EXPERIMENTAL INVESTIGATION OF PROCESS AND RESPONSE PARAMETERS IN DRILLING USING FUZZY LOGIC APPROACH

A

Thesis Report

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CERTIFICATE

I hereby declare that the work which is being presented in the dissertation entitled **"Experimental Investigation of Process and Response Parameters in Drilling using Fuzzy Logic Approach"** in partial fulfillment of the requirement of the award of degree of **Master of Engineering** in **CAD / CAM & Robotics** submitted in Mechanical Engineering Department, **Thapar University, Patiala** is an authentic record of my own carried work under the supervision of **Dr. V.K. Singla** refers others researchers work which are duly listed in the reference section.

The matter embodied in this thesis has not been submitted for the award of any other degree of this in any other university.

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ABSTRACT

Drilling is probably the most frequently used operation in industry. Sometimes, as many as 55,000 holes are generally required to be drilled as in a complete single unit production of the Airbus A350 aircraft. The carbon fibre reinforced plastics (CFRP), owing to their anisotropy and abrasive nature of their carbon fibre content, exhibit totally different drilling results as compared to those of drilling common metals and other materials. Different challenges faced in drilling CFRPs in particular, and machining FRPs in general could be classified on the one hand as the excessive tool wear, while on the other hand as workpiece material-related problems. The latter ones include part edge, surface anomalies and hole quality defects like material cracking and delamination. Delamination during drilling CFRP has been recognised as one of the major problems by almost all the researchers. It is an inter-laminar or inter-ply failure phenomenon. When occurred at the top surface around the drilled hole periphery, it is known as 'peel-up delamination' or simply hole entry delamination. It is more severe at the bottom most surface-ply of the material—known as push-out delamination or hole exit delamination.

The considerable amount of contribution in this field has been made and have been modeled analytically and validated (experimentally) the effect of various Process & Response parameters have been studied with their respective critical thrust force, torque values for the onset of the hole exit delamination. Moreover, the effect of chisel edge and a pilot-hole on to the critical thrust force and the resulting delamination has been studied. This work covered mathematical modeling of hole exit delamination with respect to the critical thrust force. The optimum value has been determined with the help of main effect plot and ANOVA Tables to findout which parameter has affected most for increasing thrust force and torque. The mathematical modeling has been carried out using Minitab 15 software and different models has been analysed with help of the taguchi design using orthogonal array. The Universal microscope has been used which determines delaminated diameter in GFRP specimens.

The fuzzy logic approach has been adopted using MATLAB software which helped to find out Torque, Thrust Force graphs with different control factors like feed, speed etc. The failure criteria has been applied for finding delamination occurring in glass fiber composite around the drilled holes. The piezoelectric dynamometer has been used for measuring thrust forces and torque on varying the feed rate, speed, and drill diameters. The drill bit like High speed steel used for carrying out the experimental works in the Machine Tool Lab. The various process parameters like different diameters, feed, speed, depth of cut has been taken to record the various response parameters like torque, thrust force, tool wear. The thrust forces and torque were measured for different machining conditions.

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CHAPTER – 1

INTRODUCTION

Composite structure materials have successfully substituted the traditional materials in several lightweight and high strength applications. These material structures are synergistic combination of two or more micro-constituents that differ in physical form and chemical composition and which are insoluble in each other. The objective of having two or more constituents is to take advantage of the superior properties of both materials without compromising on the weakness of either. In a glass fiber reinforced composite structures, the glass fibers carry the bulk load and the matrix serves as a medium for the transfer of the load. Applications of such structures are observed in aircraft components, offshore and marine, industrial, military and defense, transportation, power generation, etc. Machining of these structures involves cutting, drilling, or contouring GFRP laminates for the assembly into composite structures. In fact, drilling is one of the most common manufacturing processes used in order to install fasteners for assembly of laminates. In machining processes, however, the quality of the component is greatly influenced by the cutting conditions, tool geometry, tool material, machining process, chip formation, work piece material, tool wear and vibration during cutting, etc. Therefore, a precise machining needs to be performed to ensure the dimensional stability and interface quality. For these reasons there have been research developments with the objective of optimizing the cutting conditions to obtain a better productivity in drilling process. Productivity involves the higher, metal removal rate and Tool life result in the less rejection of the components. Thus, in material removal processes, an improper selection of cutting conditions will result in rough surfaces and dimensional errors. Possibly a dynamic phenomenon due to auto excited vibrations may appear. Therefore, it is necessary to understand the relationship among the various controllable parameters and to identify the important parameters that influence the quality of drilling. Moreover, it is necessary to optimize the cutting parameters to obtain an extended tool life and better productivity, which are influenced by cutting thrust and torque. Design of experiment [DOE] is a statistical-based approach to analyze the influence of known process variables over unknown process variables. The present work is envisaged with the aim of harnessing the features of DOE for process optimization in drilling of GFRP composites.

1.1 RADIAL DRILLING MACHINE

Radial Drilling machine is a machine fitted with a rotating cutting tool called drill bit. This radial drilling machine is used for drilling holes in various materials such as steel, cast iron and. The use of machine is in the metal working industry. A Radial Drilling machine is a large gear headed drill press in which the head moves along the arm that radiates from the column of the machine. The arm of the machine can swing in relation to the base of the machine. This swing operation helps the drill head to move out of the way so a large crane can place the heavy work piece on the base of the radial drilling machine. Also this helps in drilling holes at different locations of the work piece without actually moving the work piece. Power feed of the spindle is a common feature. Also coolant system is a common feature of the radial drilling machine. When it comes to mechanical machining, radial drilling machine is used for all functions such as drilling, counter boring, spot facing, lapping, screwing reaming, tapping and boring. Radial

drilling machines work well with a variety of material such as cast iron, steel, plastic etc. Drilling machines hold a certain diameter of drill (called a chuck) rotates at a specified rpm (revolutions per minute) allowing the drill to start a hole.

A radial drilling machine or radial arm press is a geared drill head that is mounted on an arm assembly that can be moved around to the extent of its arm reach. The most important components are the arm, column, and the drill head. The drill head of the radial drilling machine can be moved, adjusted in height, and rotated. Aside from its compact design, the radial drill press is capable of positioning its drill head to the work piece through this radial arm mechanism. This is probably one of the reasons why more machinists prefer using this type of drilling machine. In fact, the radial drilling machine is considered the most versatile type of drill press. The tasks that a radial drilling machine can do include boring holes, countersinking, and grinding off small particles in masonry works. Although some drill presses are floor mounted, the most common set-up of radial arm drill presses are those that are mounted on work benches or Tables. With this kind of set-up, it is easier to mount the drill and the work pieces. There is no need to reposition work pieces because the arm can extend as far as its length could allow. Moreover, it is easier to maneuver large work pieces with the radial arm drilling machine. Large work pieces can be mounted on the Table by cranes as the arm can be swiveled out of the way.

1.1.1 Components of radial drilling machine

Here are some of the major parts of the radial arm drilling machine explained below Column - is the part of the radial arm drill press which holds the radial arm which can be moved around according to its length

Arm Raise - adjusts the vertical height of the radial arm along the column

On/Off Button - is the switch that activates and deactivates the drill press

Arm Clamp - secures the column and the arm in place

Table - is the area where the work pieces are fed and worked on

Base - is the radial arm drill press part that supports the column and the Table

Spindle - is the rotated part of the drill press which holds the drill chuck used in holding the cutting tool

Drill Head - is the part of the drill press that penetrates through the material or work piece and drill through the specific hole size

Radial Arm - holds and supports the drill head assembly and can be moved around on the extent of its length

There are a number of advantages of using the radial arm drill press. One of these advantages is the amount of area that it can cover which is only dependent on the length of the arm. Another

advantage is the considerable size of work that it can handle since the arm can actually swivel out of the working area allowing cranes and derricks to place work pieces on the Table. Radial drilling machine usually possesses a radial arm which along with the drilling head can swing and move vertically up and down. The radial, vertical and swing movement of the drilling head enables locating the drill spindle at any point within a very large space required by large and odd shaped jobs. There are some more versatile radial drilling machines where the drill spindle can be additionally swivelled or tilted.

1.2 Kinematic System of general purpose drilling machine and their principle of working

Kinematic system in any machine tool is comprised of chain(s) of several mechanisms to enable transform and transmit motion(s) from the power source(s) to the cutting tool and the workpiece for the desired machining action. The kinematic structure varies from machine tool to machine tool requiring different type and number of tool-work motions. Even for the same type of machine tool, say column drilling machine, the designer may take different kinematic structure depending upon productivity, process capability, durability, compactness, overall cost etc targeted.

Typical kinematic system of a very general purpose drilling machine, i.e., a column drilling machine having 12 spindle speeds and 6 feeds. The kinematic system enables the drilling machine the following essential works as

• Cutting motion

The cutting motion in drilling machines is attained by rotating the drill at different speeds (r.p.m.). Like centre lathes, milling machines etc, drilling machines also need to have a reasonably large number of spindle speeds to cover the useful ranges of work material, tool material, drill diameter, machining and machine tool conditions. It is shown that the drill gets its rotary motion from the motor through the speed gear box (SGB) and a pair of bevel gears. For the same motor speed, the drill speed can be changed to any of the 12 speeds by shifting the cluster gears in the SGB. The direction of rotation of the drill can be changed, if needed, by operating the clutch in the speed reversal mechanism.

• Feed motion

In drilling machines, generally both the cutting motion and feed motion are imparted to the drill. Like cutting velocity or speed, the feed (rate) also needs varying (within a range) depending upon the tool-work materials and other conditions and requirements. The drill receives its feed motion from the output shaft of the SGB through the feed gear box (FGA), and the clutch. The feed rate can be changed to any of the 6 rates by shifting the gears. And the automatic feed direction can be reversed, when required, by operating the speed reversal mechanism. The slow rotation of the pinion causes the axial motion of the drill by moving the rack provided on the quil. The upper position of the spindle is reduced in diameter and splined to allow its passing through the gear without hampering transmission of its rotation.

• Tool work mounting

The taper shank drills are fitted into the taper hole of the spindle either directly or through taper socket(s). Small straight shank drills are fitted through a drill chuck having taper shank. The workpiece is kept rigidly fixed on the bed (of the Table). Small jobs are generally held in vice and large or odd shaped jobs are directly mounted on the bed by clamping tools using the T-slots made in the top and side surfaces of the bed.

1.3 General purpose drills

They may be classified as

According to material

• High speed steel – most common
• Cemented carbides
- Without or with coating
- In the form of brazed, clamped or solid

According to size

Large twist drills of diameter around 40 mm
• Micro drills of diameter 25 to 500 μm
• Medium range (most widely used) diameter ranges between 3 mm to 25 mm.

According to number of flutes

• Two fluted – most common
• Single flute – e.g., gun drill (robust)
• Three or four flutes – called slot drill

According to shank

• Straight shank – small size drill being held in drill chuck
• Taper shank – medium to large size drills being fitted into the spindle nose directly or through taper sockets

According to specific applications

• Centre drills- for small axial hole with 60• taper end to accommodate lathe centre for support

Drilling is a cutting process that uses a drill bit to cut or enlarge a hole in solid materials. The drill bit is a multipoint, end cutting tool. It cuts by applying pressure and rotation to the workpiece, which forms chips at the cutting edge. Drilled holes are characterized by their sharp edge on the entrance side and the presence of burrs on the exit side (unless they have been

removed). Also, the inside of the hole usually has helical feed marks. Drilling may affect the mechanical properties of the workpiece by creating low residual stresses around the hole opening and a very thin layer of highly stressed and disturbed material on the newly formed surface. This causes the workpiece to become more susceptible to corrosionat the stressed surface. For fluted drill bits, any chips are removed via the flutes. Chips may be long spirals or small flakes, depending on the material, and process parameters. The type of chips formed can be an indicator of the machinability of the material, with long gummy chips reducing machinability. When possible drilled holes should be located perpendicular to the workpiece surface. This minimizes the drill bit's tendency to "walk", that is, to be deflected, which causes the hole to be misplaced. The higher the length-to-diameter ratio of the drill bit, the higher the tendency to walk. The tendency to walk is also preempted in various other ways, which include:

- Establishing a centering mark or feature before drilling, such as by:
  - Casting, molding, or forging a mark into the workpiece
  - Center punching
  - Spot drilling (i.e., center drilling)
  - Spot facing, which is facing a certain area on a rough casting or forging to establish, essentially, an island of precisely known surface in a sea of imprecisely known surface
- Constraining the position of the drill bit using a drill jig with drill bushings

Surface finish in drilling may range from 32 to 500 microinches. Finish cuts will generate surfaces near 32 microinches, and roughing will be near 500 microinches. Cutting fluid is commonly used to cool the drill bit, increase tool life, increase speeds and feeds, increase the surface finish, and aid in ejecting chips. Application of these fluids is usually done by flooding the workpiece or by applying a spray mist.

In deciding which drill(s) to use it is important to consider the task at hand and evaluate which drill would best accomplish the task. There are a variety of drill styles that each serve a different purpose. The subland drill is capable of drilling more than one diameter. The spade drill is used to drill larger hole sizes. The indexable drill is useful in managing chips.

1.3.1 Spot drilling

The purpose of spot drilling is to drill a hole that will act as a guide for drilling the final hole. The hole is only drilled part way into the workpiece because it is only used to guide the beginning of the next drilling process.

1.3.2 Center drilling

The purpose of center drilling is to drill a hole that will act as a center of rotation for possible following operations. Center drilling is typically performed using a drill with a special shape, known as a center drill.

1.3.3 Deep hole drilling

Deep hole drilling makes reaching extreme depths possible. A high tech monitoring system is used to control force, torque, vibrations, and acoustic emission. The vibration is considered a major defect in deep hole drilling which can often cause the drill to break. Special coolant is usually used to aid in this type of drilling.

1.3.4 Gun drilling

Another type of drilling operation is called gun drilling. This method was originally developed to drill out gun barrels and is used commonly for drilling smaller diameter deep holes. This depth-to-diameter ratio can be even more than 300:1. The key feature of gun drilling is that the bits are self-centering; this is what allows for such deep accurate holes. The bits use a rotary motion similar to a twist drill however; the bits are designed with bearing pads that slide along the surface of the hole keeping the drill bit on center. Gun drilling is usually done at high speeds and low feed rates.

1.3.5 Microdrilling

Microdrilling refers to the drilling of holes less than 0.5 mm (0.020 in). Drilling of holes at this small diameter presents greater problems since coolant fed drills cannot be used and high spindle speeds are required. High spindle speeds that exceed 10,000 RPM also require the use of balanced tool holders.

1.3.6 Trepanning

Trepanning is commonly used for creating larger diameter holes (up to 915 mm (36.0 in)) where a standard drill bit is not feasible or economical. Trepanning removes the desired diameter by cutting out a solid disk similar to the workings of a drafting compass. Trepanning is performed on flat products such as sheet metal, granite (curling stone), plates, or structural members like I-beams. Trepanning can also be useful to make grooves for inserting seals, such as O-rings.

Drilling Materials

1. Metals
2. Non Metals
3. Wood
4. Plastics

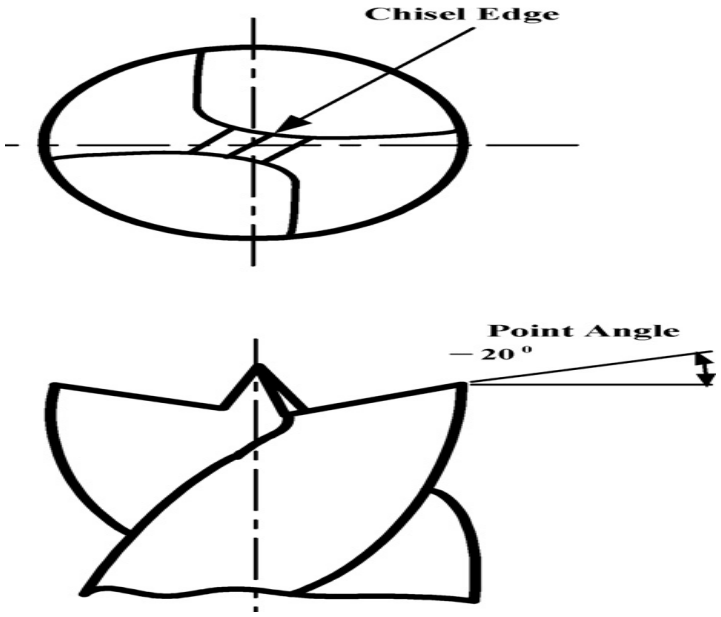


Fig.1 GEOMETRY OF DRILL BIT

1.4 Material

1.4.1 Drilling in Metal

Under normal usage, swarf is carried up and away from the tip of the drill bit by the fluting of the drill bit. The cutting edges produce more chips which continue the movement of the chips outwards from the hole. This is successful until the chips pack too tightly, either because of deeper than normal holes or insufficient backing off (removing the drill slightly or totally from the hole while drilling). Cutting fluid is sometimes used to ease this problem and to prolong the tools life by cooling and lubricating the tip and chip flow. Coolant may be introduced via holes through the drill shank, which is common when using a gun drill. When cutting aluminum in particular, cutting fluid helps ensure a smooth and accurate hole while preventing the metal from grabbing the drill bit in the process of drilling the hole.

