carry a cray analyter challenger	🚣
3000	0.02	0.05	22.81	8.01	-3.91	Control of the second second		<u> </u>	*· · · · · · · · · · · · · · · · · · ·	·		15.2
4500	0.02	0.05	60.84	8.41	-3.91	-3.00	E-17 1 1 1 1 1 1 1 1		9.97	0.998695	· Processor and a service of the ser	·

Table 4.6 Cutting in XY Direction

speed	feed	depth	Fmax	In speed	in feed	In depth	In Fmax	In Favg			S/N Ratio	
1500	0.001	0.001	92.31	7.31	-6.91	-6.91	4.53	3.46	13.39	1.13	-30.78	31.92
1500	0.001	0.02	118.08	7.31	-6.91	-3.91	4.77	3.60	19.46	1.29	-32.30	36.57
1500	0.001	0.05	58.85	7.31	-6.91	-3.00	4.07	3.44	7.05	0.85	-30.10	31.21
1500	0.005	0.001	111.44	7.31	-5.30	-6.91	4.71	4.26	9.22	0.96	-37.08	70.93
1500	0.005	0.02	107.603	7.31	-5.30	-3.91	4.68	3.62	16.67	1.22	-32.21	37.25
1500	0.005	0.05	82.58	7.31	-5.30	-3.00	4.41	3.64	7.71	0.89	-31.79	38.09
1500	0.01	0.001	112.99	7.31	-4.61	-6.91	4.73	4.36	7.32	0.86	-37.93	78.46
1500	0.01	0.02	137.62	7.31	-4.61	-3.91	4.92	3.83	19.07	1.28	-33.95	46.07
1500	0.01	0.05	95.8	7.31	-4.61	-3.00	4.56	3.63	12.23	1.09	-31.95	37.63
1500	0.02	0.001	81.42	7.31	-3.91	-6.91	4.40	4.28	5.61	0.75	-37.19	72.14
1500	0.02	0.02	119.88	7.31	-3.91	-3.91	4.79	3.80	27.54	1.44	-34.41	44.77
1500	0.02	0.05	31.14	7.31	-3.91	-3.00	3.44	2.98	5.79	0.76	-26.26	19.74
3000	0.001	0.001	84.19	8.01	-6.91	-6.91	4.43	3.59	15.74	1.20	-31.00	36.38
3000	0.001	0.02	105.59	8.01	-6.91	-3.91	4.66	4.11	25.28	1.40	-36.42	61.25
3000	0.001	0.05	64.18	8.01	-6.91	-3.00	4.16	3.18	12.00	1.08	-28.61	24.16
3000	0.005	0.001	137.26	8.01	-5.30	-6.91	4.92	4.26	17.77	1.25	-31.98	70.85
3000	0.005	0.02	143.67	8.01	-5.30	-3.91	4.97	4.36	25.03	1.40	-38.28	78.22
3000	0.005	0.05	76.26	8.01	-5.30	-3.00	4.33	3.21	15.60	1.19	-29.31	24.75
3000	0.01	0.001	126.67	8.01	-4.61	-6.91	4.84	4.39	17.32	1.24	-38.32	80.59
3000	0.01	0.02	173.81	8.01	-4.61	-3.91	5.16	4.48	24,21	1.38	-39.20	87.97
3000	0.01	0.05	73.91	8.01	-4.61	-3.00	4.30	3.48	14.50	1.16	-30.98	32.33
3000	0.02	0.001	99.39	8.01	-3.91	-6.91	4.60	4.31	16.55	1.22	-37.68	74.76
3000	0.02	0.02	89.81	8.01	-3.91	-3.91	4.50	4.16	23.05	1.36	-36.66	64.07
3000	0.02	0.05	20.37	8.01	-3.91	-3.00	3.01	2.81	2.17	0.34	-24.52	16.69
4500	0.001	0.001	68.69	8.41	-6.91	-6.91	4.23	3.77	15.07	1.18	-33.22	43.28
4500	0.001	0.02	115.23	8.41	-6.91	-3.91	4.75	4.66	5.37	0.73	-40.46	105.39
4500	0.001	0.05	62.49	8.41	-6.91	-3.00	4.14	2.78	8.69	0.94	-25.26	16.176
4500	0.005	0.001	121.475	8.41	-5.30	-6.91	4.80	4.40	15.16	1.18	-38.37	81.55
4500	0.005	0.02	150.67	8.41	-5.30	-3.91	5.02	4.72	9.49	0.98	-40.98	111.68
4500	0.005	0.05	66.61	8.41	-5.30	-3.00	4.20	2.80	12.13	1.08	-26.21	16.52
4500	0.01	0.001	132.22	8.41	-4.61	-6.91	4.88	4.62	11.24	1.05	-40.16	101.33
4500	0.01	0.02	152.01	8.41	-4.61	-3.91	5.02	4.75	8.82	0.95	-41.28	115.69
4500	0.01	0.05	53.88	8.41	-4.61	-3.00	3.99	2.88	13.05	1.12	-26.87	17.8
4500	0.02	0.001	126.12	8.41	-3.91	-6.91	4.84	4.67	10.31	1.01	-40.59	106.55
4500	0.02	0.02	141.03	8.41	-3.91	-3.91	4.95	4.74	8.50	0.93	-41.22	114.88
4500		0.05	61.28	8.41	-3.91	-3.00	4.12	3.21	13.94	1.14	-28.91	24.76

Table 4.7 Cutting in Y Direction

speed	feed		Fmax	In speed	In feed	In depth	In Fmax	In Favg	stdev	logstdev	S/N Ratio	Favg
1500	0.001	0.001	111.37	7.31	-6.91	-6.91	4.71	4.01	13.76	1.138618	-35.12	55.38
3000	0.001	0.001	121.19	8.01	-6.91	-6.91	4.80	3.93	18.76	1.273233	-34.65	50.7
4500	0.001	0.001	77.83	8.41	-6.91	-6.91	4.35	4.00	14.12	1.149835	-35.01	54.54
1500	0.001	0.02	114.34	7.31	-6.91	-3.91	4.74	3.61	22.17	1.345766	-32.66	36.83
3000	0.001	0.02	138.34	8.01	-6.91	-3.91	4.93	4.30	27.66	1.441852	-37.9	73.61
4500	0.001	0.02		8.41	-6.91	-3.91	4.71	4.63	4.88	0.68842	-40.24	102.78
1500	0.001	0.05	75.14	7.31	-6.91	-3.00	4.32	3.60	8.33	0.920645	-31.51	36.74
3000	0.001	0.05	69.32	8.01	-6.91	-3.00	4.24	3.18	14.59	1.164055	-28.96	24.021
4500	0.001	0.05	60.27	8.41	-6.91	-3.00	4.10	2.77	7.58	0.879669	-24.91	15.93
1500	0.005	0.001	114.38	7.31	-5.30	-6.91	4.74	4.18	11.73	1.069298	-36.47	65.58
3000	0.005	0.001	121.8	8.01	-5.30	-6.91	4.80	4.13	17.99	1.255031	-36.18	61.95
4500	0.005	0.001	115.51	8.41	-5.30	-6.91	4.75	4.23	18.83	1.27485	-37.08	69
1500	0.005	0.02	109.26	7.31	-5.30	-3.91	4.69	3.72	25.54	1.407221	-33.71	41.24
3000	0.005	0.02	144.33	8.01	-5.30	-3.91	4.97	4.35	26.86	1.429106	-38.28	77.58
4500	0.005	0.02	141.9	8.41	-5.30	-3.91	4.96	4.68	9.01	0.954725	-40.68	107.83
1500	0.005	0.05	79.46	7.31	-5.30	-3.00	4.38	3.62	9.77	0.989895	-31.76	37.49
3000	0.005	0.05	80.31	8.01	-5.30	-3.00	4.39	3.25	17.4	1.240549	-29.82	25.68
4500	0.005	0.05	60.77	8.41	-5.30	-3.00	4.11	2.70	11.5	1.060698	-25.47	14.92
1500	0.01	0.001	106.35	7.31		-6.91	4.67	4.38	6.936	0.841109	-38.05	79.6
3000	0.01	0.001	114.23	8.01	-4.61	-6.91	4.74	4.41	16.98	1.229938	-38.46	82.1
4500	0.01	0.001	126.05	8.41	-4.61	-6.91	4.84	4.64	10.73	1.0306	-40.36	103.715
1500	0.01	0.02	61.59	7.31	-4.61	-3.91	4.12	3.51	18.65	1.270679	-31.68	33.6
3000	0.01	0.02	160.15	8.01	-4.61	-3.91	5.08	4.21	27.99	1.447003	-37.22	67.12
4500	0.01	0.02	131.83	8.41	-4.61	-3.91	4.88	4.76	6.25	0.79588	-41.36	116.805
1500	0.01	0.05	123.13	7.31	-4.61	-3.00	4.81	2.99	13.68	1.136086	-27.67	19.97
3000	0.01	0.05	90.98	8.01	-4.61	-3.00	4.51	3.47	17.92	1.253338	-31.32	32.21
4500	0.01	0.05	55.34	8.41	-4.61	-3.00	4.01	3.09	13.8	1.139879	-28.23	21.89
1500	0.02	0.001	83.53	7.31	-3.91	-6.91	4.43	4.34	5.83	0.765669	-37.7	76.59
3000	0.02	0.001	116.68	8.01	-3.91	-6.91	4.76	4.37	18.95	1.277609	-38.23	79.43
4500	0.02	0.001	130.49	8.41	-3.91	-6.91	4.87	4.64	11.19	1.04883	-40.34	103.43
1500	0.02	0.02	119.94	7.31	-3.91	-3.91	4.79	3.61	19.58	1.291813	-32.42	
3000	0.02	0.02	76.79	8.01	-3.91	-3.91	4.34	4.07	22.04	1.343212	-35.91	58.52
4500	0.02	0.02	142.28	8.41	-3.91	-3.91	4.96		7.04	0.847573	and the same of th	ani antara da mangana antara da manana antara da manana da manana da manana da manana da manana da manana da m
1500	0.02	0.05	29.62	7.31	-3.91	-3.00	3.39	3.00	5.28	0.722634	-26.36	· · · · · · · · · · · · · · · · · · ·
3000	0.02	0.05	24.08	8.01	-3.91	-3.00			4 - mar	0.568202	-25.47	•
4500	0.02	0.05		8.41	-3.91	-3.00		· · · · · · · · · · · · · · · · · · ·	10.28	1.011993		

4.5 Multiple Linear Regression Analysis

After all the data was consolidated and organized there was one value for a particular combination for speed, feed and depth of cut as can be observed from the tables showing the data. Now, It was required to convert these values into models which would have equations giving us the empirical releion between the operating parameters. For this purpose the Linear regression Software was chosen. This software has been written in QBASIC. It can take any number of dependent and independent variables and then on running the program the output comes in the form of equation giving the relation between the dependent and the independent variable. It also performs the ANOVA test and gives the Correlation coefficient. These values for cutting in all three directions were fed to the Qbasic program and the program was run.

As an eg. consider the Rku value for cutting in the X direction. The program asks for the number of dependent and independent variables first. For all the calculations the number of dependent variables is 1 and the number of independent variables is 3. In this example the dependent variable is the Rku value. For ease of developing the model the Ln values for each of the parameters were calculated and then they were fed into the software. After the dependent variable it asks for the independent variable. The independent variables are the three operating parameters of speed, feed and depth of cut. then it asks for the number of experiments. In all the calculations the number of experiments are 36 as there are 36 values for cutting in each direction. Then the sofware one by one asks for each of these values for the dependent and

with the Regression equation and also performs all the ANOVA tests and correlation coefficients.

The final equations for cutting in all the three directions are shown below.

Thus a model was developed for cutting in each of the three directions.

4.6 Results of the MultiLinear Regression Software Analysis Regression Equations for Cutting in X Direction

- 1) In Rku = (0.136077) * In speed + (-0.1330632) * In feed + (1.213256E-02) * In depth + (-0.4251051).
- 2) In Ra = (-0.2062035) * In speed + (0.2404485) * In feed + (1.6167E-02) * In depth + 6.016497
- 3) In Rq = (-0.17784) * In speed + (0.2054301) * In feed + (1.873142E-02) * In depth + 5.87079
- 4) In Rp = (-4.876471E-02) * In speed + (0.1021114) * In feed + (-3.2936E-02) * In depth + 5.527573
- 5) In Rt = (-0.0680707) * In speed + (8.135596E-02) * In feed + (-1.5319E-03) * In depth + (-0.4251051).
- 6) In Fmax = (0.1186844) * In speed + (7.133371E-03) * In feed + (-0.1441128) * In depth + 2.804687
- 7) In Favg = (0.1781353) * In speed + (-0.1317902) * In feed + (-0.1881687) * In depth + (-0.4251051).

4.7 Regression Equations for Cutting in XY Direction

- 1) In Rku = (-0.1261514) * In speed + (-0.1423992) * In feed + (-5.987179E-04) * In depth + 1.514614
- 2) In Ra = (-0.1716371) * In speed + (0.2690618) * In feed + (2.824453E-03) * In depth + 5.851625
- 3) In Rq = (-0.2058754) * In speed + (0.2282762) * In feed + (1.639987E-02) * In depth + 6.220438
- 4) In Rp = (-0.3946911) * In speed + (3.852698E-02) * In feed + (-4.633745E-02) * In depth + 7.929195
- 5) In Rt = (-0.3712539) * In speed + (6.579253E-02) * In feed + (-1.701049E-02) * In depth + 8.563513
- 6) In Fmax = (5.9946E-02) * In speed + (6.914892E-04) * In feed + (-9.943058E-02) * In depth + 3.585588
- 7) In Favg = (0.2276881) * In speed + (0.1099545) * In feed + (-0.1939957) * In depth + (1.742931).

4.8 Regression Equations for Cutting in Y Direction

- 1) In Rku = (1.138669E-02) * In speed + (-0.1745235) * In feed + (4.151705E-02) * In depth + 0.4749272
- 2) In Ra = (-5.948769E-03) * In speed + (0.3370222) * In feed + (8.871399E-03) * In depth + 4.873497
- 3) In Rq = (1.213428E-02) * In speed + (0.2893321) * In feed + (2.253844E-02) * In depth + 4.811023

- 4) In Rp = (6.484896E-02) * In speed + (0.1049619) * In feed + (0.0548048) * In depth + 5.093226
- 5) In Rt = (0.1523802) * In speed + (0.1158374) * In feed + (7.026348E-02) * In depth + 5.097253
- 6) In Fmax = (0.0577496) * In speed + (-5.724295E-02) * In feed + (-0.1086182) * In depth + 3.273687
- 7) In Favg = (0.2608871) * In speed + (3.964887E-02) * In feed + (-0.2237481) * In depth + 0.9777973

The above equations give the relationship between the various Surface Quality parameters, Cutting Forces and the operating parameters of speed, feed and depth of cut. Thus, by plugging in numbers it is now possible to predict the Surface Quality and the Cutting force before the actual machining could be carried out. This gives the operator an idea as to what the Surface Finish could be after the machining would be done. Due to this, the operator could actually be able to select before hand the almost accurate speed, feed and depth of cut that he would need to obtain the desired surface finish. Thus, the Multiple Regression Analysis Software was used to develop these models.

4.9 Table Curve Software

The table Curve Software was used to develop the relation between the Surface Quality parameters and the Cutting force parameters. This software is much more sophisticated than the Multiple Linear Regression Software. This software has been developed by Jindel Scientific. The working of this software was

described in bried in the earlier chapter. In this software there is a FILE Menu which enables us to import data from excel or Lotus spreadsheet into the software. The data that was consolidated was saved on excel spreadsheet and the columns which had this data were saved onto a clipboard. This clipboard was imported from the excel spreadsheet into the Jandel Scientific Table Curve Software. After the import was carried out, the processing of the data was done by selecting the process menu. the best fit curve was selected. This software gives the output of only 2 different parameters, one is the dependent and the other is the independent. The interest of the research was to develop a relation between the Surface Quality parameter and the Cutting force parameter. Here. the Surface texture parameter was highlighted as the X value and the cutting force as the Y. The equation was in the form of $Y = constant \times X$, thus giving the relation between the Surface Quality parameter and the Cutting force parameter. In this research work there are 5 Surface Texture parameters, the maximum cutting force and the avg. cutting force. Hence, this software gave 10 graphs taking into consideration all the combinations. Since there are 3 directions of cutting, it gave these 10 graphs for each of the three directions, thus resulting into 30 graphs, which took care of all the combinations.

Plottings in figures 4.1, 4.2, 4.3, 4.4 are some of the core graphs which give the relationship between the cutting force and the surface quality parameters. The remaining graphs are attached in the appendix.

Cutting in X Direction

Rank 1 Eqn 8005 $y=a+bexp(-0.5(ln(x/c)/d)^2)$ [Log-Normal]

 $r^2 = 0.624464705 \;\; \text{DF Adj} \; r^2 = 0.576008538 \;\; \text{FitStdErr} = 77.9327765 \;\; \text{Fstat} = 17.7372326$

a=199.24202 b=6334.9412

c=100.02607 d=0.016840752

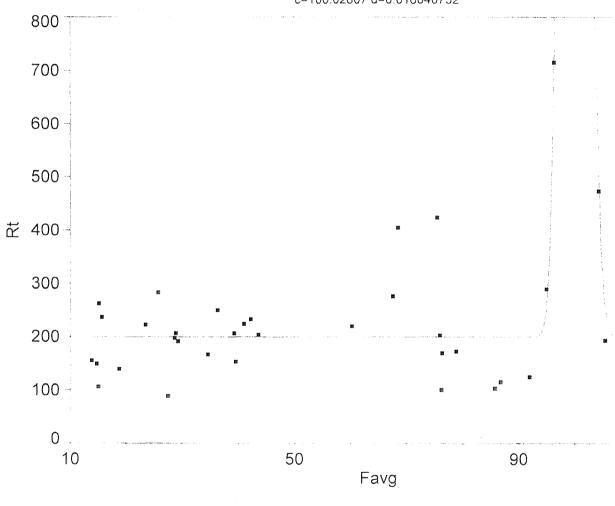


Fig 4.1 Curve Fit using Table Curve

Cutting in X Direction

Rank 1 Eqn 4776 $y=a+bx+cx^3+d/x^2+ee^{-x}$

 r^2 =0.214754964 DF Adj r^2 =0.0838807915 FitStdErr=11.6657357 Fstat=2.11953071

a=46.759246 b=-0.18822465 c=2.9462718e-07

d=-30198.568 e=3.8504456e+11

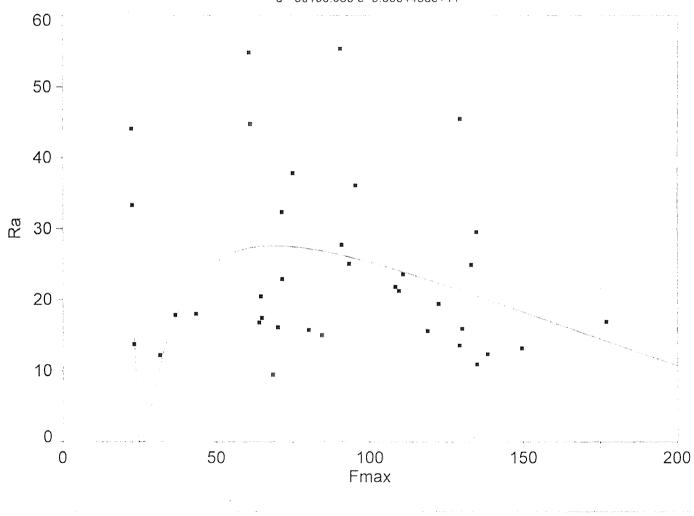


Fig 4.2 Curve Fit using Table Curve

Cutting in XY Direction

Rank 1 Eqn 4504 y=a+bx+cx 2 lnx+dx $^{0.5}$ lnx+ex/lnx r 2 =0.125631685 DF Adj r 2 =0 FitStdErr=13.1736402 Fstat=1.11354168 a=53384.951 b=2941.6927 c=-0.0078263958

d=7133.9106 e=-31116.669

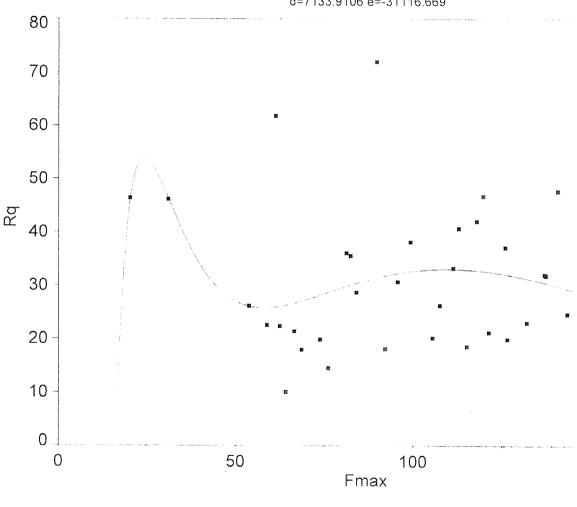


Fig 4.3 Curve Fit using Table Curve

Cutting in Y Direction

Rank 1 Eqn 8004 $y=a+b/(1+((x-c)/d)^2)$ [Lorentzian]

r²=0.155728759 DF Adj r²=0.0467905344 FitStdErr=121.473646 Fstat=1.96750367

a=228.50377 b=313.90878

c=74.166438 d=1.6762655

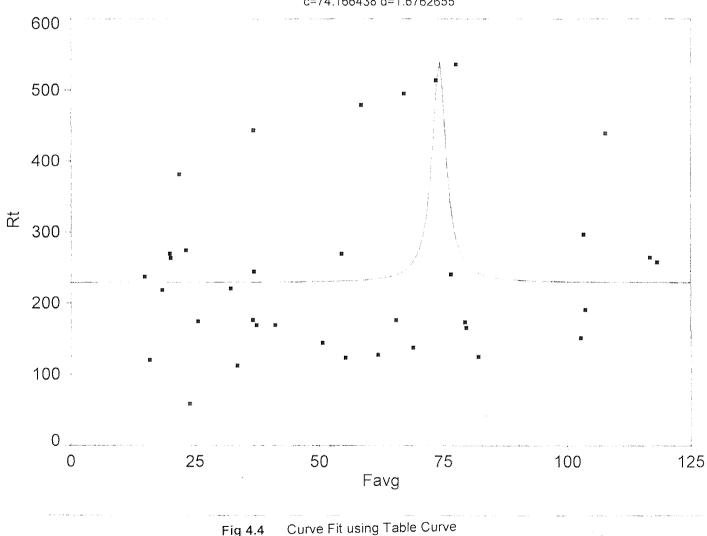


Fig 4.4

4.10 Comparison of Different Operating Parameters at Different Levels of Cutting

Once these relations were established it was further of interest of the research work to compare the different operating parameters at different levels of cutting. The entire data was sorted in the ascending order of speed, feed and depth of cut and then graphs were plotted with the Surface Quality parameter on the Y axis and the feedrates on the X axis. Each graph would have 9 lines on it and this would help to compare visually between the different operating parameters at the different levels of cutting.

The graphs 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, and 4.11 show the core comparisons for cutting in the three different directions. The remaining graphs are attached in the appendix.

For e.g. a graph with the Rku values on the Y axis and the feedrates on the X axis gives the comparison between the Rku values at different levels of cutting in the X direction. Similarly graphs were obtained for analysis for all other Surface Texture parameters and Cutting forces for cutting in the X, XY and Y direction.