For heavy feeds and comparatively deep holes oil-hole drills can be used, with a lubricant pumped to the drill head through a small hole in the bit and flowing out along the fluting. A conventional drill press arrangement can be used in oil-hole drilling, but it is more commonly seen in automatic drilling machinery in which it is the workpiece that rotates rather than the drill bit. In computer numerical control (CNC) machine tools a process called peck drilling, or interrupted cut drilling, is used to keep swarf from detrimentally building up when drilling deep holes (approximately when the depth of the hole is three times greater than the drill

diameter). Peck drilling involves plunging the drill part way through the workpiece, no more than five times the diameter of the drill, and then retracting it to the surface. This is repeated until the hole is finished. A modified form of this process, called high speed peck drilling or chip breaking, only retracts the drill slightly. This process is faster, but is only used in moderately long holes otherwise it will overheat the drill bit. It is also used when drilling stringy material to break the chips.

1.4.2 Drilling in wood

Wood being softer than most metals, drilling in wood is considerably easier and faster than drilling in metal. Cutting fluids are not used or needed. The main issue in drilling wood is assuring clean entry and exit holes and preventing burning. Avoiding burning is a question of using sharp bits and the appropriate cutting speed. Drill bits can tear out chips of wood around the top and bottom of the hole and this is undesirable in fine woodworking applications. The ubiquitous twist drill bits used in metalworking also work well in wood, but they tend to chip wood out at the entry and exit of the hole. In some cases, as in rough holes for carpentry, the quality of the hole does not matter, and a number of bits for fast cutting in wood exist, including spade bits and self-feeding auger bits. Many types of specialised drill bits for boring clean holes in wood have been developed, including brad-point bits, Forstner bits and hole saws. Chipping on exit can be minimized by using a piece of wood as backing behind the work piece, and the same technique is sometimes used to keep the hole entry neat. Holes are easier to start in wood as the drill bit can be accurately positioned by pushing it into the wood and creating a dimple. The bit will thus have little tendency to wander.

Others

Some materials like plastics as well as other non-metals and some metals have a tendency to heat up enough to expand making the hole smaller than desired.

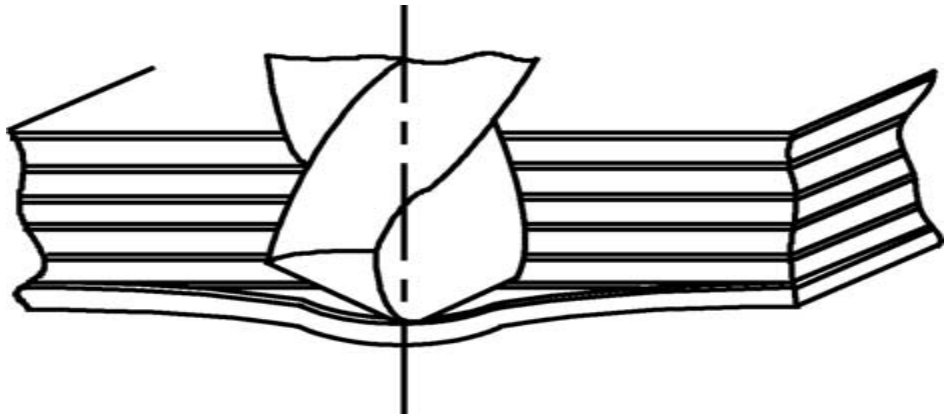


Fig.1.1 Drilling in Composites

1.5 Drill Motor

A drill or drill motor is a tool fitted with a rotating cutting tool, usually a drill bit, used for drilling holes in various materials. The cutting tool is gripped by a chuck at one end of the drill and rotated while pressed against the target material. The tip of the cutting tool does the work of cutting into the target material. This may be slicing off thin shavings (twist drills or auger bits), grinding off small particles (oil drilling), crushing and removing pieces of the workpiece (SDS masonry drill), countersinking, counter boring, or other operations. Drills are commonly used in woodworking, metalworking, construction and most "do it yourself" projects. Specially designed drills are also used in medicine, space missions and other applications. There are many types of drills: some are powered manually, others use electricity (electric drill) or compressed air (pneumatic drill) as the motive power, and a minority are driven by an internal combustion engine (for example, earth drilling augers). Drills with a percussive action (hammer drills) are mostly used in hard materials such as masonry (brick, concrete and stone) or rock. Drilling rigs are used to bore holes in the earth to obtain water or oil. Oil wells, water wells, or holes forgeo thermal heating are created with large drilling rigs. Some types of hand-held drills are also used to drive screws. Some small appliances that have no motor of their own may be drill-powered, such as small pumps, grinders, etc. The hammer drill is similar to a standard electric drill, with the exception that it is provided with a hammer action for drilling masonry. The hammer action may be engaged or disengaged as required. Most electric hammer drills are rated (input power) at between 600 and 1100 watts. The efficiency is usually 50-60% i.e. 1000 watts of input is converted into 500-600 watts of output (rotation of the drill and hammering action).

The hammer action is provided by two cam plates that make the chuck rapidly pulse forward and backward as the drill spins on its axis. This pulsing (hammering) action is measured in Blows Per Minute (BPM) with 10,000 or more BPMs being common. Because the combined mass of the chuck and bit is comparable to that of the body of the drill, the energy transfer is inefficient and can sometimes make it difficult for larger bits to penetrate harder materials such as poured concrete. The operator experiences considerable vibration, and the cams are generally made from hardened steel to avoid them wearing out quickly. In practice, drills are restricted to standard masonry bits up to 13 mm (1/2 inch) in diameter. A typical application for a hammer drill is installing electrical boxes, conduit straps or shelves in concrete. In contrast to the cam-type hammer drill, a rotary/pneumatic hammer drill accelerates only the bit. This is accomplished through a piston design, rather than a spinning cam. Rotary hammers have much less vibration and penetrate most building materials. They can also be used as "drill only" or as "hammer only" which extends their usefulness for tasks such as chipping brick or concrete. Hole drilling

progress is greatly superior to cam-type hammer drills, and these drills are generally used for holes of 19 mm (3/4 inch) or greater in size.

1.6 Thrust Force

Thrust force during drilling can be defined as “the force acting along the axis of the drill during the cutting process.” Cutting forces help monitor tool wear, since forces increase with tool wear. Thrust force is also used to monitor tool wear and, in turn, monitor tool life. Tool failure can occur if tool wear is not monitored. Other than being an important factor in the monitoring of tool wear, thrust force is considered to be the major contributor of delamination during drilling. Considerable research has been done to prove that there is a “critical thrust force” that causes delamination, and thrust force below that will constrain or eliminate delamination during drilling. Vibratory drilling has been known as one of the methods to reduce thrust force during drilling of steel and during drilling of composites. Machining of delamination free composites using conventional methods would lower the cutting quantities. If the “critical thrust force” is known, then the machining efficiency can be increased and higher quantities can be machined. This thesis deals with the prediction of thrust force at which delamination will occur during drilling of composites.

CHAPTER – 2

LITERATURE REVIEW

Taguchi method systematically reveals the complex cause and effect relationship between design parameter and performance. Taguchi methods are most recent additions to the tool kit of design, process, and manufacturing engineers and quality assurance experts. In contrast to stastical process control which attempt to control the factors that adversely affect the quality of production.

2.1 Feed

Capello E, **Tagliaferri V [1]** studied the effect of the drilling on the residual mechanical behavior of glass fiber reinforced plastic (GFRP) laminates when the hole is subjected to bearing load. In the first part, the influence of drilling parameters on the type and extension of the damage is analyzed. The damage was described at the macro level (delaminated area) and at the micro level (cracks, fiber-matrix debonding, etc.). The Design of Experiments and Analysis of Variance techniques are used in order to determine the statistical influence of the drilling parameters on the delamination area. Moreover, the effects of drilling with or without a support beneath the specimens are analyzed and discussed. Push-down delamination was mainly affected by the feed rate, by the presence of support beneath the specimen, and by the twist drill temperature.

G. Caprino and V. Tagliaferri studied [2] to clarify the interaction mechanisms between the drilling tool and material. Drilling tests were carried out on glass-polyester composites using standard HSS tools; drilling was interrupted at preset depths to study damage development during drilling. The specimens, polished by a metallographic technique, were examined by optical microscopy to identify any damage. The results obtained were useful in describing the damage history and to help design drill geometries specifically conceived for composite machining. The qualitative agreement of the observed behavior with the predictions of the model presented in the literature and some of their intrinsic limitations are assessed.

R. Piquet et. al [3] studied the drilling with a twist drill and a specific cutting tool of structural thin backing plates in carbon/epoxy. The possibility to manufacture carbon/epoxy with a conventional cutting tool was analysed and the limits of the twist drill were shown. Consequently we defined a specific cutting tool. Series of comparative experiments were carried out using a conventional twist drill and this specific cutting tool. The results shown the capabilities of the 18 specific cutting tool because several defects and damages usually encountered in twist drilled holes were minimised or avoided (entrance damage, roundness and diameter defects and plate exit damage).

E.-S. Lee [4] studied the machinability of GFRP by means of tools made of various materials and geometries was investigated experimentally. By proper selection of cutting tool material and geometry, excellent machining of the workpiece is achieved. The surface quality relates closely

to the feed rate and cutting tool. When using glass fibre reinforced plastics (GFRP) it is often necessary to cut the material, but the cutting of GFRP is often made difficult by the delamination of the composite and the short tool life.

L-B Zhang, L-J Wang and X-Y Liu [5] studied the analysis for multidirectional composite laminates is based on linear elastic fracture mechanics (LEFM), classical bending plate theory and the mechanics of composites. This paper presents a general closed-form mechanical model for predicting the critical thrust force at which delamination is initiated at different ply locations. Good correlation is observed between the model and the experimental results.

2.2 Speed

E. Ugo. Enemuoh et. al [6] studied new comprehensive approach to select cutting parameters for damage-free drilling in carbon fiber reinforced epoxy composite material is presented. The approach is based on a combination of Taguchi's experimental analysis technique and a multi objective optimization criterion. The optimization objective includes the contributing effects of the drilling performance measures: delamination, damage width, surface roughness, and drilling thrust force. A hybrid process model based on a database of experimental results together with numerical methods for data interpolation are used to relate drilling parameters to the drilling performance measures. Case studies are presented to demonstrate the application of this method in the determination of optimum drilling conditions for damage-free drilling in BMS 8-256 composite laminate.

J. Paulo Davim and Pedro Reis [7] studied the cutting parameters (cutting velocity and feed rate) on power (P_c), specific cutting pressure (K_s), and delamination in carbon fiber reinforced plastics (CFRPs). A plan of experiments, based on the techniques of Taguchi, was established considering drilling with prefixed cutting parameters in an autoclave CFRP composite laminate. The analysis of variance was preformed to investigate the cutting characteristics of CFRPs using cemented carbide (K10) drills with appropriate geometries. The objective was to establish a correlation between cutting velocity and feed rate with the power (P_c) specific cutting pressure (K_s) and delamination factor (F_d) in a CFRP material. Finally, this correlation was obtained by multiple linear regressions.

C. C. Tsao,H. Hocheng [8] studied prediction and evaluation of delamination factor in use of twist drill, candle stick drill and saw drill. The approach is based on Taguchi's method and the analysis of variance (ANOVA). An ultrasonic C-Scan to examine the delamination of carbon fiber-reinforced plastic (CFRP) laminate is used in this paper. The experiments were conducted to study the delamination factor under various cutting conditions. The experimental results indicate that the feed rate and the drill diameter are recognized to make the most significant contribution to the overall performance. The objective was to establish a correlation between feed rate, spindle speed and drill diameter with the induced delamination in a CFRP laminate. The correlation was obtained by multi-variable linear regression and compared with the experimental results.

U. A. Khashaba [9] studied the Delamination-free in drilling different fiber reinforced thermoset composites was the main objective of research. Therefore the influence of drilling and material variables on thrust force, torque and delamination of GFRP composites was investigated

experimentally. Drilling variables were cutting speed and feed. Material variable include matrix type, filler and fiber shape. Drilling process was carried out on cross-winding/polyester, continuous-winding with filler/polyester, chopped/polyester, woven/polyester and woven/epoxy composites. A simple inexpensive accurate technique was developed to measure delamination size. The thrust forces in drilling continuous-winding composite are more than three orders of magnitude higher than those in the cross-winding composites. Delamination, chipping and spalling damage mechanisms were observed in drilling chopped and continuous-winding composites. Delamination-free in drilling cross-winding composites was achieved using variable feed technique.

J. Paulo Davim, Pedro Reis and C. Conceicao Antonio [10] studied the cutting parameters (cutting velocity and feed) and the influence of the matrix under specific cutting force (kc), delamination factor (F_d) and surface roughness (R_a) in two types of matrix (Viapal VUP 9731 and ATLAC 382-05). A plan of experiments, based on the orthogonal array, was established considering drilling with prefixed cutting parameters in two hand lay-up FRPs materials. Finally the analysis of variance (ANOVA) was preformed to investigate the cutting characteristics of FRPs composite material using a cemented carbide (K10) drill with appropriate geometry.

2.3 Thrust Force and Torque

I. El-Sonbaty, U. A. Khashaba and T. Machaly [11] studied the influence of some parameters on the thrust force, torque and surface roughness in drilling processes of fiber-reinforced composite materials. These parameters include cutting speed, feed, drill size and fiber volume fraction. The quasi-isotropic composite materials were manufactured from randomly oriented glass fiber-reinforced epoxy, with various values of fiber volume fractions (V_f), using hand-layup technique. Two components drill dynamometer has been designed and manufactured to measure the thrust and torque during the drilling process. The dynamometer was connected with a data acquisition, which installed in a PC computer. This set-up enables to monitor and record the thrust force and torque with the aid of a computer program that designed using Lab View utilities.

Jin Pyo Jung, Geun Woo Kim and Kang Yong Lee [12] studied new formulation for the critical thrust force necessary to propagate the delamination generated during the drilling operation of an antisymmetric angle-ply laminate is proposed by modeling the delamination zone as an elliptical shape. The critical thrust force is analytically derived with the consideration of bending, twisting and mid-plane extension of the delamination zone. And then to maximize the critical thrust force, the optimal design of an angle-ply laminate is performed to find the optimal number of fiber per millimeter, optimum diameter of fiber and optimum lamination angle using ADS (Automated Design Synthesis).

Velayudham A, Krishnamurthy R and Soundarapandian T [13] studied the dynamics of drilling of high volume fraction glass fibre reinforced composite. At high fibre volume, fibres do not show much relaxation and normal hole shrinkage associated with polymeric composites was not observed during drilling. Peak drilling thrust, dimension of holes drilled and vibration induced during drilling are observed to correlate with each other. Vibrations study has been

attempted through wavelet packet transform and the results demonstrated its capability in signal characterisation.

2.4 Delamination

N.S. Mohan, S.M. Kulkarni and A. Ramachandra [14] studied the drilling parameters and specimen parameters evaluated were speed, feed rate, drill size and specimen thickness on FRP. A signal-to-noise ratio is employed to analyze the influence of various parameters on peel up and push down delamination factor in drilling of glass fibre reinforced plastic (GFRP) composite laminates. The main objective of this study was to determine factors and combination of factors that influence the delamination using Taguchi and response surface methodology and to achieve the optimization machining conditions that would result in minimum delamination. From the analysis it is evident that among the all significant parameters, specimen thickness and cutting speed have significant influence on peel up delamination and the specimen thickness and feed have more significant influence on push down delamination.