Comparison of the Rku values at the different levels of cutting for cutting in the X Direction

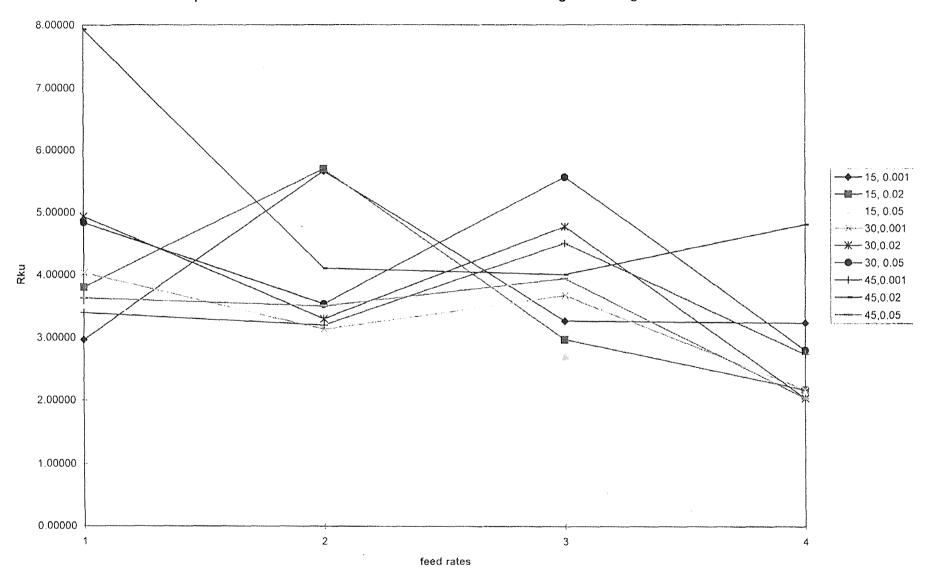


Fig 4.5 Comparison graph

Comparison of the Ra values at different levels of cutting for cutting in the X Direction

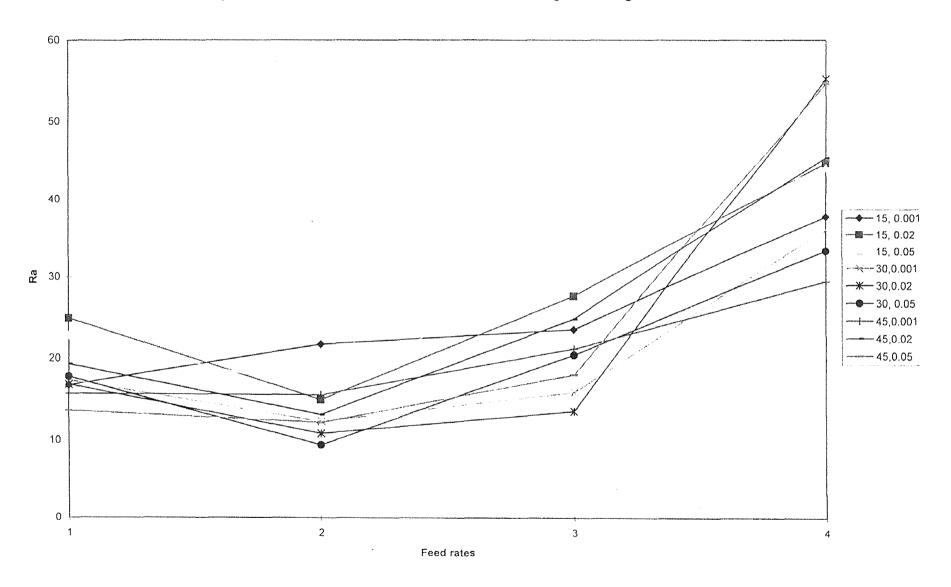


Fig 4.6 Comparison graph

comparison of the Fmax values at different levels of cutting for cutting in the X Direction

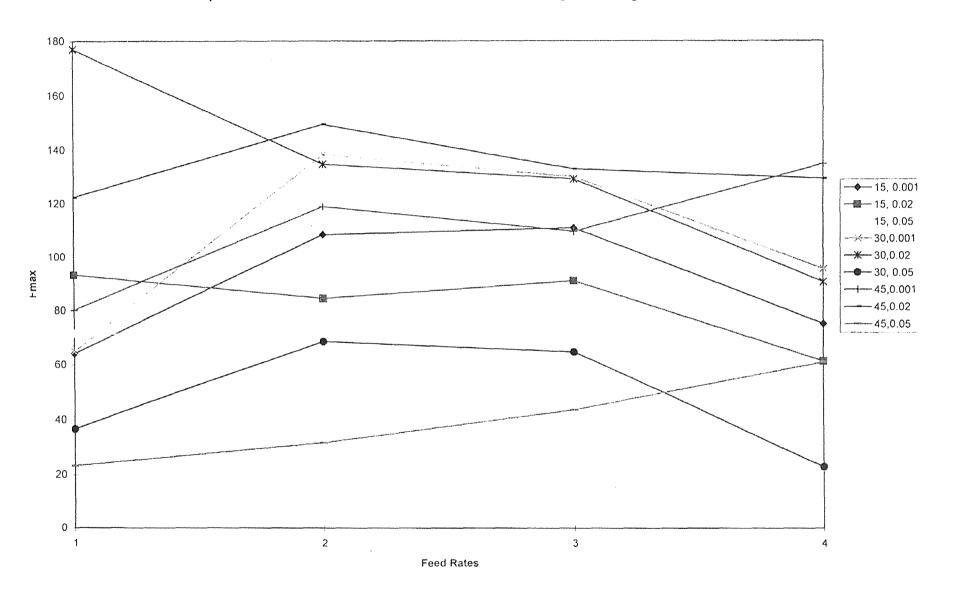


Fig 4.7 Comparison graph

Comparison of the Ra values at different levels of cutting for cutting in the XY Direction

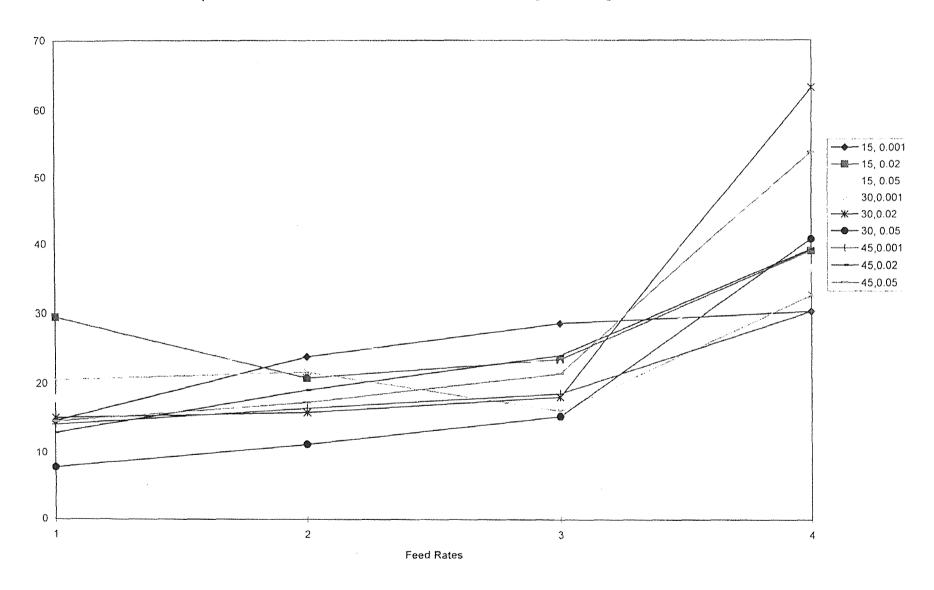


Fig 4.8 Comparison graph

Comparison of the Ra values at different levels of cutting for cutting in the Y Direction

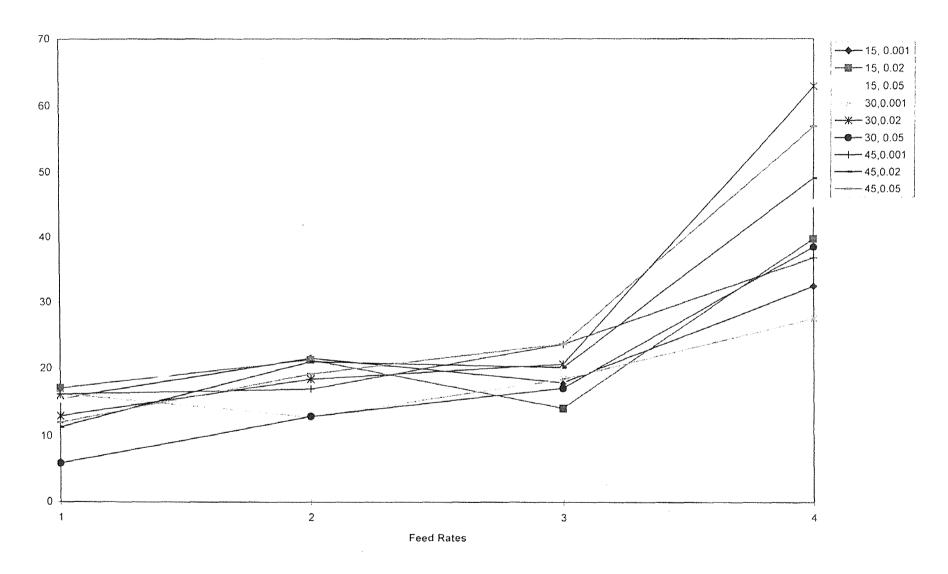


Fig 4.9 Comparison graph

Comparison of the Fmax values at different levels of cutting for Cutting in the XY Direction

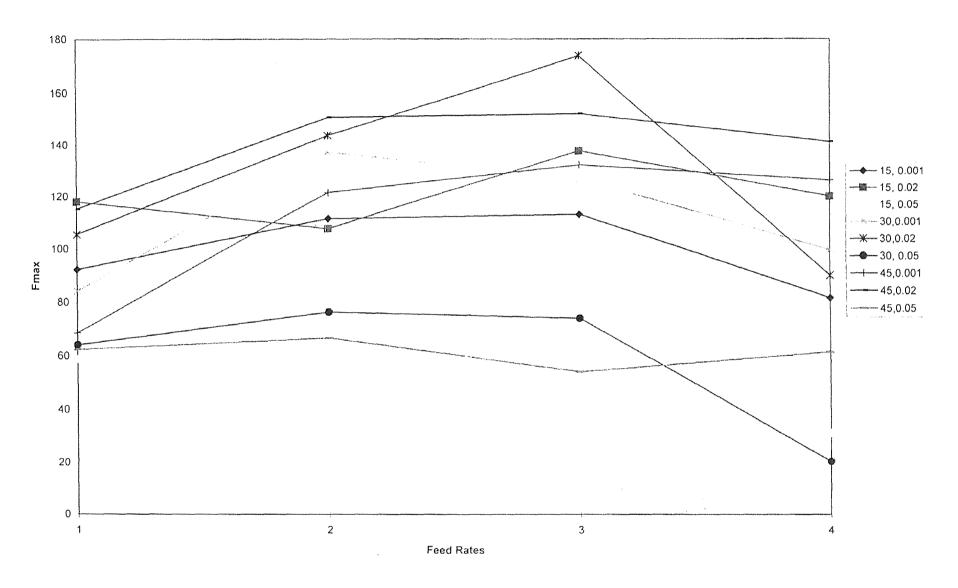


Fig 4.10 Comparison graph

Comparison of the Fmax values at different levels of cutting for cutting in the Y Direction