C.C. Tsao and H. Hocheng [15] studied the effects of backup plate on delamination in drilling composite materials using saw drill and core drill. The critical drilling thrust force at the onset of delamination is calculated and compared with that without backup. Saw drills and core drills produce less delamination than twist drills by distributing the drilling thrust toward the hole periphery. Delamination can be effectively reduced or eliminated by slowing down the feed rate when approaching the exit and by using back-up plates to support and counteract the deflection of the composite laminate leading to exit side delaminations. The use of the back-up does reduce the delamination in practice, which its effects have not been well explained in analytical fashion.

I. Singh and N. Bhatnagar [16] studied to correlate drilling-induced damage with drilling parameters. Tool point geometry is considered a major factor that influences drilling-induced damage. Experiments were conducted and drilling-induced damage was quantified using the digital image processing technique. The results also reestablished the cutting speed to feed ratio as an important variable that influences drilling-induced damage. Mathematical models for thrust, torque, and damage are proposed that agree well with the experiments.

S. Arul et. al [17] studied the drilling of polymeric composites which aimed to establish a technology that would ensure minimum defects and longer tool life. Specifically, the authors conceived a new drilling method that imparts a low-frequency, high amplitude vibration to the workpiece in the feed direction during drilling. Using high-speed steel (HSS) drill, a series of vibratory drilling and conventional drilling experiments were conducted on glass fiber-reinforced plastics composites to assess thrust force, flank wear and delamination factor. In addition, the process status during vibratory drilling was also assessed by monitoring acoustic emission from the workpiece. From the drilling experiments, it was found that vibratory drilling method is a promising machining technique that uses the regeneration effect to produce axial chatter, facilitating chip breaking and reduction in thrust force.

H. Hocheng and C.C. Tsao [18] studied the critical thrust force at the onset of delamination, and compares the effects of these different drill bits. The results confirm the analytical findings and are consistent with the industrial experience. Ultrasonic scanning is used to evaluate the

extent of drilling-induced delamination in fiber-reinforced materials. The advantage of these special drills is illustrated mathematically as well as experimentally, that their thrust force is distributed toward the drill periphery instead of being concentrated at the center. The allowable feed rate without causing delamination is also increased. The analysis can be extended to examine the effects of other future innovative drill bits.

J. Rubioa et. al [19] studied HSM to realize high performance drilling of glass fibre reinforced plastics (GFRP) with reduced damage. In order to establish the damage level, digital analysis is used to assess delamination. A comparison between the conventional (Fd) and adjusted (Fda) delamination factor is presented. The experimental results indicate that the use of HSM carried out for drilling GFRP ensuring low damage levels. Drilling is probably the machining process most widely applied to composite materials; nevertheless, the damage induced by this operation may reduce drastically the component performance.

V. Krishnaraj, S. Vijayarangan and A. Ramesh Kumar [20] studied the damage generated during the drilling of Glass Fibre Reinforced Plastics (GFRP) which was detrimental for the mechanical behaviour of the composite structure. This work was focused on analysing the influence of drilling parameters (spindle speed and feed) on the strength of the GFR woven fabric laminates and further to study the residual stress distribution around the hole after drilling. Holes were drilled at the centre of the specimens in a CNC machining centre using 6 mm diameter micrograin carbide drill for various spindle speeds (1000 4000 rpm) and feed rates (0.02, 0.06, 0.10 and 0.20 rev/min). Degree of damage depends on the feed rate and spindle speed. Experimental results indicate that failure strength and stress concentration are related to the drilling parameters and a drilling parameter (3000 rpm and 0.02 mm/rev), which gives better mechanical strength.

U.A. Khashaba M.A. Seif and M.A. Elhamid [21] studied the effects of the drilling parameters, speed, and feed, on the required cutting forces and torques in drilling chopped composites with different fiber volume fractions. Three speeds, five feeds, and five fiber volume fractures are used in this study. The results show that feeds and fiber volumes have direct effects on thrust forces and torques. On the other hand, increasing the cutting speed reduces the associated thrust force and torque, especially at high feed values. Using multivariable linear regression analysis, empirical formulas that correlate favorably with the obtained results have been developed. These formulas would be useful in drilling chopped composites. The influence of cutting parameters on peel-up and push-out delaminations that occurs at drill entrance and drill exit respectively the specimen surfaces have been investigated. No clear effect of the cutting speed on the delamination size is observed, while the delamination size decreases with decreasing the feed. Delamination-free in drilling chopped composites with high fiber volume fraction remains as a problem to be further investigated.

Redouane Zitoune, Vijayan Krishnaraj and Francis Collombet [22] studied the parametric influences on thrust force, torque as well as surface finish, the experimental results shown that the quality of holes can be improved by proper selection of cutting parameters. This is substantiated by monitoring thrust force, torque, surface finish, circularity and hole diameter. For the CFRP, the circularity is found to be around 6 lm at low feed rates, when the feed is increased the circularity increases to 25 lm. The wear tests carried out show that, during first 30 holes,

thrust force in CFRP undergoes a more important increase (90%) than thrust force of aluminium (6%).

2.5 Drill Wear

I.S. Shyha et. al [23] studied the effect of drill geometry and drilling conditions on tool life and hole quality. Main effects plots and percentage contribution ratios (PCR) are detailed in respect of response variables and process control factors. More conventionally, tool wear and cutting force data are plotted tabulated, together with micrographs of hole entry/exit condition and internal hole damage. Drill geometry and feed rate in general had the most effect on measured outputs. Thrust force was typically below 100 Nattestcessation; however, drill wear progression effectively doubled the magnitude of force from test outset. Entry and exit delamination factors (Fd) of 1.3 were achieved while the maximum number of drilled holes for a tool life criterion VBB max of r 100 mm was 2900 holes using a stepped, uncoated drill with a feed rate of 0.2 mm/rev.

S.R. Karnik et.al [24] studied the delamination behaviour as a function of drilling process parameters at the entrance of the CFRP plates. The delamination analysis in high speed drilling is performed by developing an artificial neural network (ANN) model with spindle speed, feed rate and point angle as the affecting parameters. A multilayer feed forward ANN architecture, trained using error-back propagation training algorithm (EBPTA) is employed for this purpose. Drilling experiments were conducted as per full factorial design using cemented carbide (grade K20) twist drills that serve as input–output patterns for ANN training. The validated ANN model is then used to generate the direct and interaction effect plots to analyze the delamination behavior. The simulation results illustrate the effectiveness of the ANN models to analyze the effects of drilling process parameters on delamination factor. The analysis also demonstrates the advantage of employing higher speed in controlling the delamination during drilling.

L.M.P. Durao et.al [25] studied to minimization of axial thrust force during drilling reduces the probability of delamination onset, as it has been demonstrated by analytical models based on linear elastic fracture mechanics (LEFM). A finite element model considering solid elements of the ABAQUS software library and interface elements including a cohesive damage model was developed in order to simulate thrust forces and delamination onset during drilling. Thrust force results for delamination onset are compared with existing analytical models.

Redouane Zitoun and Francis Collombe [26] studied a numerical FE analysis is proposed to calculate the thrust forces responsible for the defect at the exit of the hole during the drilling phase of long-fibre composite structures, within a quasi-static framework. This numerical model compared with the analytical models studied in the literature – takes into account the tool point geometry as well as the shear force effects in the laminate.

On the other hand, soft computing methods have been successfully applied to different applications in the field of petroleum industry such as reservoir characterization (Zellou and Ouenes, 2007), optimum bit selection (Yilmaz et al., 2002), trap quality evaluation (Shi et al., 2004), and drilling rate prediction (Bahari and Baradaran, 2009) during past decades. In fact, these intelligent methodologies have many features that make them attractive to use in these

problems. Among these, however, the ability to deal with ill-defined and noisy real signals and datasets are the most important one. Hole making is one of the most important process in manufacturing (Serope Kalpakjian, 2001). One of the methods to make a hole is by drilling operation (Osawa et al, 2005). Drills basically have high length to diameter ratios, thus they are capable to produce a deep holes (Serope Kalpakjian, 2001). However, the friction will occur when the drills touches the surface of the work piece (Serope Kalpakjian, 2001). This situation will make the rpm of the motor decreasing and this will make the hole making less accurate as it should be from theoretically. There are several type of drilling which are gun drilling, twist drill, and trepanning.

Abrao et al. have focused the investigation on the effect of cutting tool geometry and material on thrust force and delamination produced while drilling GFRP composites. Durao et al. have studied the effect on drilling characteristics of hybrid carbon + glass/epoxy composites. They validated the influence of delamination in bearing stress of drilled hybrid carbon + glass/epoxy quasi-isotropic plates. They conducted the experiments with five different drill bits viz., HSS twist drill, carbide twist drill, carbide brad, carbide dagger and special step drills. Dandekar et al. carried out a experimental study of comparing the drilling characteristics of E-glass fabric reinforced polypropylene composite and aluminum alloy 6061-T6. Mohan et al. have studied the influence of cutting parameters, drill diameter and thickness while machining GFRP composites and analyze the delamination. Paulo Davim et al. have studied the influence of cutting parameters (cutting velocity and feed) while machining GFRP with two different matrixes in order to study its influence along with those parameters on delamination. Khashaba et al. have studied the influence of material variables on thrust force, torque and delamination while drilling of GFRP composites with different types of fiber structures. They have carried out the experiment with cross winding /polyester, continuous winding/polyester, woven polyester and woven /epoxy. Among all it seems woven epoxy came out with best results in terms of torque, thrust force. Tsao et al. have studied the drilling of CFRP composite. Here the approach carried was carried out based on Taguchi techniques and analysis of variance. The main focus of this work is to have a correlation between drill diameter, feed rate and spindle speed .The experiments were carried out at 3 levels .The phenomenon of interaction was not considered and the results indicated that the drill diameter have a significant contribution to the overall performance. From the above literature, it has been known that the delamination due to thrust force and torque produced in drilling are important concern and is to be modeled. For modeling thrust force and torque in drilling of composite materials fuzzy logic approach is used in this work. Artificial intelligence tools are playing an important role in modeling and analysis. Fuzzy logic is relatively easier to develop and require less hardware and software resources. Fuzzy logic controller is the successful application of fuzzy set theory and was introduced by Zadeh in 1965 as an extension of the set theory by the replacement of the characteristic function of a set by a membership function whose value range from 0 to 1. A considerable amount of investigations have been directed towards the prediction and measurement of thrust forces. The thrust force generated during drilling have a direct influence on the cutting of material. Wear on the tool, accuracy of the workpiece and quality of the hole obtained in drilling are mainly depends on thrust force. Balazinski and Jemielnaik introduced the fuzzy decision support system for the estimation of the depth of cut and flank wear during the turning process. Arghavani et al. used fuzzy logic approach for the selection of gaskets in sealing performance. Yue jiao et al. used fuzzy adaptive networks in machining process modeling. They have used fuzzy logics for

surface roughness prediction in turning operations. Palani kumar et al. used fuzzy logic for optimizing the multiple performance characteristics. Recently Latha and Senthil kumar have successfully applied fuzzy logic for the prediction of delamination in drilling of glass fibre reinforced plastics. In the present work a user friendly fuzzy logic based system has been designed for the prediction of thrust force and torque in drilling of glass fiber reinforced plastic composites. The experiments are conducted on computer numerical control machining centre. L18 orthogonal array is used for experimentation. Special multi-facet drill is used for the investigation. The results indicated that the fuzzy logic model can be effectively used for the drilling of composites.

CHAPTER – 3

DESIGN OF EXPERIMENT

3.1 Outline of Thesis Work

The recent study consists of experimentations, parametric analysis using MATLAB software and finally mathematical modeling using MINITAB 15 software. Experimentation generally specifies the machining of Mild Steel specimen on Radial drilling machine. A kistler dynamometer has been installed on drilling machine for calculating thrust forces and torque on work piece while machining. Taguchi method using design of experiments approach has been used to optimize a process. Here we have applied D.O.E approach for modeling of thrust forces and torque in drilling process, the various input parameters have been taken under experimental investigation and then model has prepared for doing experimentation. The results obtain has been analyzed and the models produced by using MINITAB software. These models produced shown the results that which parameter is more effective in producing more thrust forces and torque. Different tool materials of drill bits have been used made of HSS.

3.2 Various Input Parameters

1. Feed rate
2. Cutting Force
3. Speed
4. Drill bit material
5. Geometry of drill bit
6. Diameter
7. Depth of Cut

3.3 Output Parameters

1. Thrust Force
2. Torque
3. Tool Wear

After research it has been found that above are important input parameters for studying Thrust forces and Torque. After literature review three main input parameters are Speed, Feed Rate, Depth of Cut are used for experimentation and other is drill bit material. Three type of drill

material has been used for three set of experimentation by taking same input parameters. The specimen is made of Mild Steel. The standard high-speed steel twist drills of 10 mm & 12 mm diameters with different point angles was used in the present investigation. Each fresh drill point was used to make the holes in order to nullify the effect of tool wear on cutting forces.

3.4 Design of Experiment

The objective of this research work is to study the effect of different parameters such as feed rate and speed and for this purpose, design models have been prepared by choosing different levels:

a) Cutting force.
b) Feed rate.
c) Speed.
d) Workpiece materials.
e) Depth of Cut.
f) Diameters.

For conducting the experiments, it has been decided to follow the Taguchi method of experimental design and an appropriate orthogonal array is to be selected after taking into consideration the above design variables. Out of the above listed design variables, the orthogonal array was to be selected for four design variables (namely feed rate and speed) which would constitute the orthogonal array. The two most important outputs are thrust force and torque for this research work has been analyzed. The effect of the variation in input process parameter will be studied on these response parameters and the experimental data will be analyzed as per Taguchi method to find out the optimum machining condition and percentage contribution of each factor.

3.5 Tool Used in Machining

Twist drill has been used of material made of HSS.

HSS composition 1.20 -1.40% carbon; 0.50% Manganese; 1.00% maximum Silicon; 3.5 to 4.5% Chromium; 2.25-2.75% Vanadium; 5.60- 6.40% Tungsten; 5.60- 6.40% Molybdenum; 5.0 to 7.0% Cobalt

3.6 Experimental Procedure

The key factor in developing a mathematical model is to obtain sufficient experimental data simulating the working environment in the laboratory. The dependently controllable factors affecting the thrust forces and torque were identified as the Feed rate, Cutting speed. The Experiment has been conducted by Drilling of mild steel, using HSS Twist Drill of 10 mm and 12 mm diameter. The cutting force components and torque has been measured with a Piezo-electric three-component dynamometer (Kistler), a multi channel charge amplifier (Kistler, Type 5070A) and a data acquisition system. Experiments were carried out under various cutting conditions like different speeds, feed rates. To reduce the total number of experiments and to

obtain data uniformly from all the regions of the selected working area, a factorial design procedure has been adopted.

3.7 Experimental Set Up

Radial drilling has been used for experimental work for drilling holes. Three different types of drills has been used. Total three drills has been used. In experiment drill bit of 10 mm has been used for drilling 10 mm diameter hole and so on.

3.8 Radial Drilling Machine

A radial drilling machine has been used for the experiment having different range of feed & speed. Different range of speed can be chosen in machine by shifting the gears according to required speed.

Fig.3.1 HSS Drill Bits

3.9 Dynamometer

Piezo-electric three-component dynamometer (Kistler, Type 5070A) has been used for measuring the thrust forces and torque. Readings from the dynamometer were fed to the computer for analytical and saving purposes. Each of these values were measured by voltage fluctuation recorded by dynamometer during drilling operation.

Fig. 3.2 A radial drilling machine

Different range of feed like coarse, fine and manual can be chosen from this machine like coarse have feed of range 0.2 mm/rev and fine have range of 0.1 mm/rev. And manual feed we can give by own according to time a drill takes to travel into workpiece.

Table 3.1 Experimental L18 Orthogonal Array (Taguchi Design)

S No.	Diameter (mm)	Speed (rpm)	Feed rate (mm/rev)	Thrust force (N)	Depth of Cut (mm)
1	10	300	0.6	1480	4
2	10	300	0.6	1480	8
3	10	300	0.6	1480	12
4	10	600	0.8	1540	4
5	10	600	0.8	1540	8
6	10	600	0.8	1540	12
7	10	900	1.0	1620	4
8	10	900	1.0	1620	8
9	10	900	1.0	1620	12
10	12	300	0.8	1620	4
11	12	300	0.8	1620	8
12	12	300	0.8	1620	12
13	12	600	1.0	1540	4
14	12	600	1.0	1540	8
15	12	600	1.0	1540	12
16	12	900	0.6	1480	4
17	12	900	0.6	1480	8
18	12	900	0.6	1480	12

3.10 Cutting forces

The cutting force (F) appearing when processing a fine hole may be expressed as the sum of force for removing a material as follows and the pressure(P) for removing a chip which occurred between the particles of the micro drill and the fine hole.

$$F = Fa + \int P \, dA \ldots\ldots\ldots (3.1)$$

The increase in pressure for removing a chip occurred between the particles of a micro drill and the fine hole, generating the rise of heat in the process part of the fine hole as well as the change of cutting force. Heat generated from micro drilling accelerates the oxidation of the particles, which is a major reason for tool wear. Tangential cutting force is by far the greater (if translated to the planer this is the force acting on the tool in the direction of the workpiece travel). Axial cutting force is the force required to keep the cutting edge in contact with the workpiece (perpendicular to the surface of the workpiece on the planer).

Table 3.2 Standards L18 Orthogonal Array (Taguchi Design)

S No.	Diameter (mm)	Speed (rpm)	Feed rate (mm/rev)	Thrust force (N)	Depth of Cut (mm)
1	1	1	1	1	1
2	1	1	1	1	2
3	1	1	1	1	3
4	1	2	2	2	1
5	1	2	2	2	2
6	1	2	2	2	3
7	1	3	3	3	1
8	1	3	3	3	2
9	1	3	3	3	3
10	2	1	2	3	1
11	2	1	2	3	2
12	2	1	2	3	3
13	2	2	3	2	1
14	2	2	3	2	2
15	2	2	3	2	3
16	2	3	1	1	1
17	2	3	1	1	2
18	2	3	1	1	3

3.11 Delamination

It is a mode of failure for composite materials. Modes of failure are also known as 'failure mechanisms'. In laminated materials, repeated cyclic stresses, impact, and so on can cause layers to separate, forming a mica-like structure of separate layers, with significant loss of mechanical toughness. Delamination also occurs in reinforced concrete structures subject to reinforcement corrosion, in which case the oxidized metal of the reinforcement is greater in volume than the original metal. The oxidized metal therefore requires greater space than the original reinforcing bars, which causes a wedge-like stress on the concrete. This force eventually overcomes the relatively weak tensile strength of concrete, resulting in a separation (or delamination) of the concrete above and below the reinforcing bars.The cause of fiber pull-out (another form of failure mechanism) and delamination is weak bonding. Thus, delamination is an insidious kind of failure as it develops inside of the material, without being obvious on the surface, much like metal fatigue. Delamination failure may be detected in the material by its sound; solid composite has bright sound, while delaminated part sounds dull, reinforced concrete sounds solid, whereas delaminated concrete will have a light drum-like sound when exposed to a dragged chain pulled across its surface. Bridge decks in cold climate countries which use de-icing salts and chemicals are commonly subject to delamination and as such are typically scheduled for annual inspection by chain-dragging as well as subsequent patch repairs of the surface. Other nondestructive testingmethods are used, including embedding optical

fibers coupled with optical time domain reflectometer testing of their state, testing with ultrasound, radiographic imagining, and infrared imaging.

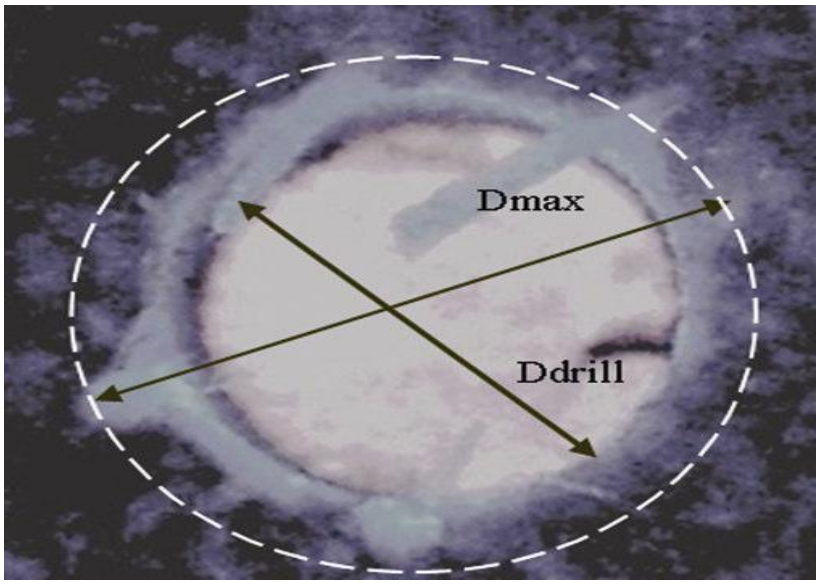


Fig. 3.3 The delamination size around the drilled hole

3.12 Tool wear

Tool wear describes the gradual failure of cutting tools due to regular operation. It is a term often associated with tipped tools, tool bits, or drill bits that are used with machine tools.

Types of wear include:

- **flank wear** in which the portion of the tool in contact with the finished part erodes. Can be described using the Tool Life Expectancy equation.
- **crater wear** in which contact with chips erodes the rake face. This is somewhat normal for tool wear, and does not seriously degrade the use of a tool until it becomes serious enough to cause a cutting edge failure.

Can be caused by spindle speed that is too low or a feed rate that is too high. In orthogonal cutting this typically occurs where the tool temperature is highest. Crater wear occurs approximately at a height equaling the cutting depth of the material. Crater wear depth ~ t_0 t_0= cutting depth

- built-up edge in which material being machined builds up on the cutting edge. Some materials (notably aluminum and copper) have a tendency to anneal themselves to the cutting edge of a tool. It occurs most frequently on softer metals, with a lower melting point. It can be prevented by increasing cutting speeds and using lubricant. When drilling it can be noticed as alternating dark and shiny rings.
- **glazing** occurs on grinding wheels, and occurs when the exposed abrasive becomes dulled. It is noticeable as a sheen while the wheel is in motion.
- **edge wear**, in drills, refers to wear to the outer edge of a drill bit around the cutting face caused by excessive cutting speed. It extends down the drill flutes, and requires a large volume of material to be removed from the drill bit before it can be corrected.

Effects of Tool wear

Some General effects of tool wear include:

- increased cutting forces
- increased cutting temperatures
- poor surface finish
- decreased accuracy of finished part

Reduction in tool wear can be accomplished by using lubricants and coolants while machining. These reduce friction and temperature, thus reducing the tool wear.

3.13 Tool life Expectancy

The **Taylor Equation for Tool Life Expectancy** provides a good approximation.

$V_c T^n = C$…….(3.2)

A more general form of the equation is

$V_c T^n \times D^x f^y = C$…….(3.3)

where

- V_c=cutting speed
- T=tool life
- D=depth of cut
- F=feed rate
- x and y are determined experimentally
- n and C are constants found by experimentation or published data; they are properties of tool material, workpiece and feed rate.

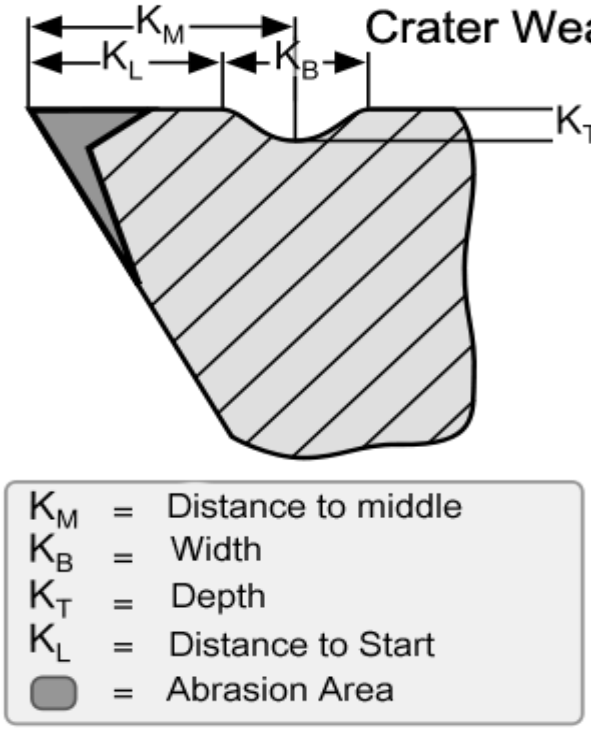


Fig. 3.4 Crater wear (www.wikipedia.org)

3.14 Temperature Considerations

At high temperature zones crater wear occurs. The highest temperature of the tool can exceed 700 °C and occurs at the rake face whereas the lowest temperature can be 500 °C or lower depending on the tool.

3.15 Energy Considerations

Energy comes in the form of heat from tool friction. It is a reasonable assumption that 80% of energy from cutting is carried away in the chip. If not for this the workpiece and the tool would be much hotter than what is experienced. The tool and the workpiece each carry approximately 10% of the energy. The percent of energy carried away in the chip increases as the speed of the cutting operation increases. This somewhat offsets the tool wear from increased cutting speeds. In fact, if not for the energy taken away in the chip increasing as cutting speed is increased; the tool would wear more quickly than is found.

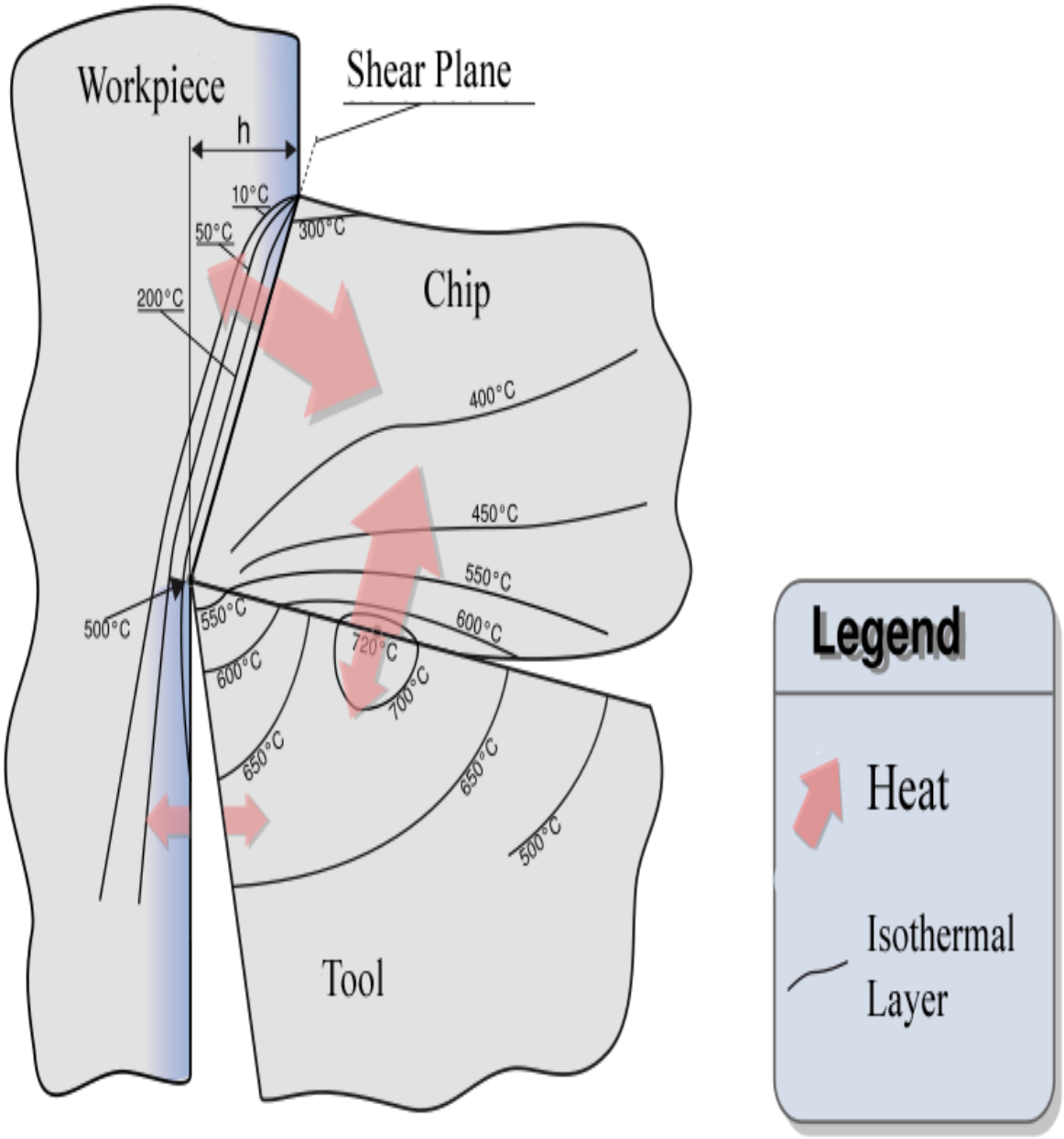


Fig. 3.5 Temperature gradient of tool, workpiece and chip during orthogonal cutting. As can easily be seen, heat is removed from the workpiece and the tool to the chip. Tool wear occurs around the 720 degree area of the tool (www.wikipedia.org)

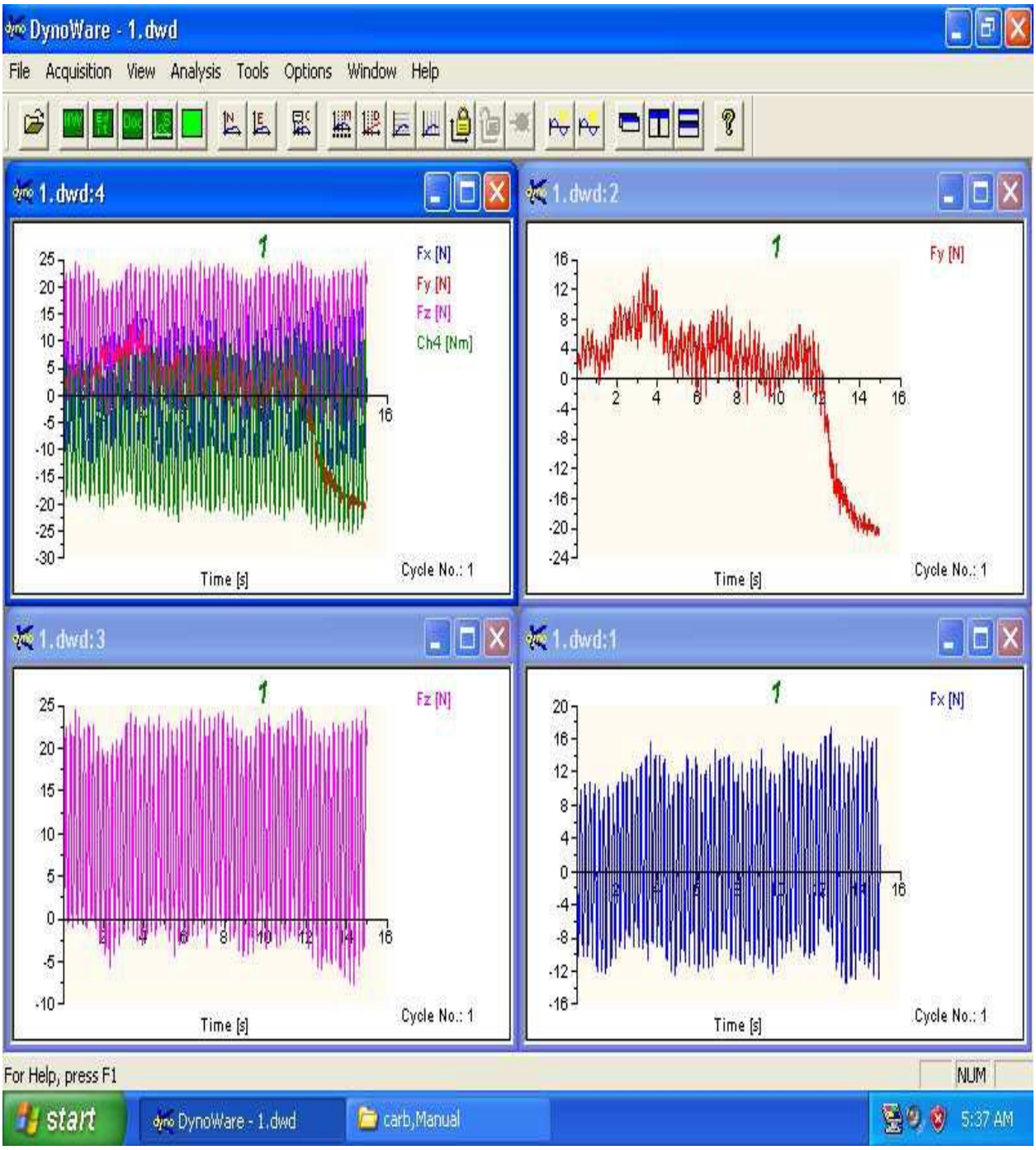


Figure 3.6 Experiment No. 1
(Depth of Cut, DOC = 4 mm, Feed = 0.6 mm/rev, Speed = 300 rpm)