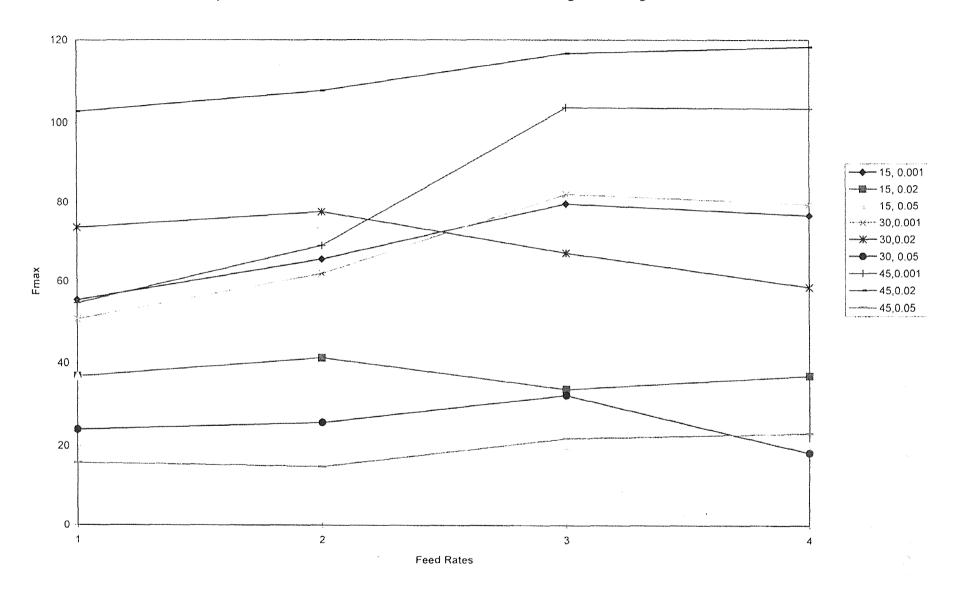


Fig 4.11 Comparison graph

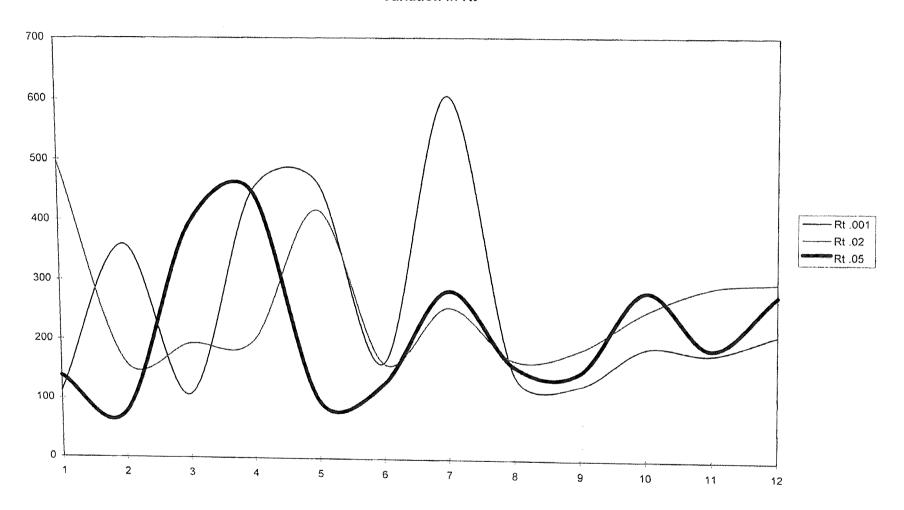
4.11 Variation in the Surface Texture Parameters and the Cutting forces

Proceeding towards the final stage of the case study, graphs were plotted which show the variation of the Surface Texture parameter / cutting force parameter at the different feedrates. In these graphs the Y axis is the Surface Texture / Cutting force parameter and the X axis is the number of points for the corresponding operating parameter under consideration.

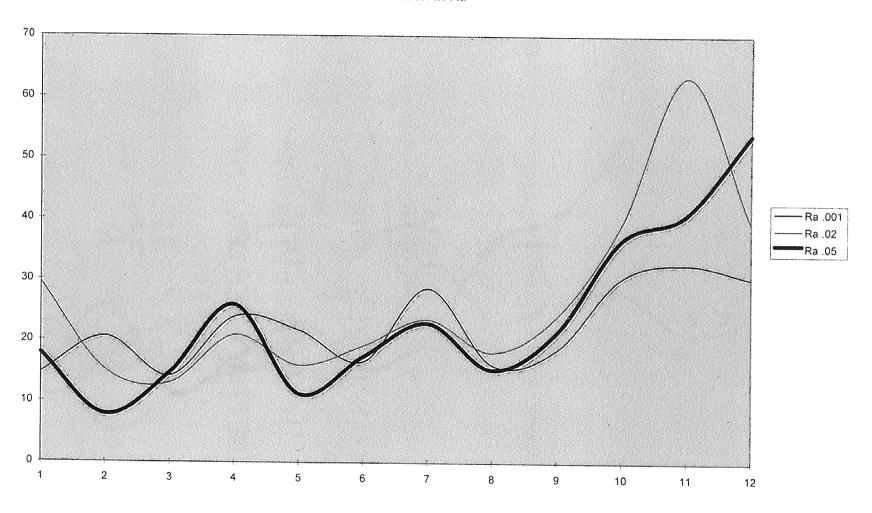
There are 36 values for each of the cutting directions. There are 3 speeds 4 feeds and 3 depths of cuts. If the variation of Rku for eg. has to be studied with respect to the different spindle speeds then the Y axis will have all the Rku values and the X axis will have the 12 points for each spindle speed. The graph will show 3 curves, one for each spindle speed, thus making it very simple to visually analyze the variation of the parameter under consideration.

Similarly the variation graphs for other parameters and directions of cutting were plotted. It was observed that the Ra and Rq showed a similar variation pattern for cutting in all the three directions. Similarities were also observed between the Rp and the Rt values. That consistency supports the fact that Rp and Rt are the peak value measurements and that Rq is the RMS parameter for Ra. Some of the important graphs are shown below and the rest are attached in the appendix.

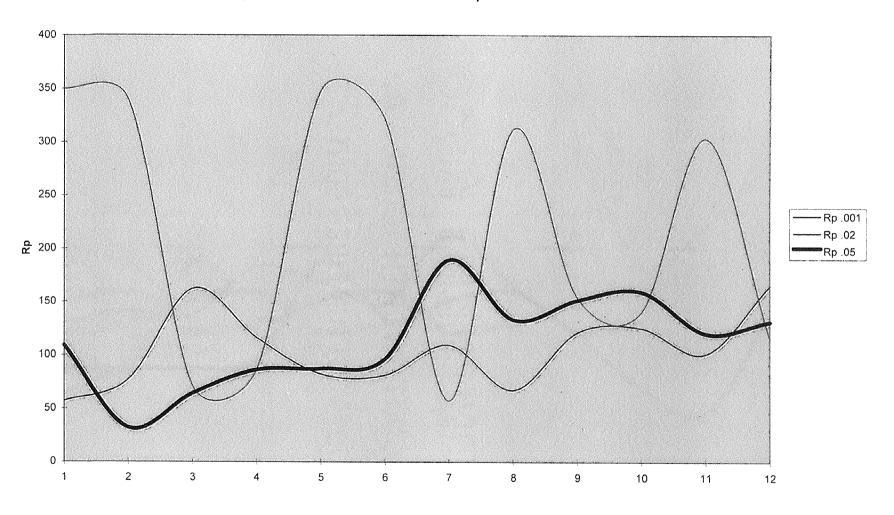
Variation in Rt



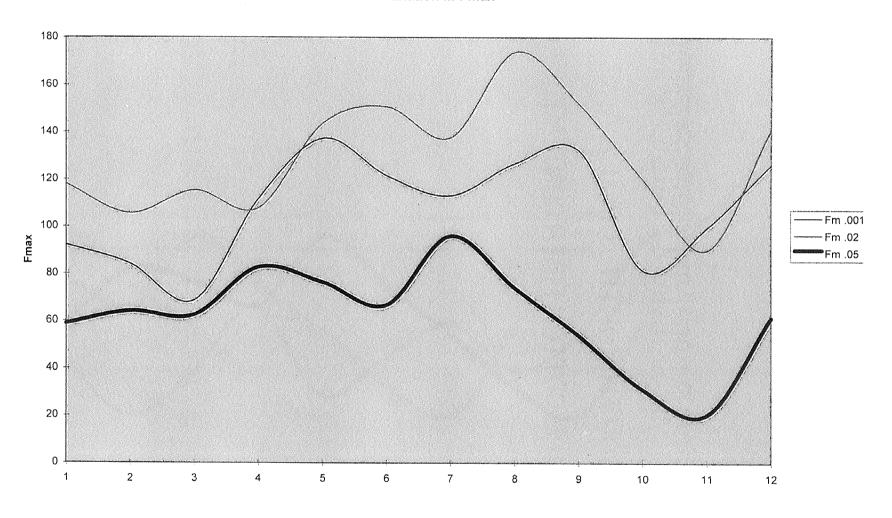
Variation in Ra



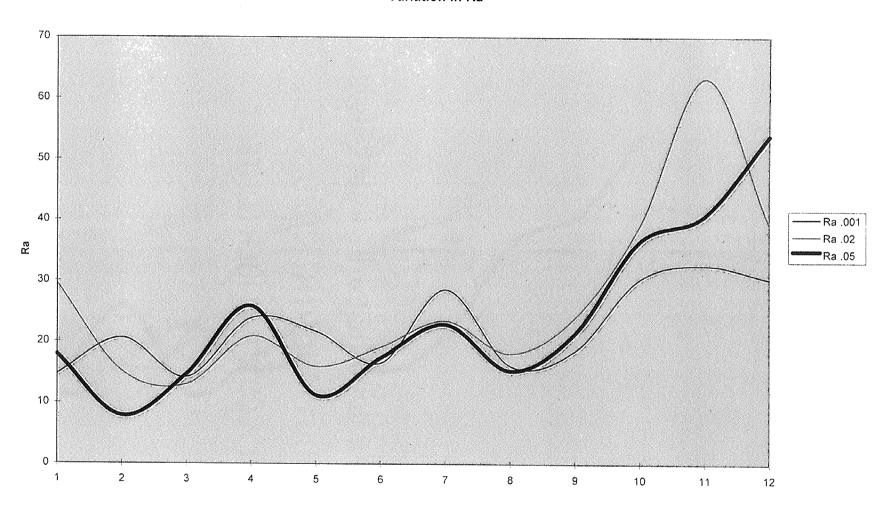
Variation in Rp



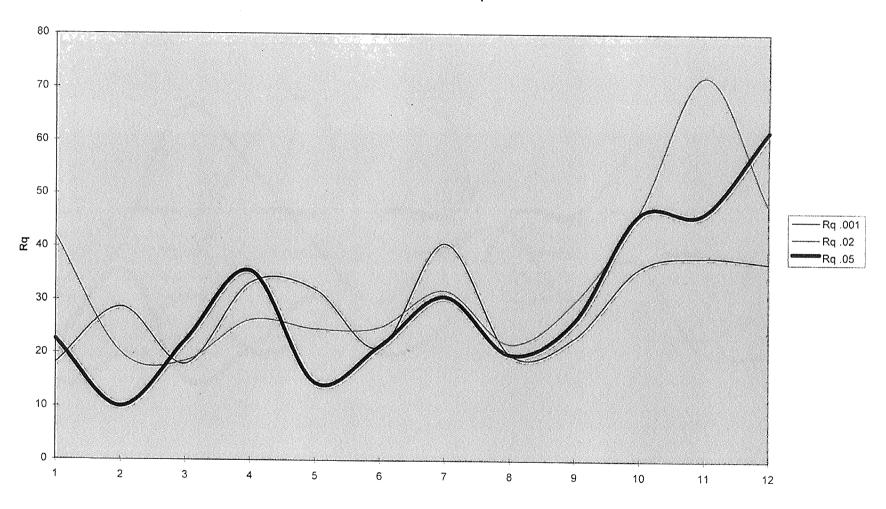
Variation in Fmax



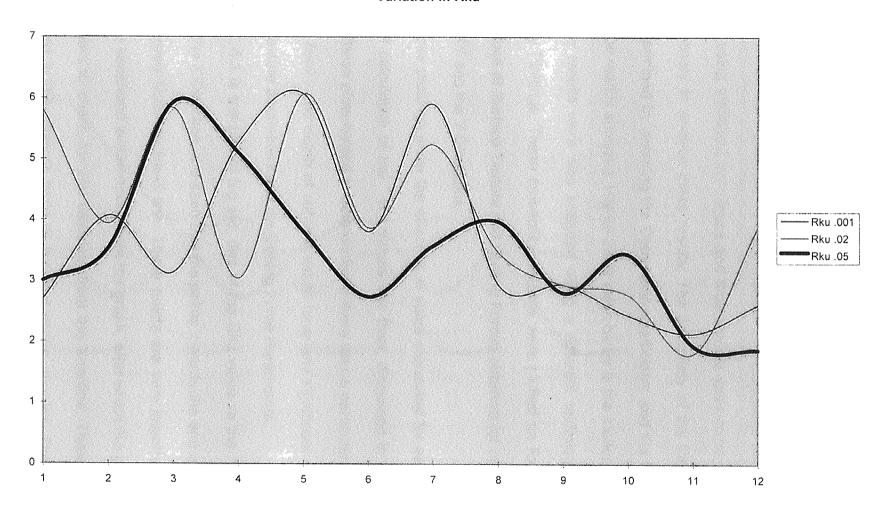
Variation in Ra



Variation in Rq



Variation in Rku



CHAPTER 5

5.1 ANALYSIS OF RESULTS

The results that were obtained from the number of experiments performed were analyzed using statistical techniques and thus models were come up with. It is now necessary to analyze these results. The adequacy of the models can be easily determined by checking the Correlation coefficients and the F values and they can be readily analyzed. Higher the R value better is the model.