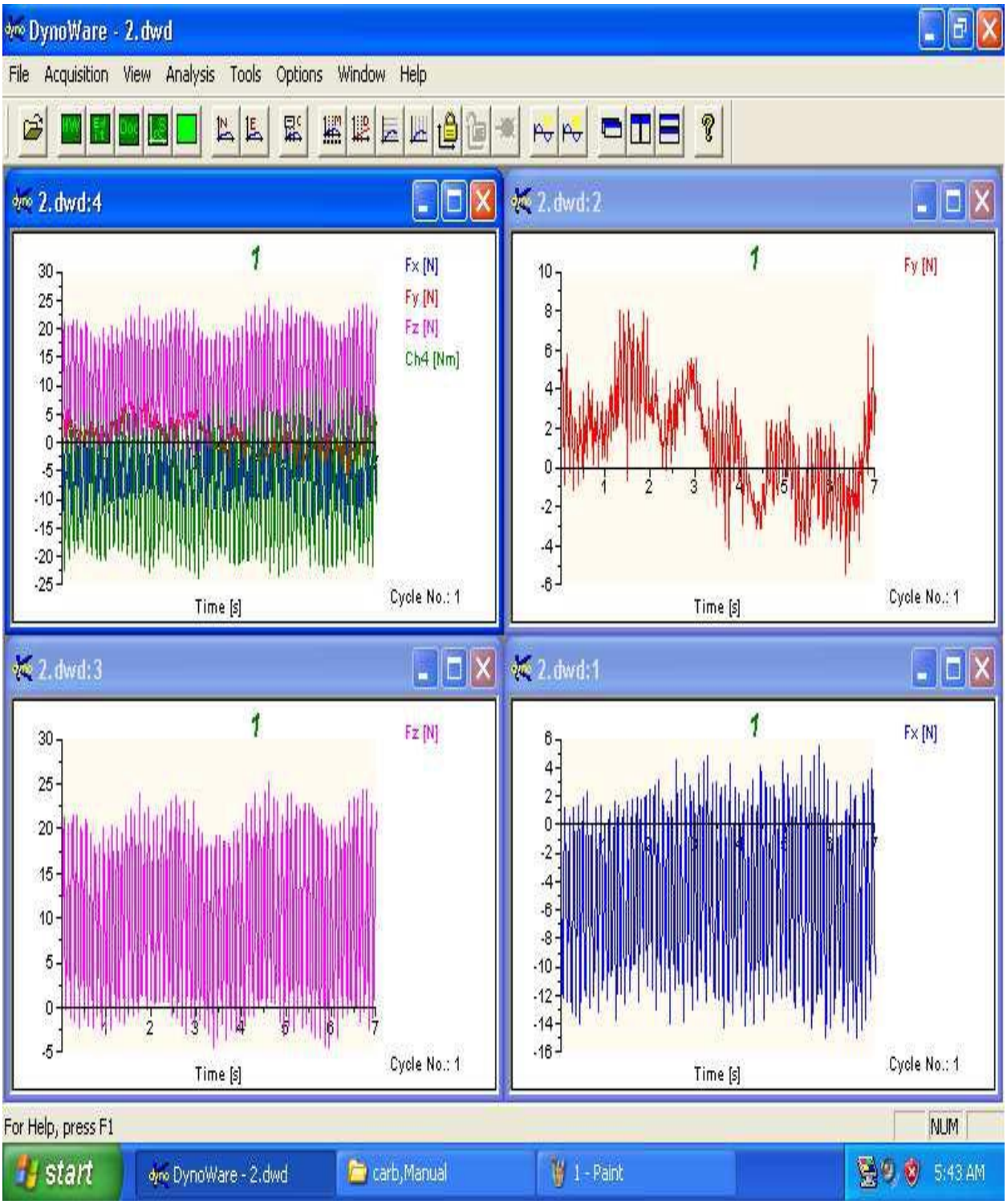


Figure 3.7 Experiment No. 2
(Depth of Cut, DOC = 8 mm, Feed = 0.6 mm/rev, Speed = 300 rpm)

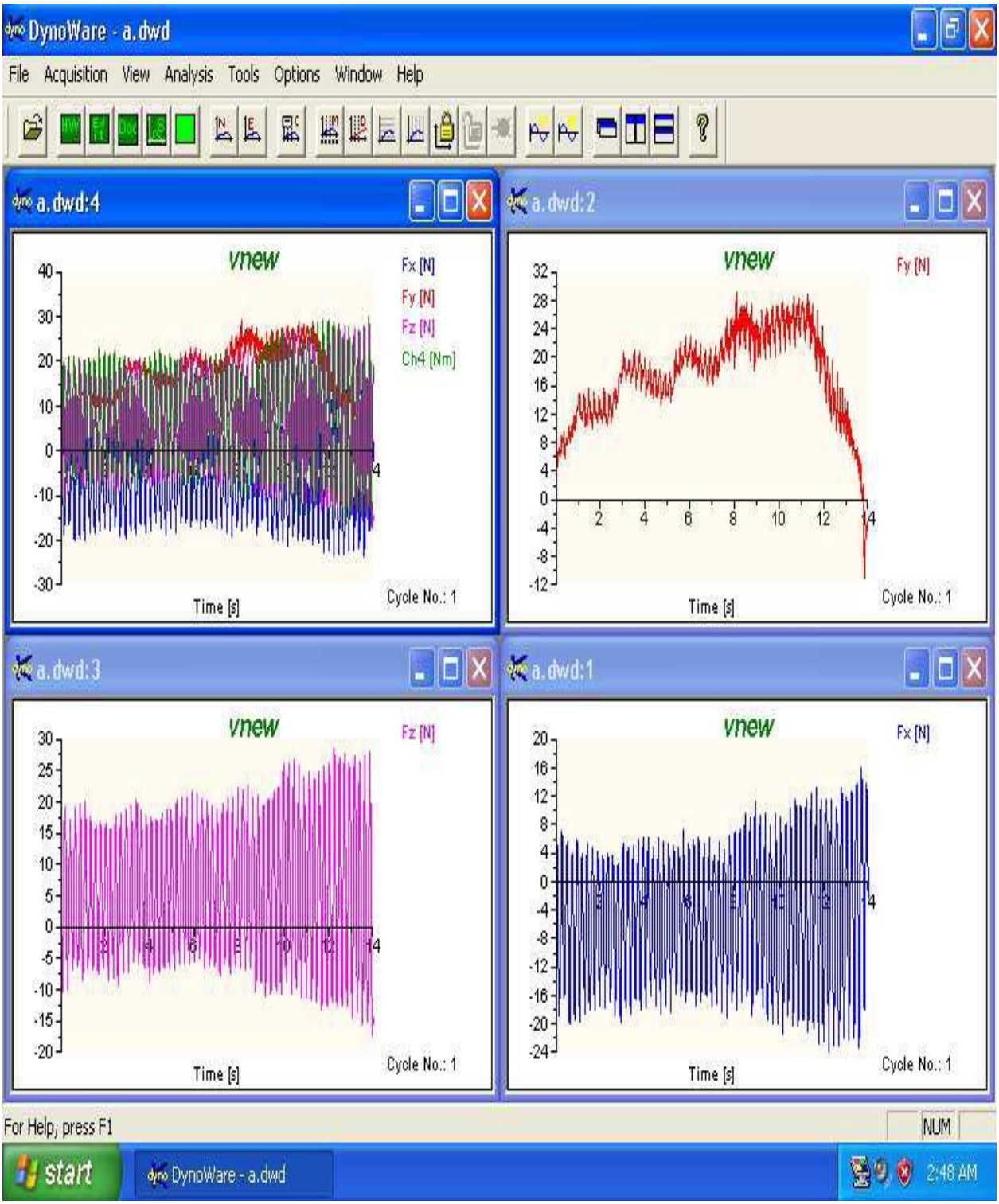


Figure 3.8 Experiment No. 3
(Depth of Cut, DOC = 12 mm, Feed = 0.6 mm/rev, Speed = 300 rpm)

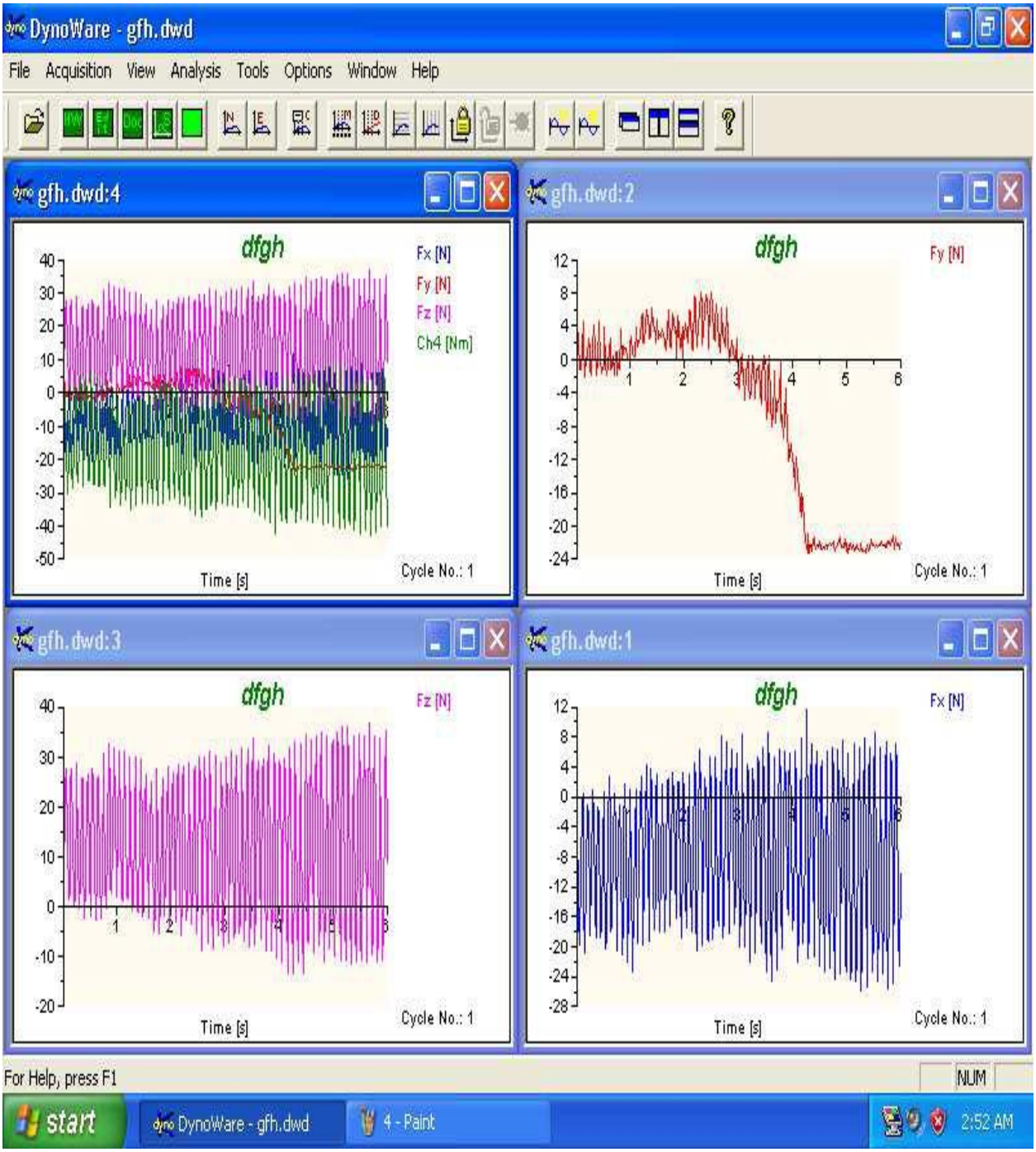


Figure 3.9 Experiment No. 4
(Depth of Cut, DOC = 4 mm, Feed = 0.8 mm/rev, Speed = 600 rpm)

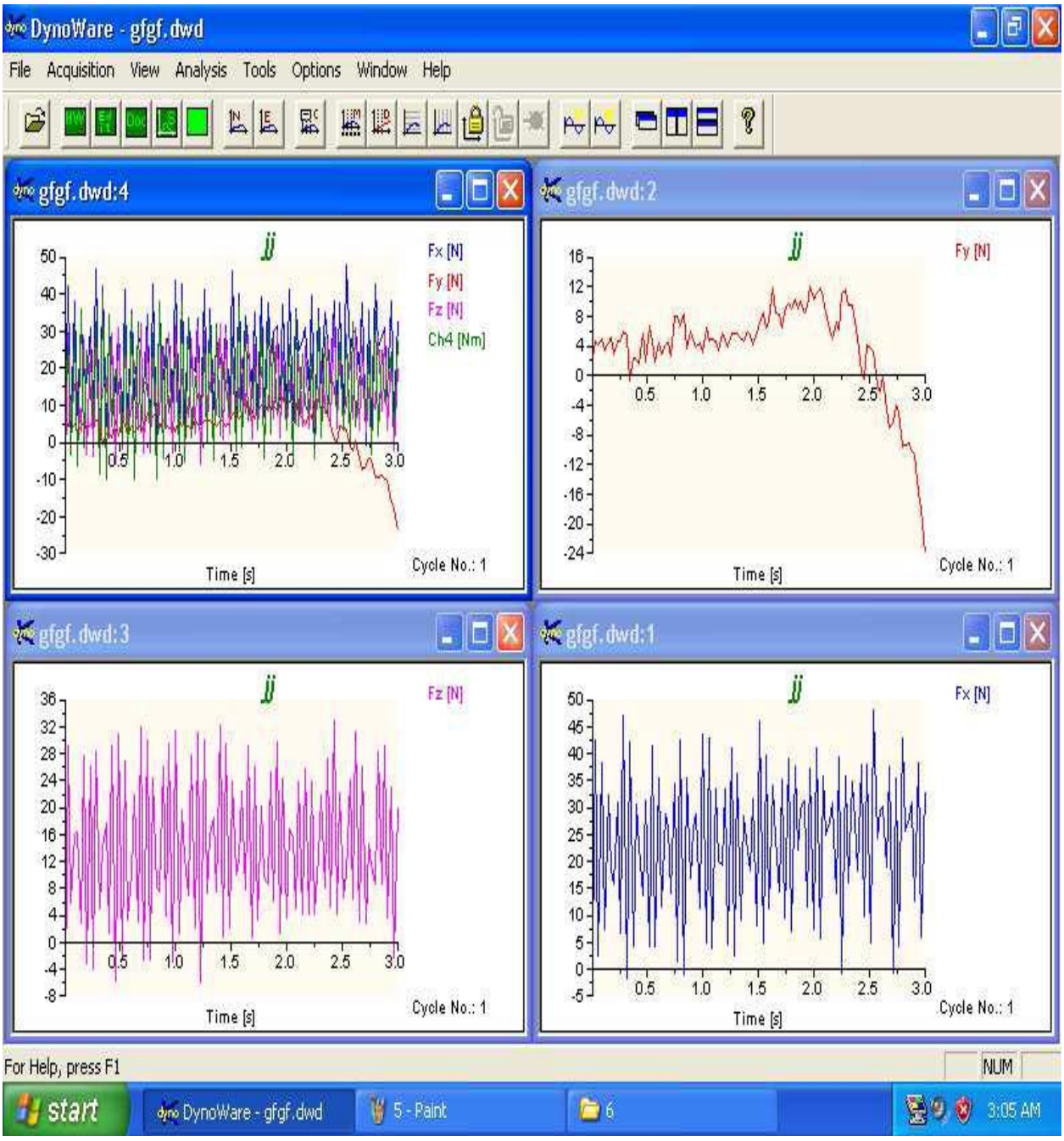


Figure 3.10 Experiment No. 5
(Depth of Cut, DOC = 8 mm, Feed = 0.8 mm/rev, Speed = 600 rpm)