The results were also analyzed using a different technique called the Probability Plottings. These probability plottings were plotted on Excel by using the 36 values of Surface Texture and Cutting Forces obtained for cutting in each of the X, XY and the Y Directions.

These plottings show the effect vs vi value calculated for each plot. The method of calculation of the "vi "values has been discussed in the previous chapter. These plots helped in determining if there was a particular combination of speed, feed, and depth of cut that would have any significant effect on the Surface Texture parameters and the Cutting Force Parameters.

Fig. 5.1 is the plot of log std. dev of the Rku value vs the "Vi" value for cutting in the X Direction. It is seen that the points towards the end of the plotting deviate largely from the trend line. These points are very important and they have to be separated and removed from the graph, after which the graph can be plotted again to check for any deviation from the trendline. These points are summarized in the analysis table at the end of the chapter. The figures 5.2

through 5.11 are the plottings for the effects of the different surface quality and cutting force parameters.

These are the possible combinations and any of the above combinations may have a significant effect on the Surface Texture parameter or/and the Cutting force parameter. Thus for a particular parameter, e.g. Rku, the effect was calculated for the Rku value for cutting in the X Direction. The effect is calculated as the difference between the maximum and the minimum of the Rku value for that particular combination. Similarly the effects were calculated for Ra, Rq, Rp, Rt, Fmax, their log standard deviations and the Signal to noise ratios. These effects were arranged in the ascending order and then vi was calculated.

$$vi = (n - 0.5)/n * 100$$

where n is the number of combinations into consideration for that particular probability plot.

Thus, the vi values and the effects are calculated and then the graph of effect versus the vi is plotted. After the graph is plotted a linear trendline is established to check whether all the points follow the trend or not. If any point does not seem to follow the trend it is separated and the graph is plot again. This procedure is carried out until a linear trend is observed. These probability plottings determine any significance of any particular operating parameter as main effect, or the two interaction effect or the triple interaction effect.

Some of the important probability plots are as shown below and the remaining are attached in the appendix. The analysis of these probability

plottings for the Surface Texture parameters are shown in the excel spreadsheet which has been imported from Microsoft Excel after summarizing the entire data from the probability plottings.

logstd Rt SAN Rt	72 0.817	ogsid Ri S/N Ri	86 0.06931 -36.2	logstd Rt S/N Rt	
Logsid Rp. SIN Rp. RR.	388	logstd Rp S/N Rp Rt	0 .30.27	logstd Rp S/N Rp Rt •	32 0.46 .27.84
iogsiu Rq Silv Rq Rp	173	logstd Rg S/N Rg Rp	10.033	logstd Rq S/N Rq Rp*	97.
d . feed and depth of n the two interaction bserved that the triple filluence in some cases.	0.04	log std Ra S/N Ra Rq	.17.95	log std Ra S/N Ra Rq	
It was observed after the analysis that the operating parameters of speed , feed and depth of cut by themselves had no significant effect on the various R values. Even the two interaction effect did not have any significant influence on the R values. But it was observed that the triple interaction effect of speed, feed and depth of cut did have a significant influence in some cases. They are mentioned below. They are mentioned below. They are mentioned below. The paralysis for X Axis Speed Geod Geoth Rik SIN Rku Ra 109 sid Ra SIN Ra	33 -1.1.23 -1.1.23 -6.18	logstd Rk S/N Rku Ra		logstd Rk S/N Rku Ra	33
It was observed after the analysis that the op- cut by themselves had no significant effect or effect din out have any significant influence or interaction effect of speed, feed and depth of They are mentioned below. The analysis for X Axis Speed feed depth Riv.	3000 0.02 0.05 2.033 4500 0.021 0.065 2.033 4500 0.001 0.001 0.001 4500 0.001 0.001 4500 0.001 0.05 3000 0.005 0.05 3000 0.005 0.05 3000 0.005 0.05 3000 0.005 0.05 3000 0.005 0.05 3000 0.005 0.05 3000 0.005 0.05 3000 0.005 0.005	feed depth Rku	0.001 0.001	ine analysis ton it Axis speed feed depth Rku	0.02 0.005 0.005 0.001 0
It was observed after the an cut by themselves had no select did not have any sign interaction effect of speed. They are mentioned below. The analysis for X.A.	3000 4500 4500 4500 4500 3000 3000 3000	paul paeds	3000 3000 3000 3000 3000 3000 4500 4500	beeds	8888888888

Cutting in Y Direction Log Std. Dev.

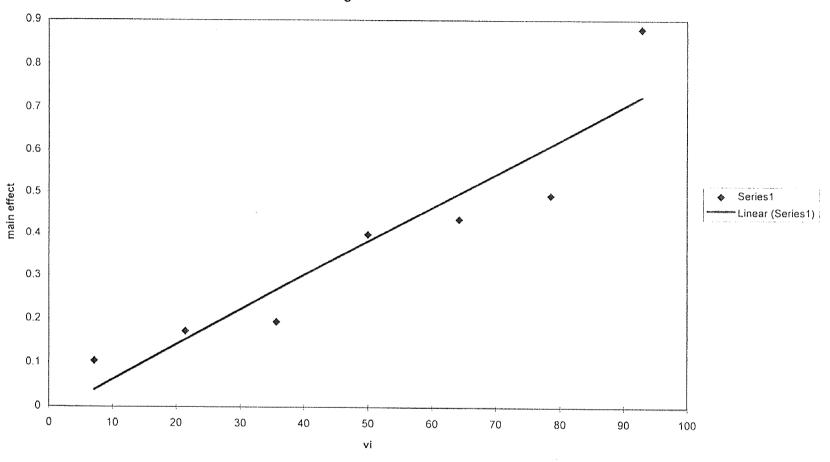
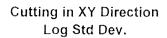


Fig 5.1 Probability Plotting



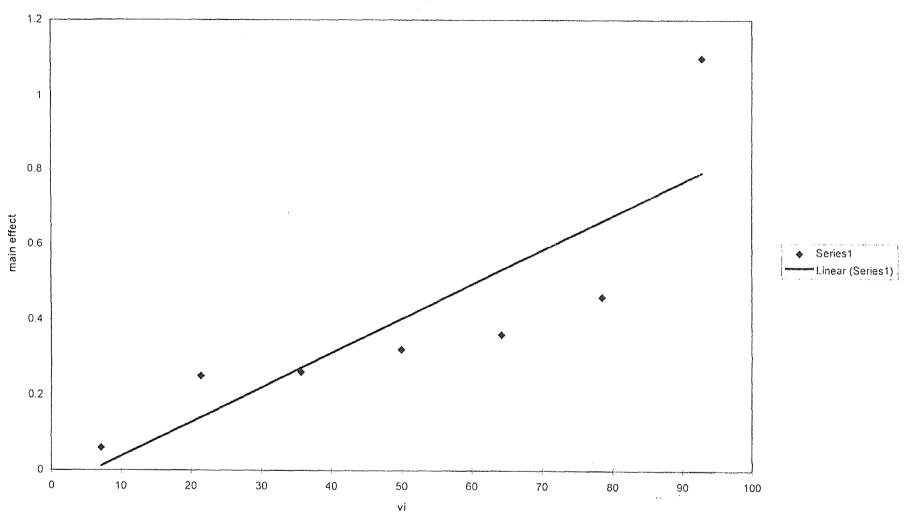


Fig 5.2 Probability Plotting

Cutting in X Direction Log Std Dev.

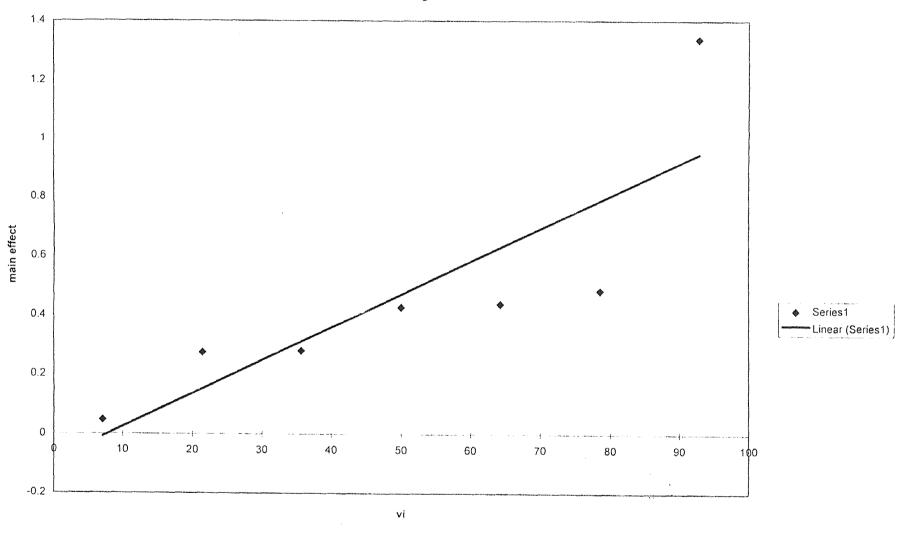


Fig 5.3 Probability Plotting

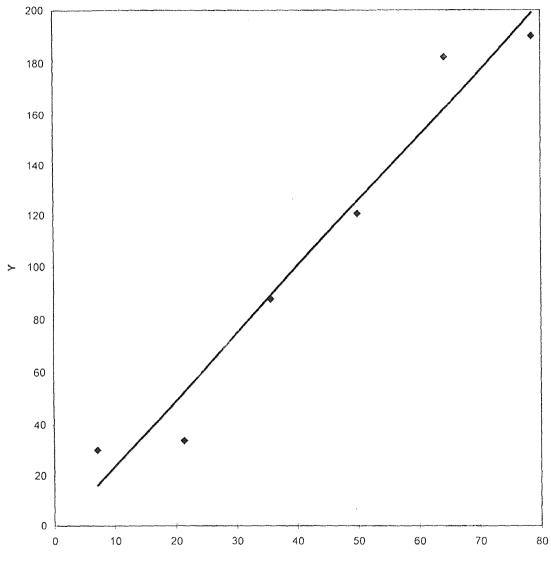


Fig 5.4 Probability Plotting

♦ Series1
Linear (Series1)

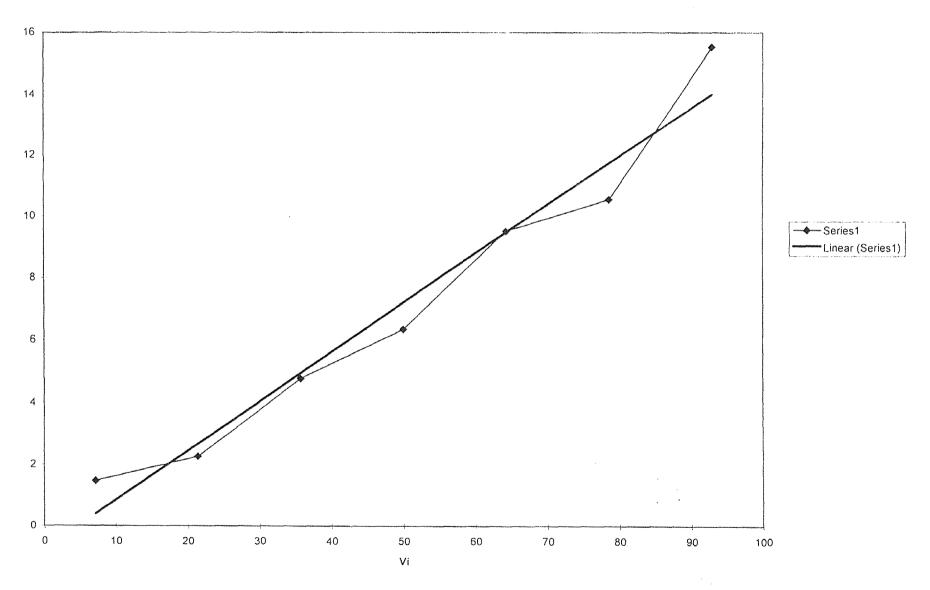


Fig 5.5 Probability Plotting

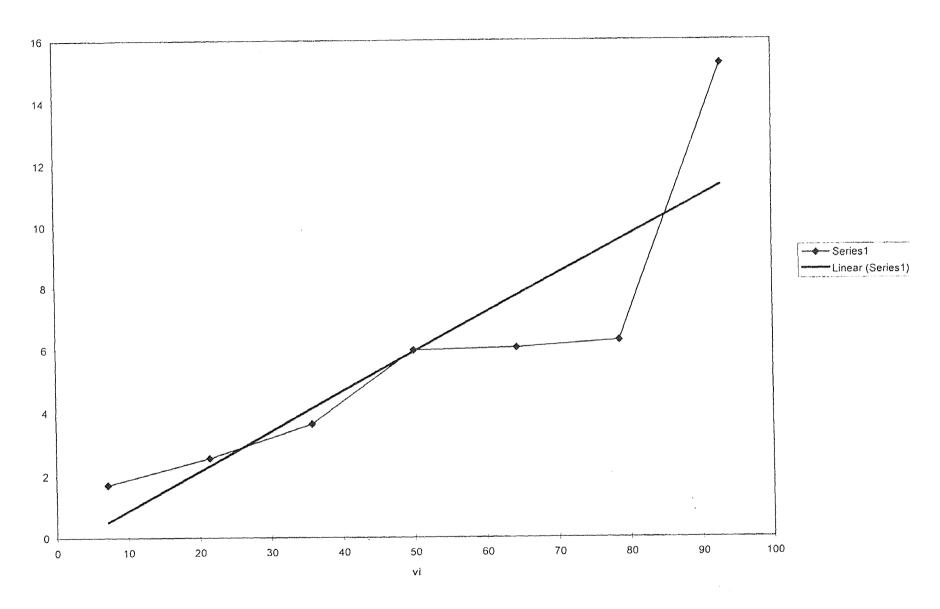


Fig 5.6 Probability Plotting

S/N Rt (mod)

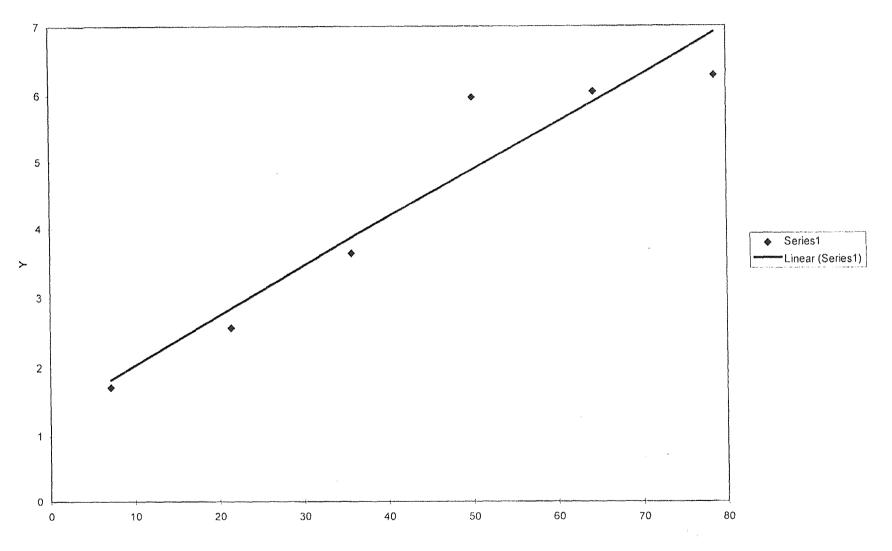


Fig 5.7 Probability Plotting

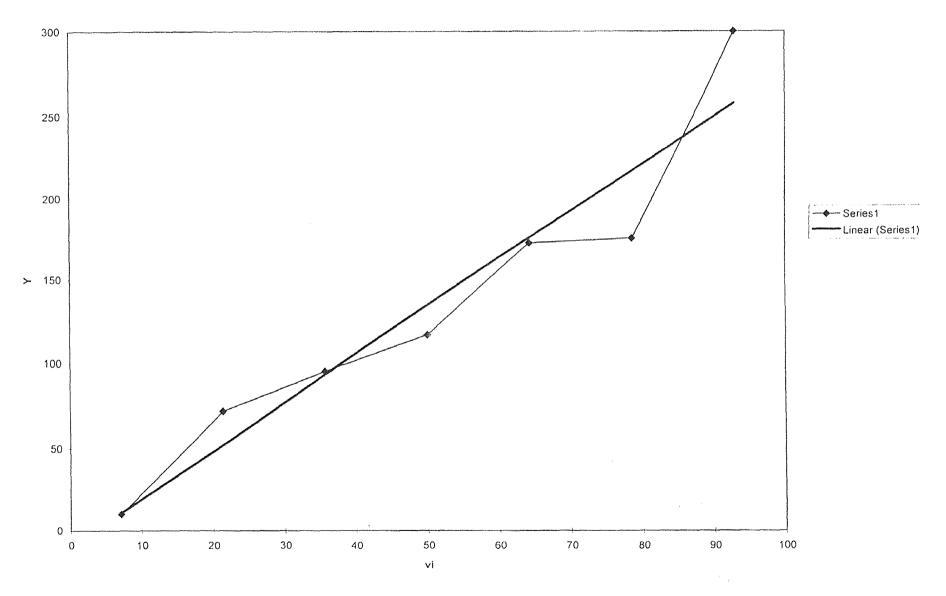
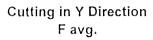


Fig 5.8 Probability Plotting



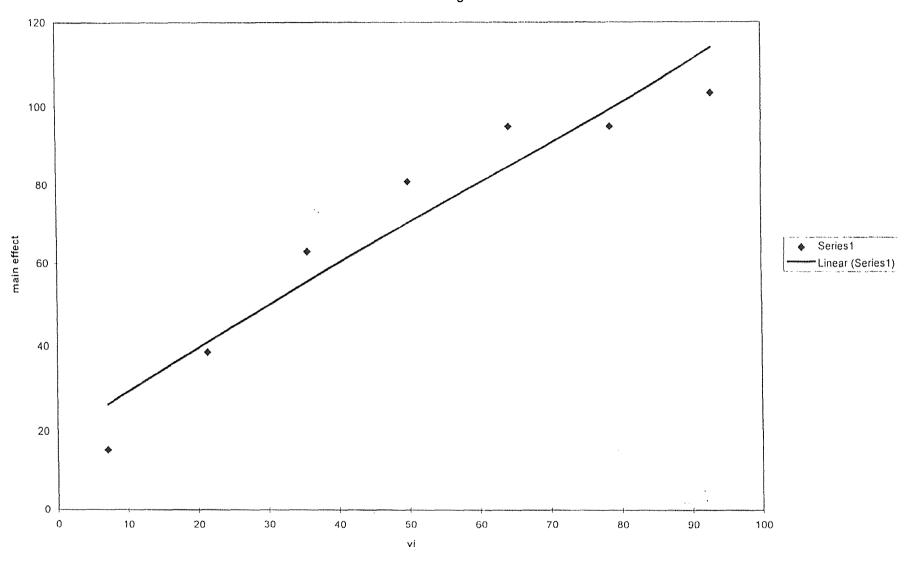


Fig 5.9 Probability Plotting

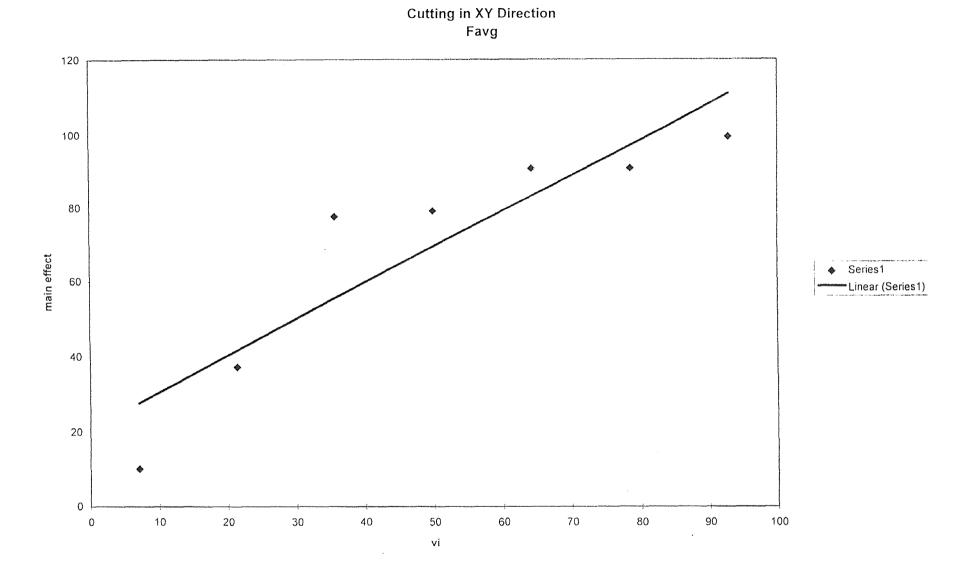


Fig 5.10 Probability Plotting

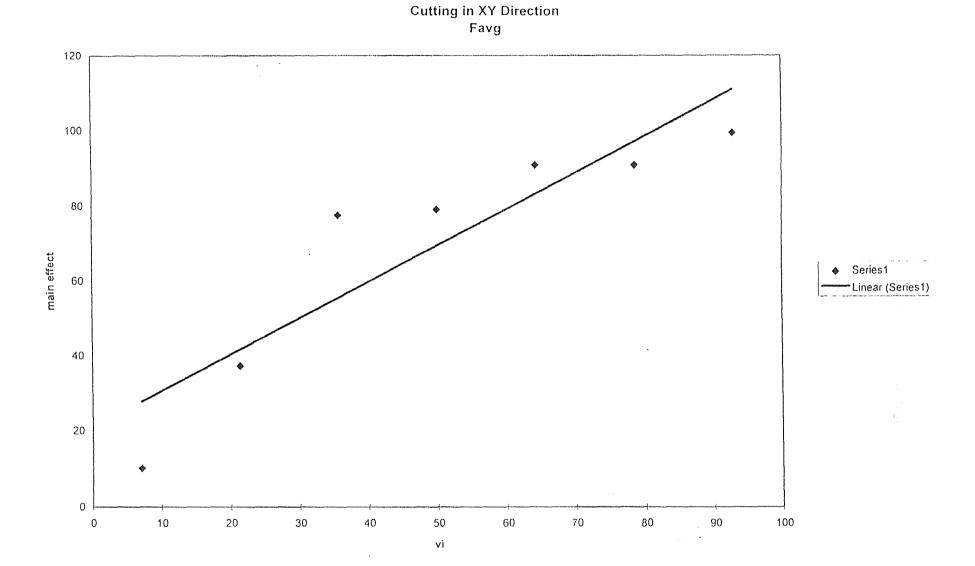


Fig 5.11 Probability Plotting

5.2 Cutting in X Direction

For cutting in the X Direction it was observed that the two interaction effect of speed-feed, feed-depth of cut, speed-depth of cut had a significant effect on the maximum cutting force. The two interaction effect of speed-feed and the single effect of depth of cut had a significant effect on the average value of the cutting forces. The triple interaction effect of speed-feed-depth of cut had a significant effect on the log stdev of the Fmax values.

5.3 Cutting in XY Direction

For cutting in the XY Direction it was observed that the single effect of depth of cut had a significant effect on the average value of the cutting forces. There was no significant effect of any particular operating parameter seen on the maximum value of the cutting forces. The triple interaction effect of speed-feed-depth of cut had a significant effect on the log stdev of the Fmax values.

5.4 Cutting in Y Direction

For cutting in the Y Direction it was seen that the two interaction effect of speed-feed and the single effect of depth of cut had a significant effect on the maximum value of the cutting forces. The triple interaction effect of speed-feed-depth of cut had a significant effect on the log stdev of the Fmax values. There was no significant effect of any particular operating parameter seen on the average value of the cutting forces.

It was observed that for cutting in any of the three directions, the S/N Ratio of the Fmax values did not show any significance at any level of cutting.

The following table summarizes the above results, showing the factor, level of cutting, main effect for cutting in the three directions.