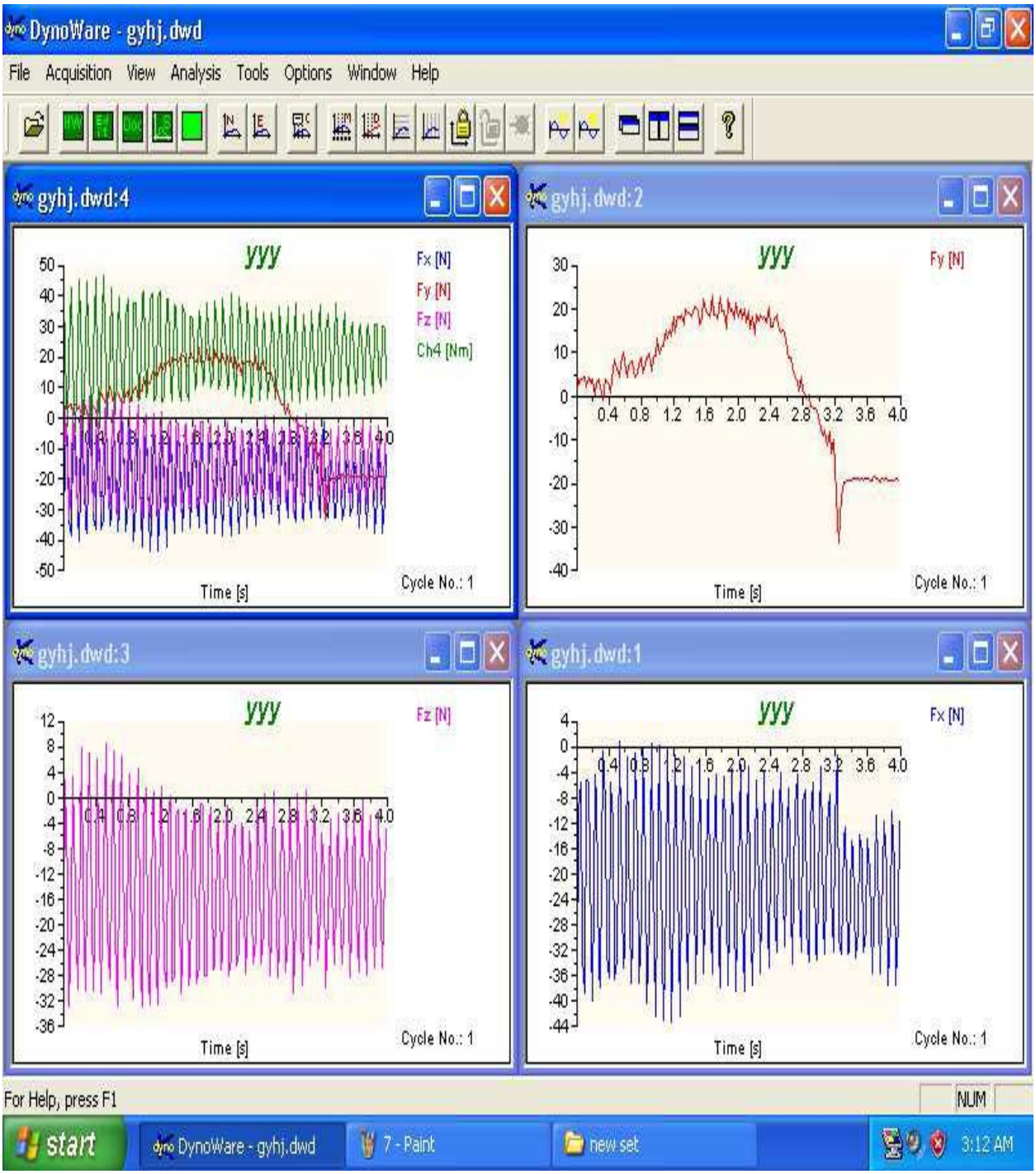


Figure 3.11 Experiment No. 6
(Depth of Cut, DOC = 12 mm, Feed = 0.8 mm/rev, Speed = 600 rpm)

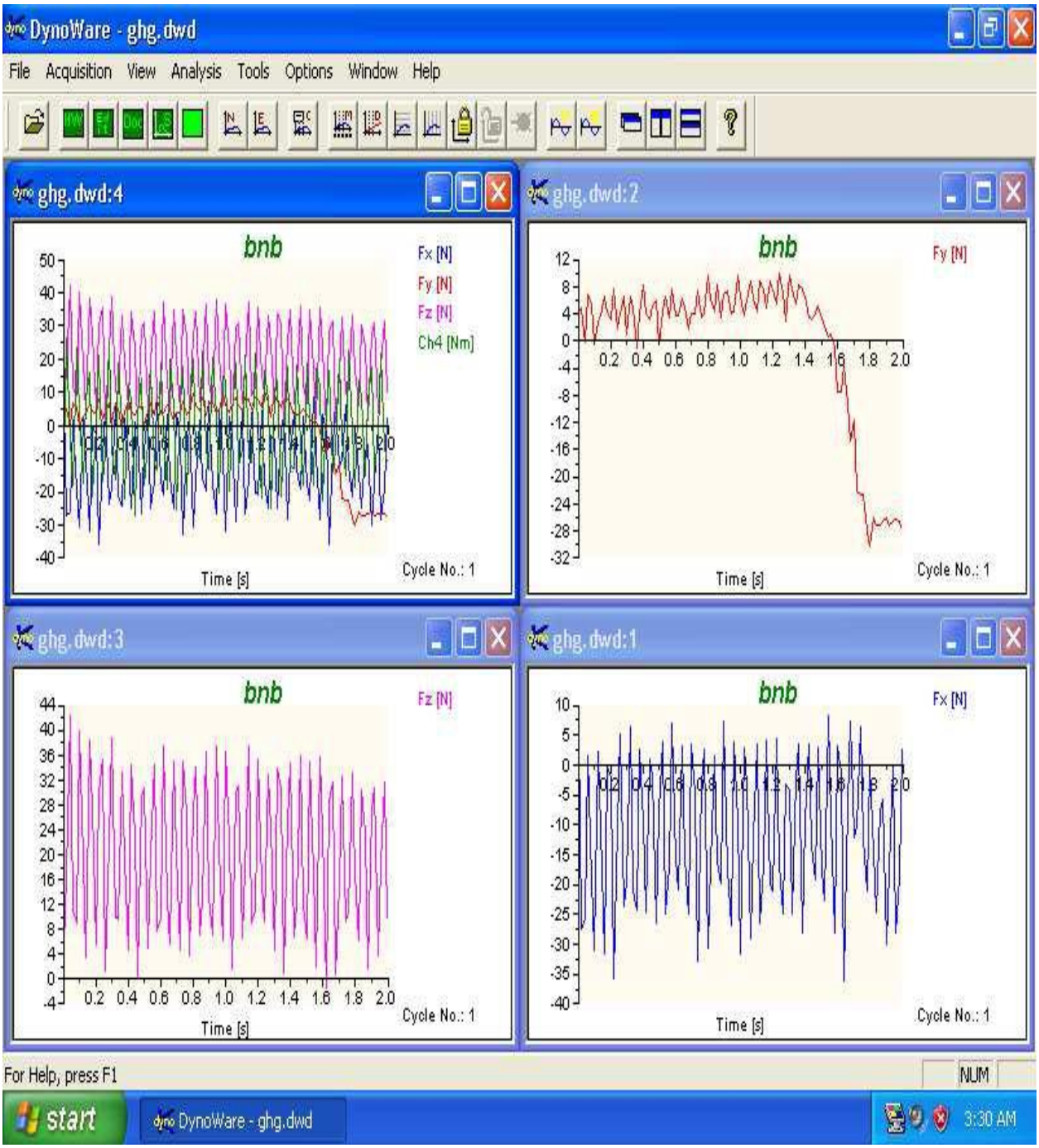


Figure 3.12 Experiment No. 7
(Depth of Cut, DOC = 4 mm, Feed = 1.0 mm/rev, Speed = 900 rpm)

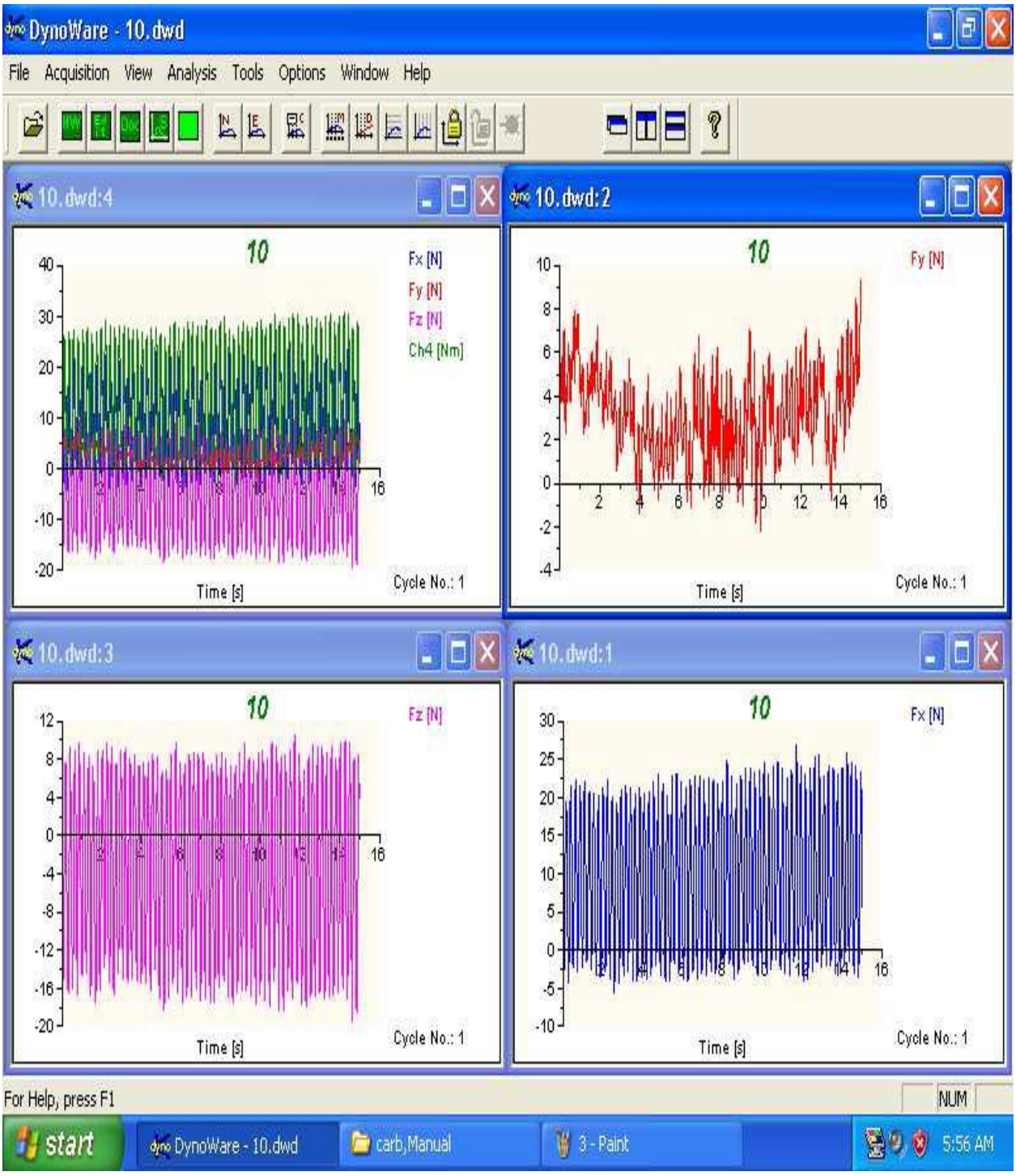


Figure 3.13 Experiment No. 8
(Depth of Cut, DOC = 8 mm, Feed = 1.0 mm/rev, Speed = 900 rpm)

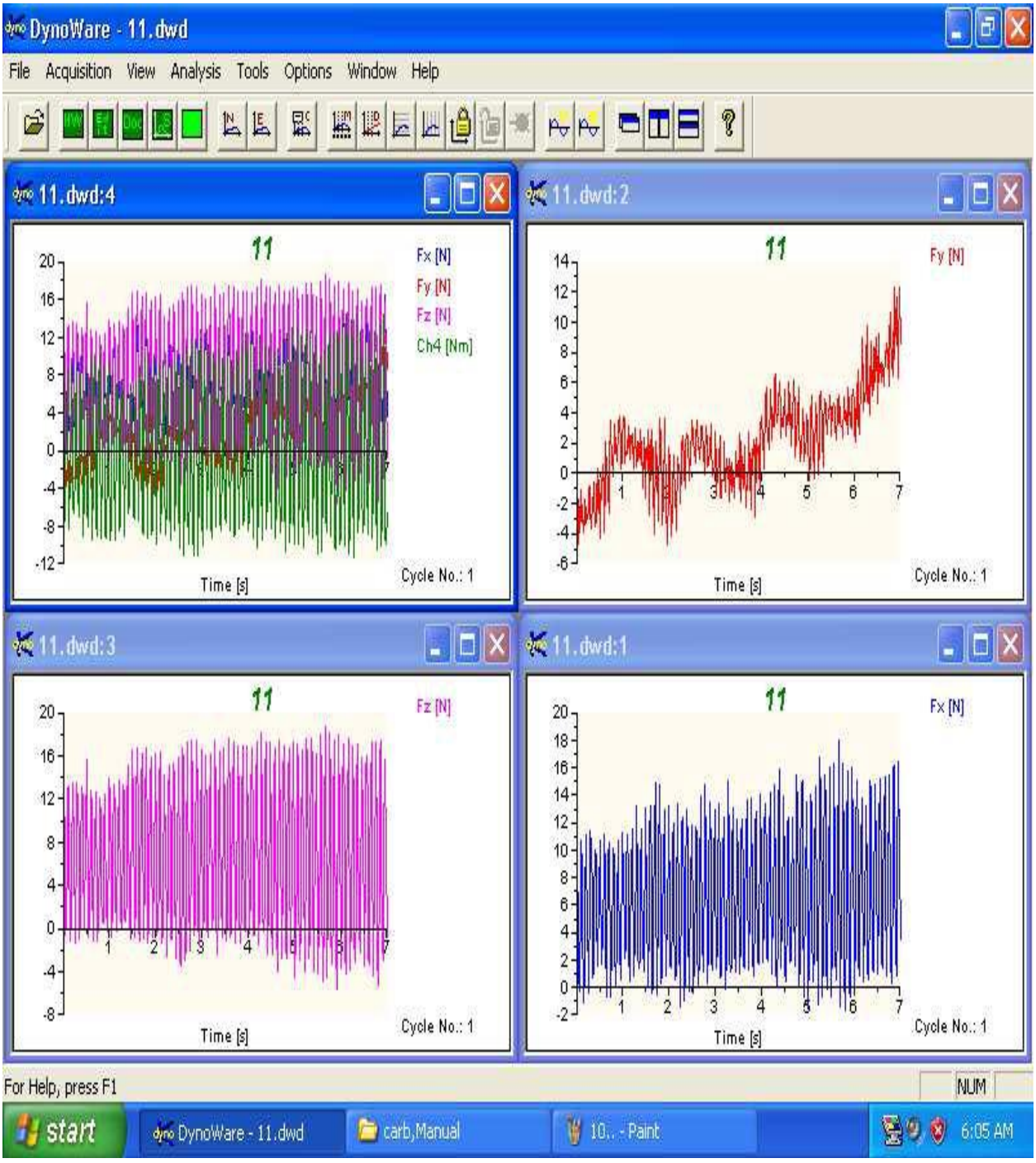


Figure 3.14 Experiment No. 9
(Depth of Cut, DOC = 12 mm, Feed = 1.0 mm/rev, Speed = 900 rpm)

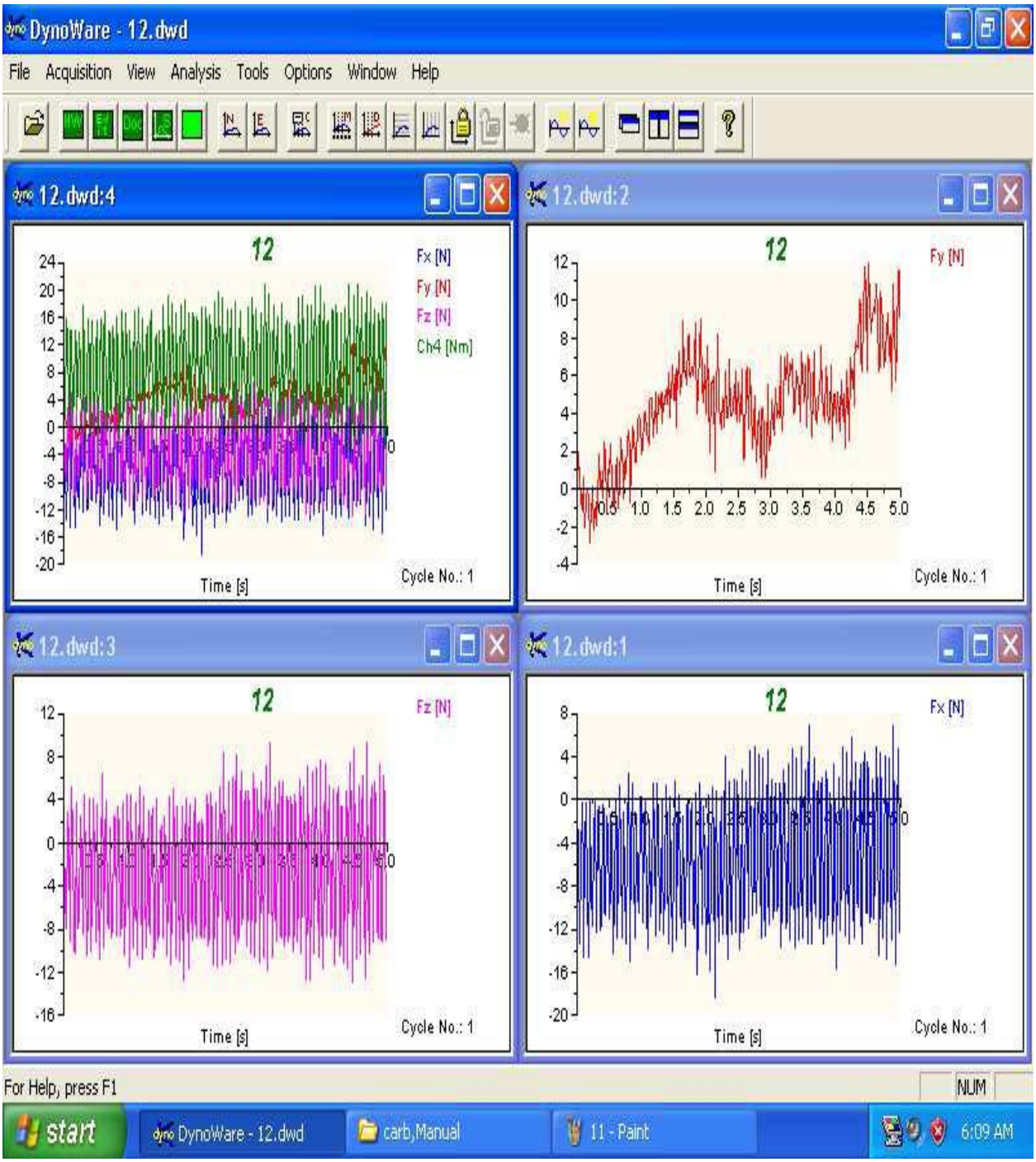


Figure 3.15 Experiment No. 10
(Depth of Cut, DOC = 4 mm, Feed = 0.8 mm/rev, Speed = 300 rpm)

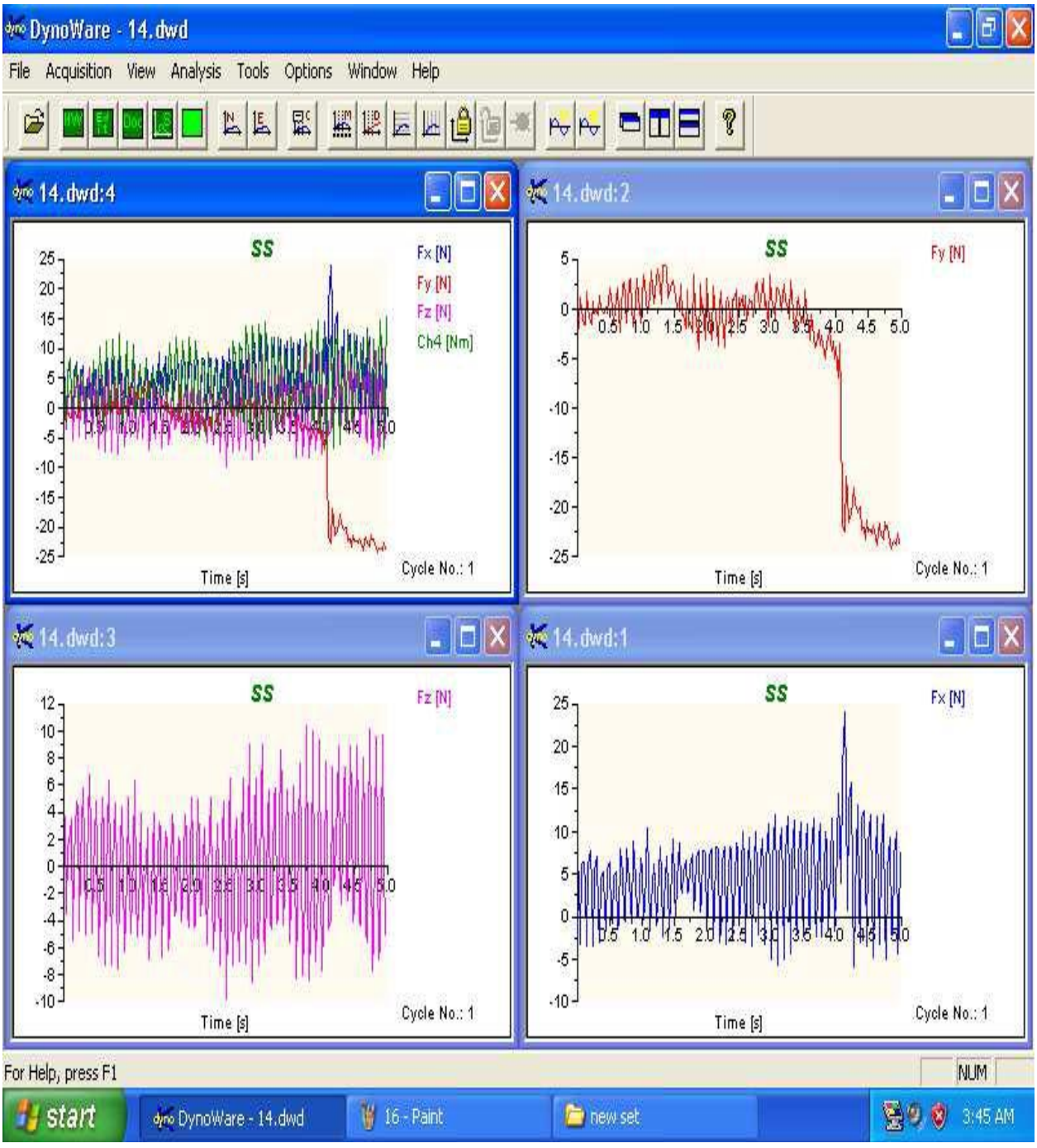


Figure 3.16 Experiment No. 11
(Depth of Cut, DOC = 8 mm, Feed = 0.8 mm/rev, Speed = 300 rpm)

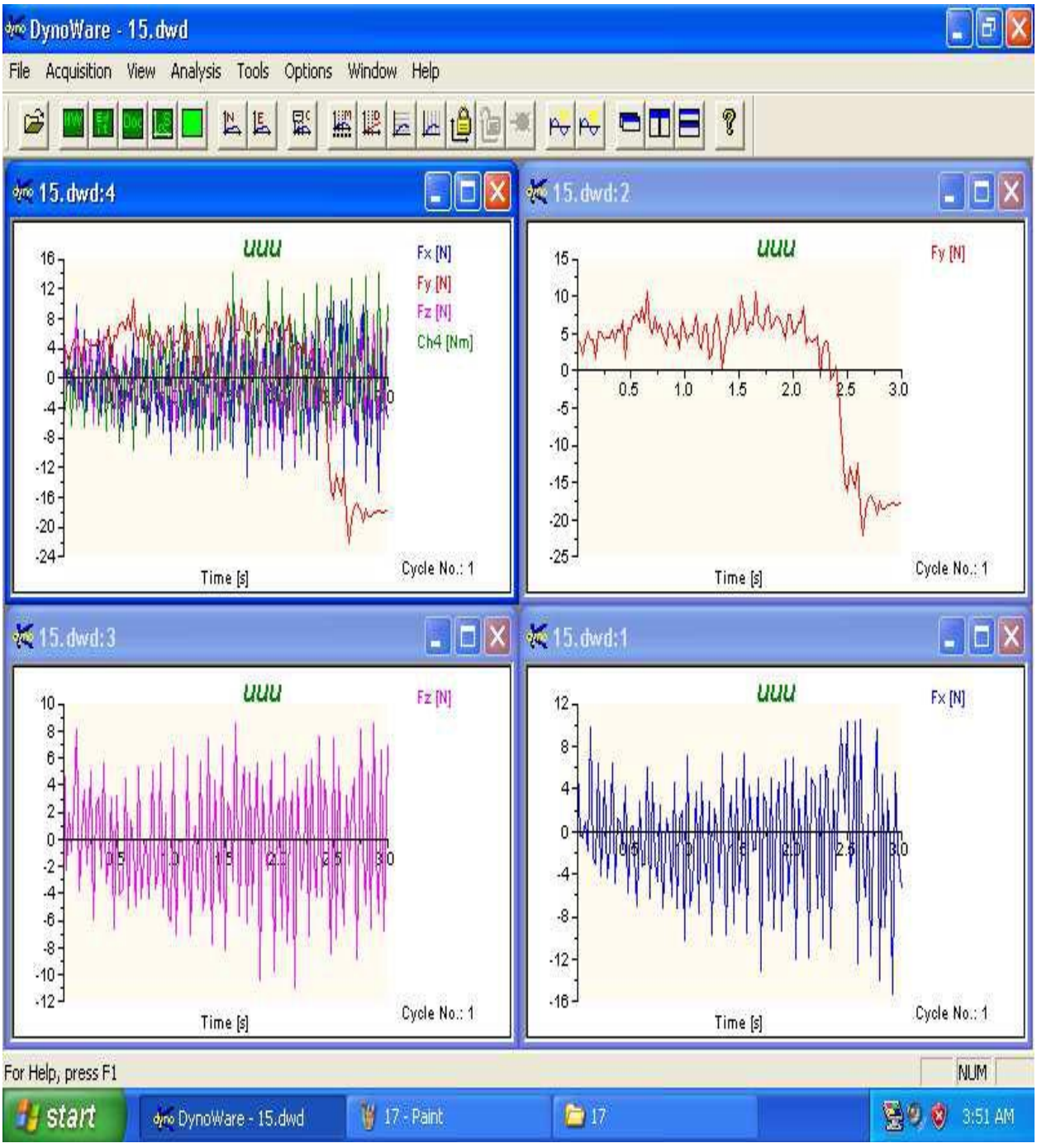


Figure 3.17 Experiment No. 12
(Depth of Cut, DOC = 12 mm, Feed = 0.8 mm/rev, Speed = 300 rpm)

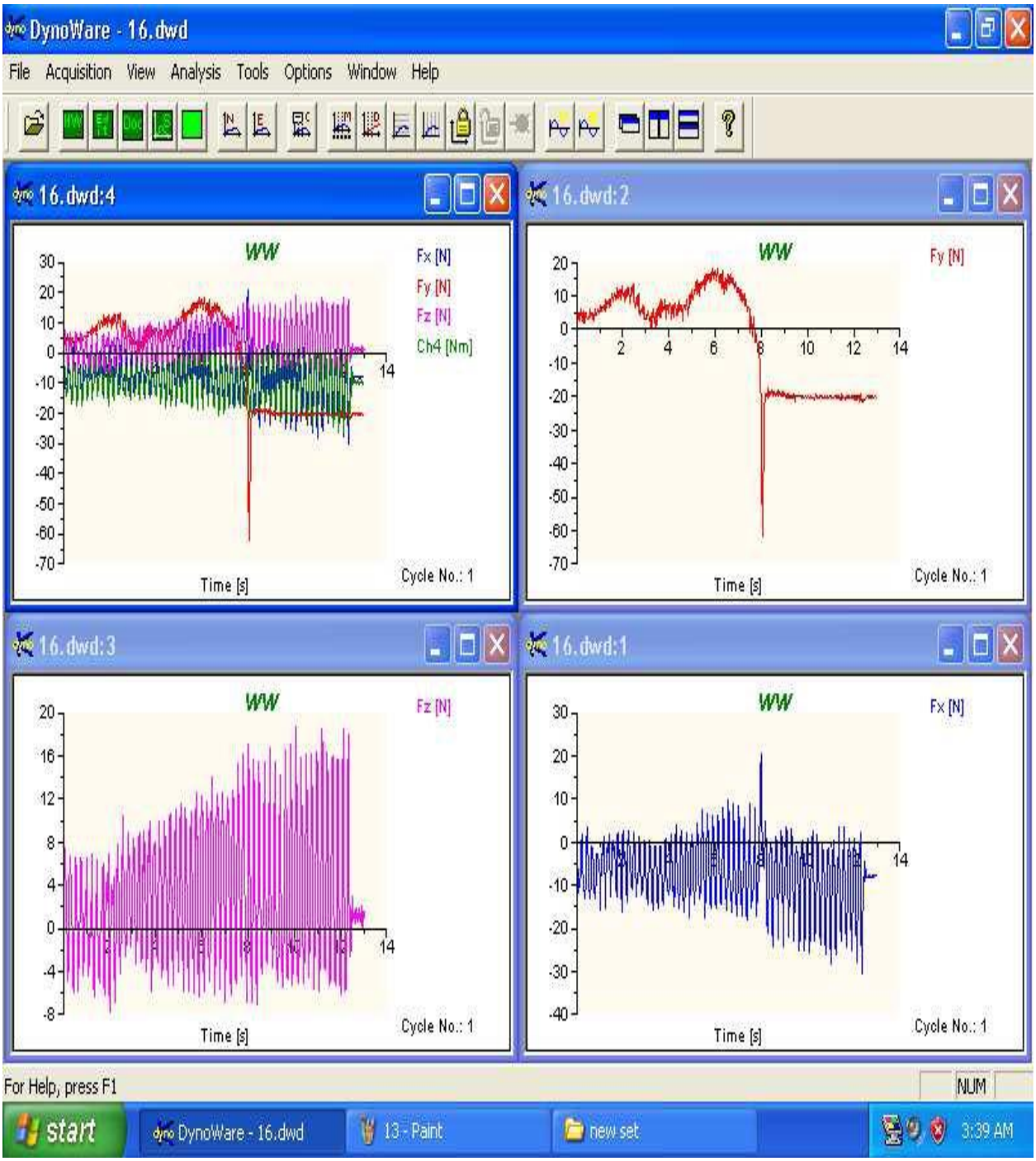


Figure 3.18 Experiment No. 13
(Depth of Cut, DOC = 4 mm, Feed = 1.0 mm/rev, Speed = 600 rpm)