 Table 5.1
 Analysis of Results of Probability Plottings

						
<u>Analysi</u> :	s for X Axis	<u> </u>				
speed	feed	depth	Fmax(Effect)	Favg(effect)	log	stdev
					Fmax(effect)
3000	0.001	0.02	116.17			
3000	0.001	0.02	101.94			
4500	0.02	0.001		85.7		
4500	0.005	0.02		75.16		
4500	0.005	0.02		70.46		
1500	0.02	0.05			1.338	
Analysis	for XY Ax	<u>is</u>				
speed	feed	depth	Fmax(Effect)	Favg(effect)	log	stdev
					Fmax(e	effect)
4500	0.02	0.001		77.6		
3000	0.02	0.05			1.1	

Table 5.1 (Continued)

Analysis	s for Y Axis				4.	ž: s	
			Ť			÷:	
speed	feed	depth	Fmax(effect)	Favg(effect)	log	stdev	
					Fmax	(effect)	
3000	0.01	0.02	49.3				
3000	0.01	0.02	37.02				
3000	0.02	0.05			0.86		
					·····		

After the analysis of the results, It was observed that the level of speed to obtain the maximum cutting force is 3000 RPM.

The feed at which the maximum cutting force can be obtained is 0.001 in the X Direction and 0.01 in the Y Direction. If these are the feed rates in the X and Y Directions then theoretically, according to the geometry of the workpiece the feed in the XY direction should be a little over 0.01 inches/min. However practically it would not be possible to achieve that feed rate and we could go to a feed rate of 0.02.

The depth of cut at which the maximum cutting force can be obtained is 0.02 in. in the X and the Y Direction, for maximum cutting force in the XY direction the depth of cut could be reduced to 0.001.

From these above observations and results it can be concluded that the optimum level of cutting to obtain the maximum cutting forces would be speed = 3000 RPM

feedrate = 0.001 (X Direction), 0.02 (XY Direction), 0.01 (Y Direction) in/min.

5.5 Analysis of the Comparisons of Different Surface Texture Parameters and Cutting Forces versus the 4 Different Feedrates at a Particular Spindle Speed and Depth of cut.

From the graphs in Chapter 5 it is very evident that the surface texture parameters display similar characteristics for cutting in the three directions. The Ra and Rq values for cutting in each direction show a similar trend and it is right as Rq is the RMS value of the Ra, thus proving that the results obtained and analysis carried out is quite accurate.

Rp, Rt and Fmax also have similarities in the trend for cutting in the three directions. These graphs give support to the probability plottings and after the analysis of these graphs it can be stated that the cutting conditions for optimum results would be

speed = 3000 RPM

feed rate = 0.005 in/min

depth of cut = 0.05 in.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The research work that has been done gives the empirical relationship between the different Surface Texture Parameters and the Milling Operation parameters. It gives the empirical relatioship between the maximum and the average cutting forces and the Milling operating parameters. It also gives us the empirical relationship between the Surface Texture parameters and the Cutting Forces.

Hence, It is now possible to have an estimate of the output of the Cutting Force or the Surface Texture result by the empirical relatinships. The equations that have been derived can be used to estimate the expected Surface Texture result and the expected Cutting force if a particular combination of spindle speed, feed rate and depth of cut be used.

Those equations having a higher value of the Correlation Coefficient should give better and more accurate predictions of the results. These equations shall be a great help when actual milling operation is being carried out. One can have an idea before hand as to what kind of Surface Texture should he expect and also what would the cutting forces be.

In an unattended machining environment it would be possible to predict the results before the actual machining and then set the operating parameters of speed, feed and depth of cut according to the results that are desired.

The probability plottings give us the significant factors and their effects in

obtaining a particular Surface Texture result or a particular Cutting Force. These plottings have given an optimum level of cutting. When cutting would be done at that level one should get the most optimum results for Surface Texture and Cutting forces. This would greatly enhance the productivity and also improve the quality of the machined component.

6.2 Recommendations

The research work that has been done helps greatly in determining the optimum conditions of cutting in a milling operation. In unattended machining environment, there should be an adaptive control system, which would give a constant feedback of the Surface Texture being obtained and the Cutting Forces being developed. This adaptive control system should be capable of comparing the actual obtained values of the forces and the texture to those that are desired. The desired values are calculated by the equations already derived. The adaptive control system would compare the desired and the actual value and then take corrective actions by either changing the speed or feed or the depth of cut or any combination of the three milling operating parameters. It can also be in the form of a G and M code where it would immediately halt the machining operation if the actual measured results deviate largely from the desired results.

APPENDIX A TABLE CURVE SOFTWARE RESULTS

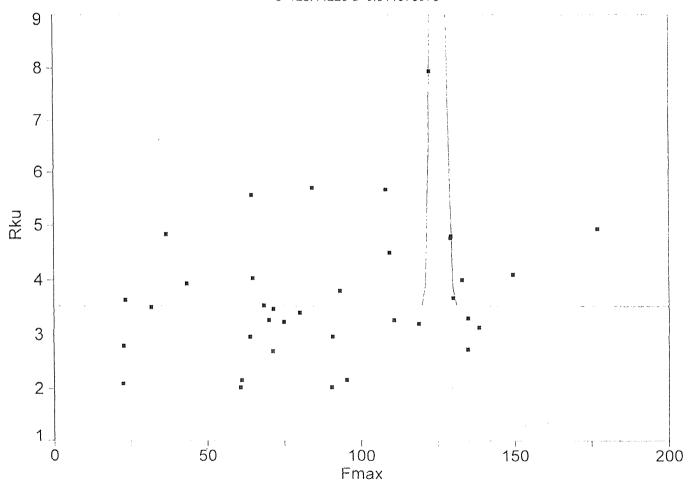
Cutting in X Direction

Rank 1 Eqn 8005 $y=a+bexp(-0.5(ln(x/c)/d)^2)$ [Log-Normal]

 r^2 =0.395338573 DF Adj r^2 =0.317317744 FitStdErr=1.00695681 Fstat=6.97405952

a=3.51925 b=38.803566

c=125.44229 d=0.011578976



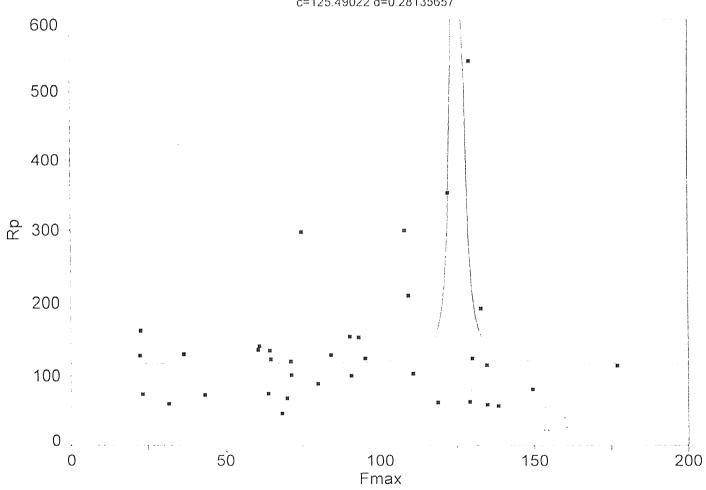
Cutting in X Direction

Rank 1 Eqn 8004 $y=a+b/(1+((x-c)/d)^2)$ [Lorentzian]

 r^2 =0.251080484 DF Adj r^2 =0.154445708 FitStdErr=88.8484109 Fstat=3.57607429

a=116.8581 b=25954.384

c=125.49022 d=0.28135657



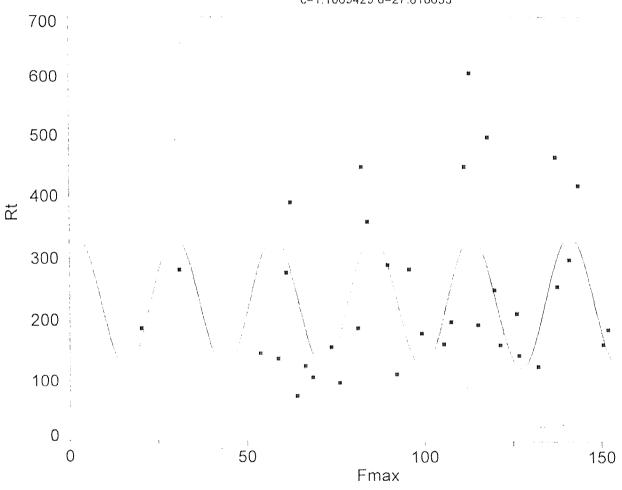
Cutting in XY Direction

Rank 1 Eqn 8014 $y=a+b\sin(2\pi x/d+c)$ [Sine]

 $r^2 = 0.323578678 \;\; \text{DF Adj} \; r^2 = 0.236298507 \;\; \text{FitStdErr} = 112.519609 \;\; \text{Fstat} = 5.10259772$

a=228.78952 b=106.99618

c=1.1069429 d=27.818633



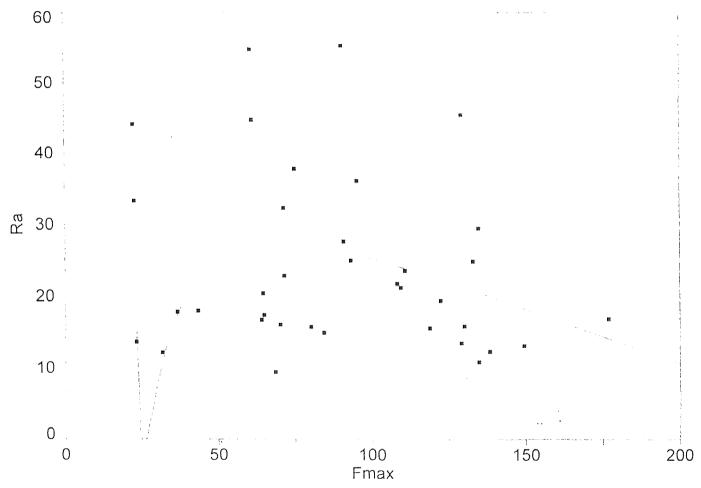
Cutting in X Direction

Rank 1 Eqn 4776 $y=a+bx+cx^3+d/x^2+ee^{-x}$

 $r^2 = 0.214754964 \;\; \text{DF Adj} \; r^2 = 0.0838807915 \;\; \text{FitStdErr} = 11.6657357 \;\; \text{Fstat} = 2.11953071$

a=46.759246 b=-0.18822465 c=2.9462718e-07

d=-30198.568 e=3.8504456e+11



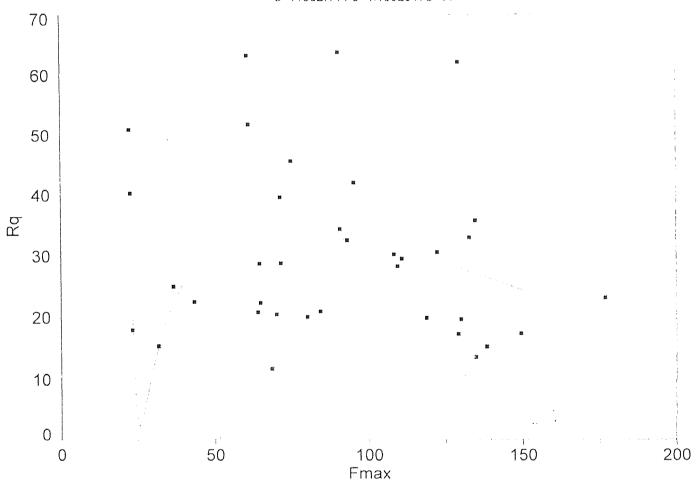
Cutting in X Direction

Rank 1 Eqn 5090 y=a+bx+c/lnx+d/x^{0 5}+ee-x

 $r^2 = 0.186145907 \;\; \text{DF Adj} \; r^2 = 0.0505035586 \;\; \text{FitStdErr} = 13.6424853 \;\; \text{Fstat} = 1.77259142$

a=1763.8827 b=-0.53819104 c=-12959.913

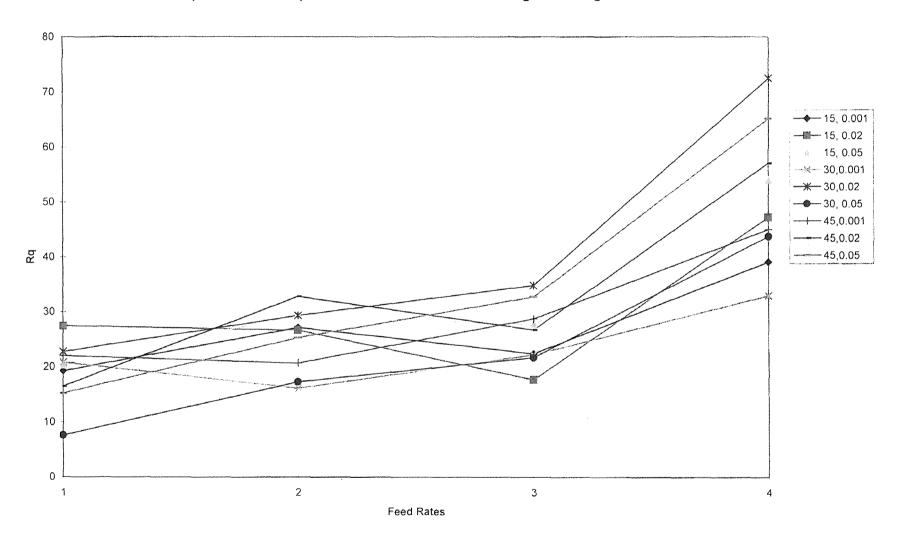
d=11362.144 e=4.1992917e+11



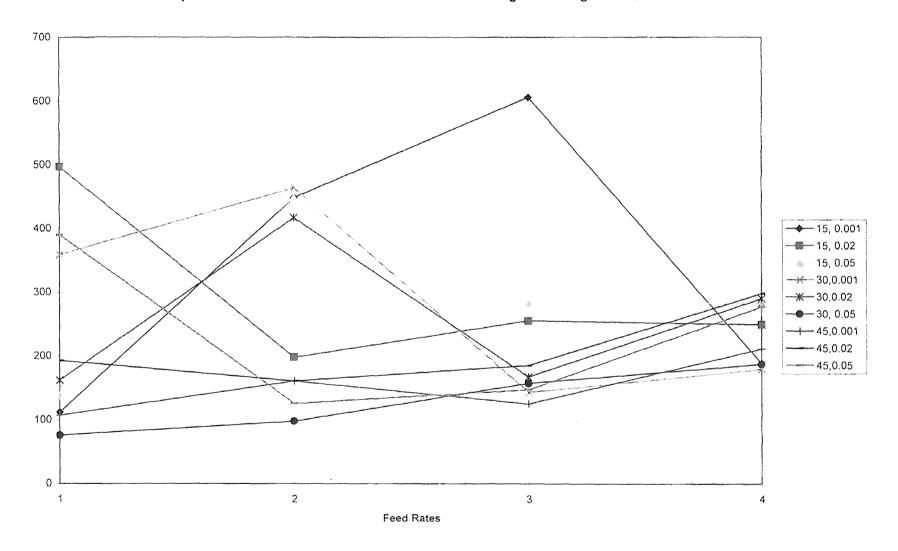
APPENDIX B

PLOTTINGS OF THE COMPARISONS OF THE DIFFERENT OPERATING PARAMETERS AT DIFFERENT LEVELS OF CUTTING

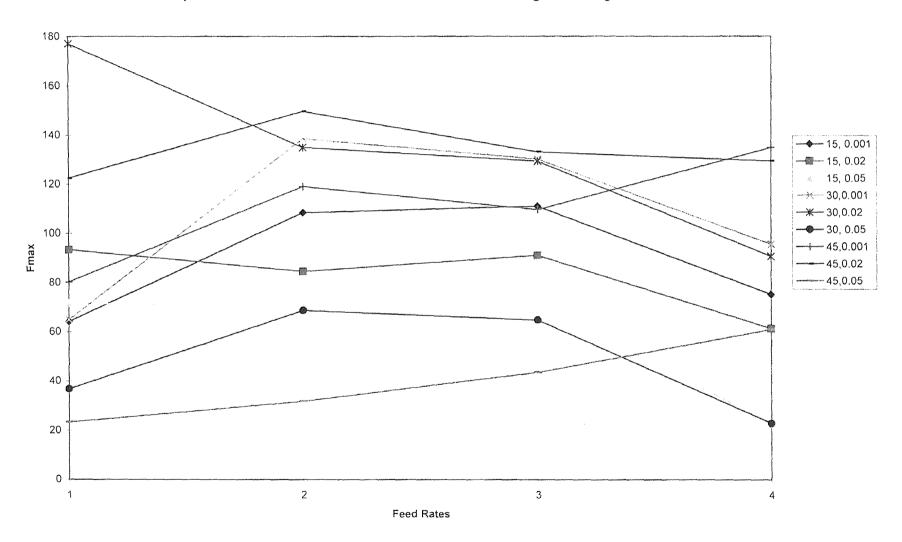
Comparison of the Rq values at different levels of cutting for cutting in the Y Direction



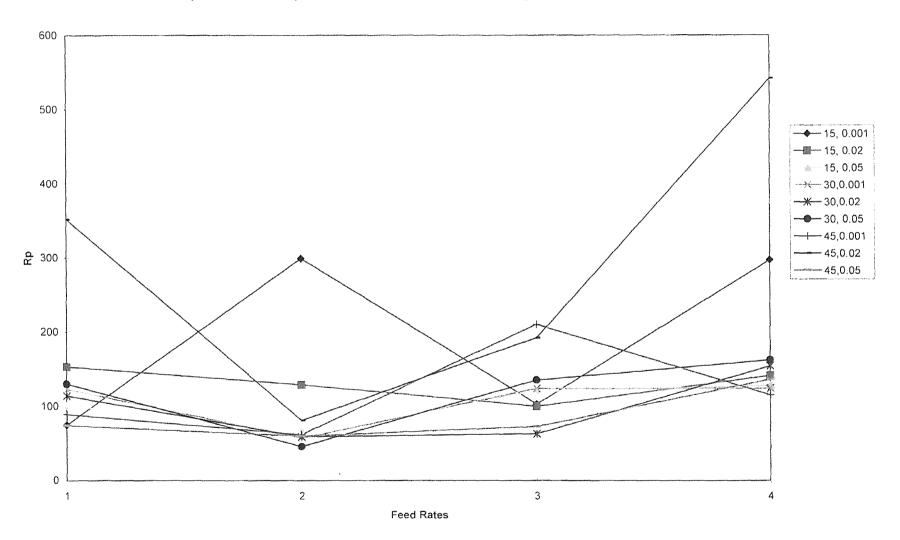
Comparison of the Rt values at different levels of cutting for cutting in the XY direction



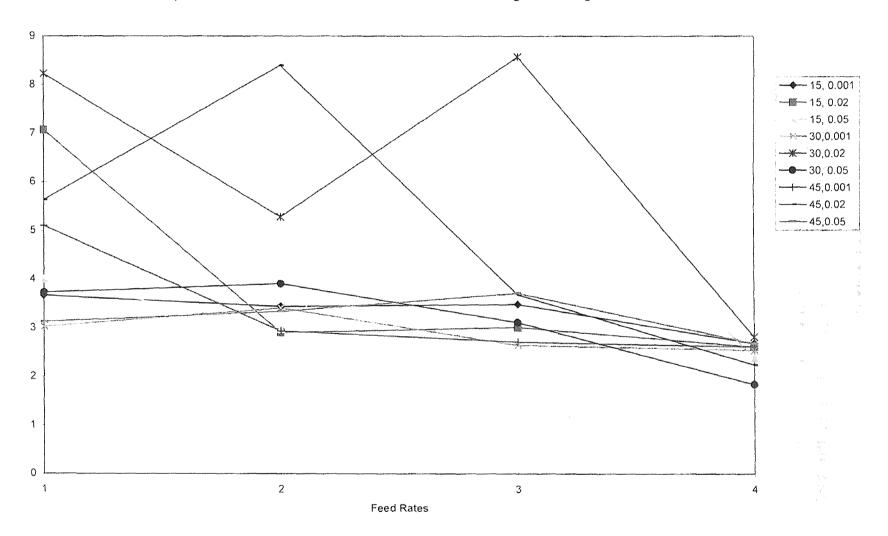
comparison of the Fmax values at different levels of cutting for cutting in the X Direction



Comparison of the Rp values at different levels of cutting for cutting in the X Direction



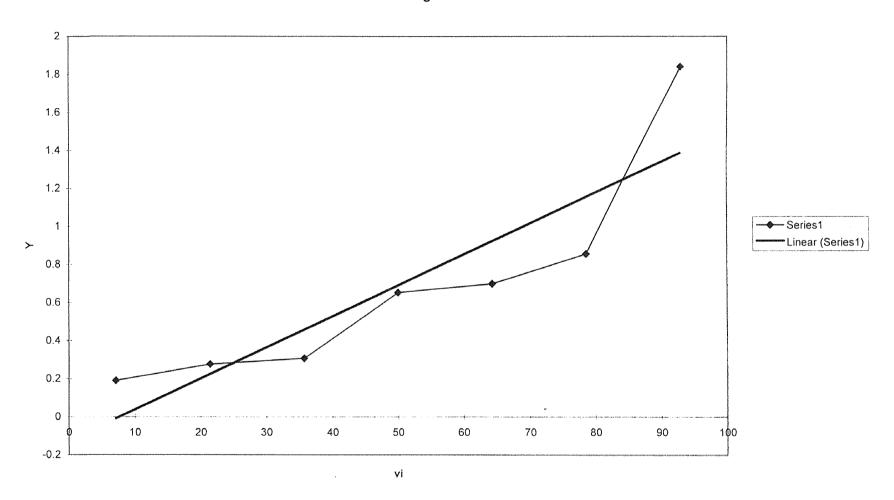
Comparison of the Rku values at different levels of cutting for cutting in the Y Direction



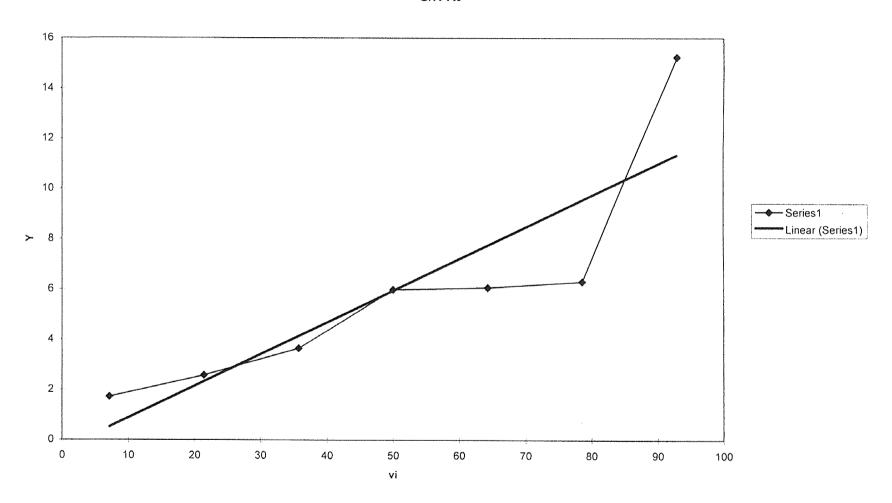
APPENDIX C

PLOTTINGS OF THE VARIATIONS OF THE SURACE TEXTURE AND THE CUTTING FORCE PARAMETERS AT DIFFERENT LEVELS OF CUTTING

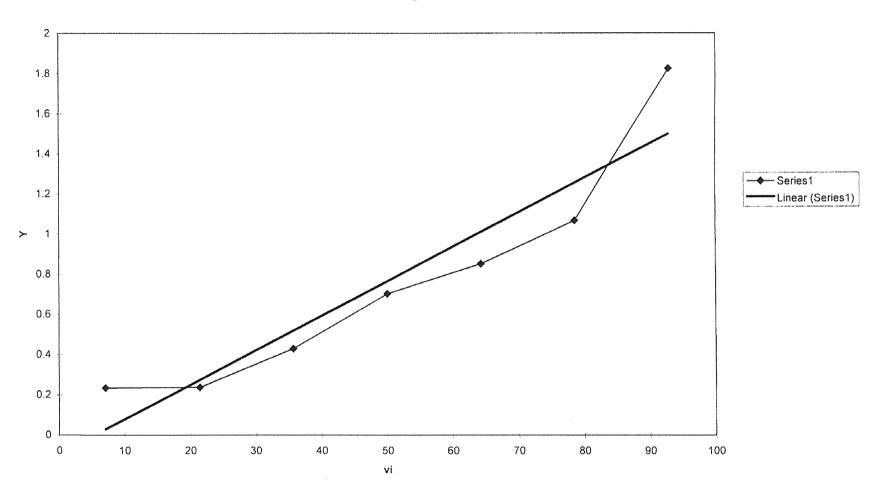
Log Std Rt











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