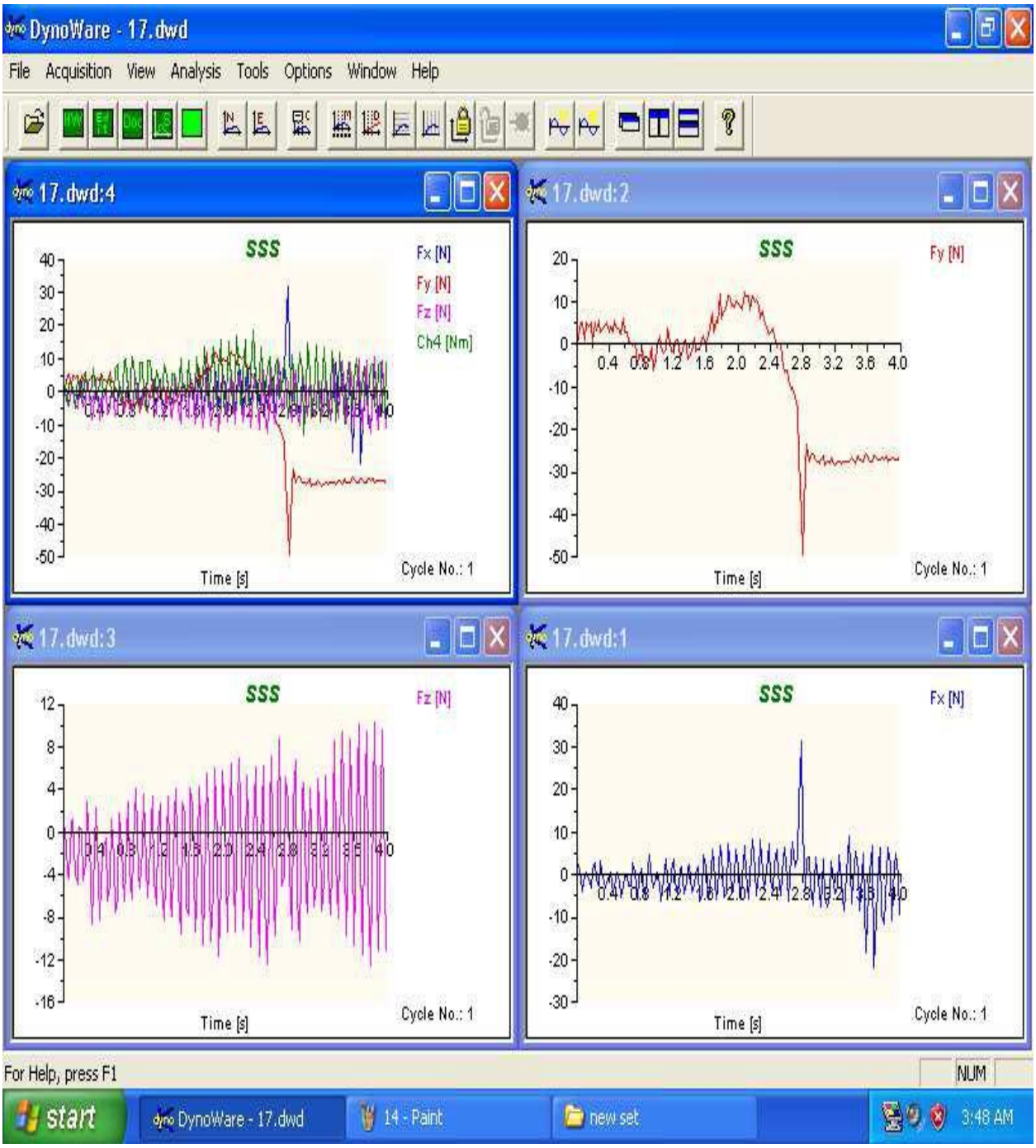


Figure 3.19 Experiment No. 14
(Depth of Cut, DOC = 8 mm, Feed = 1.0 mm/rev, Speed = 600 rpm)

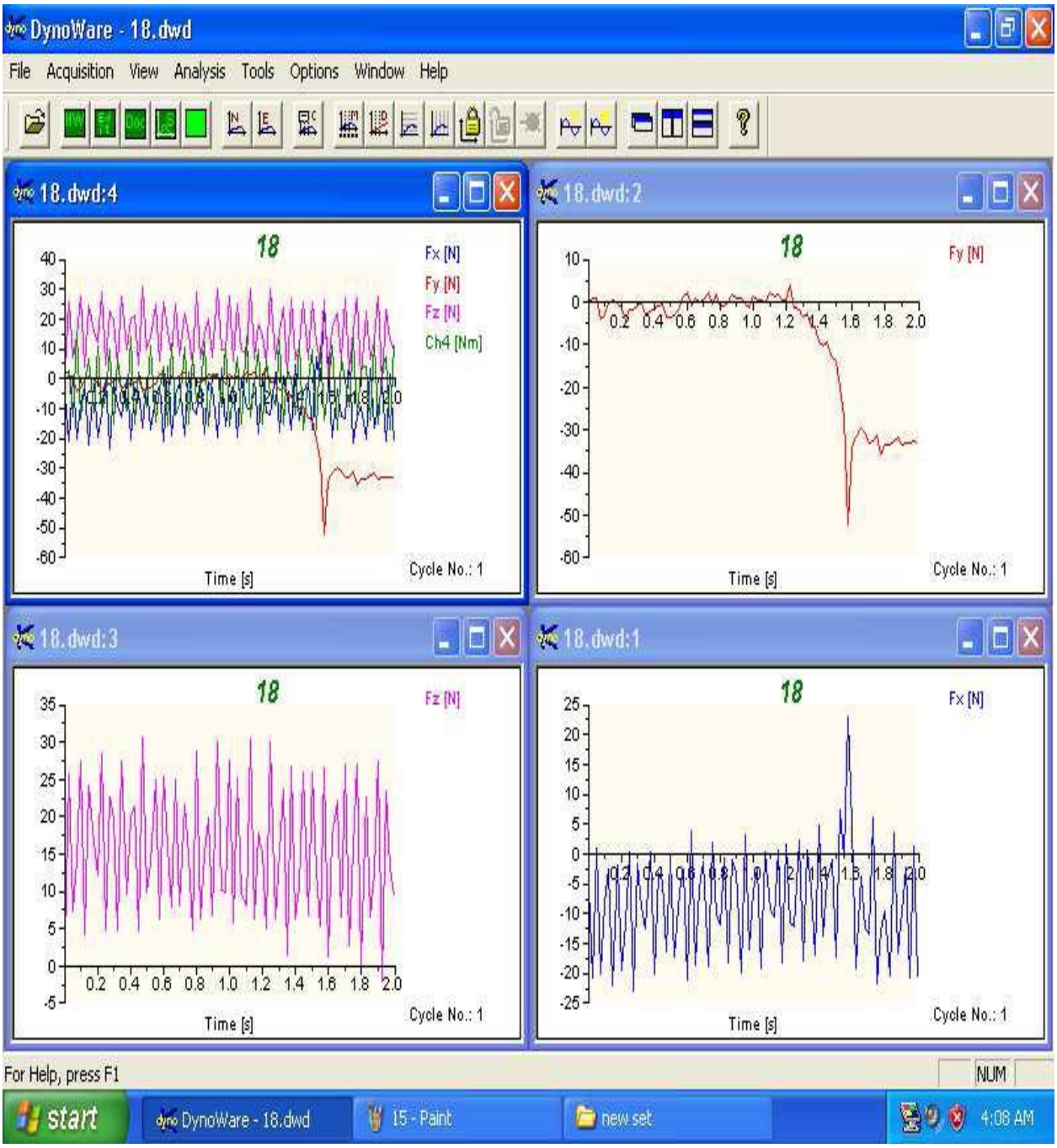


Figure 3.20 Experiment No. 15
(Depth of Cut, DOC = 12 mm, Feed = 1.0 mm/rev, Speed = 600 rpm)

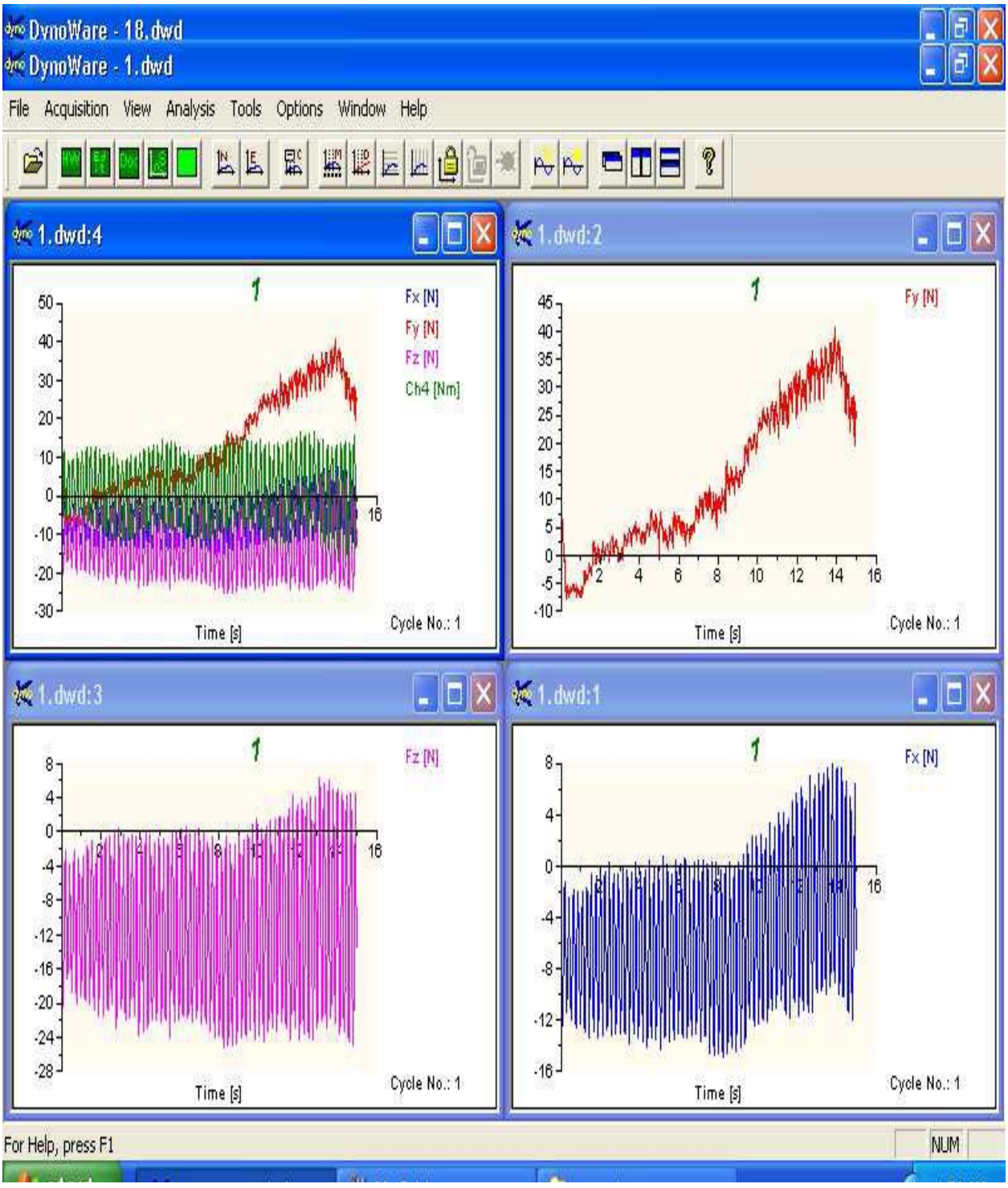


Figure 3.21 Experiment No. 16
(Depth of Cut, DOC = 4 mm, Feed = 0.6 mm/rev, Speed = 900 rpm)

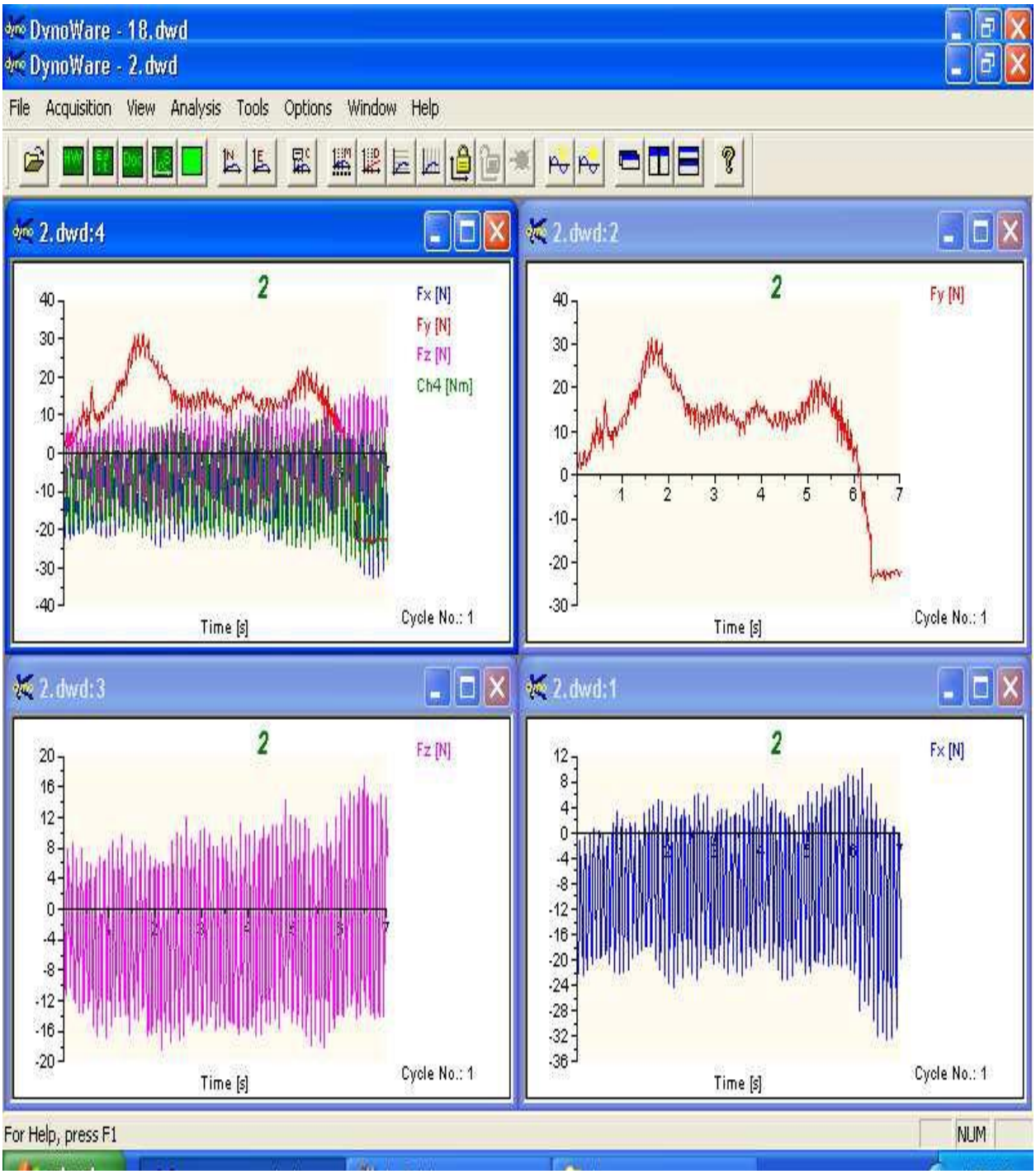


Figure 3.22 Experiment No. 17
(Depth of Cut, DOC = 8 mm, Feed = 0.6 mm/rev, Speed = 900 rpm)

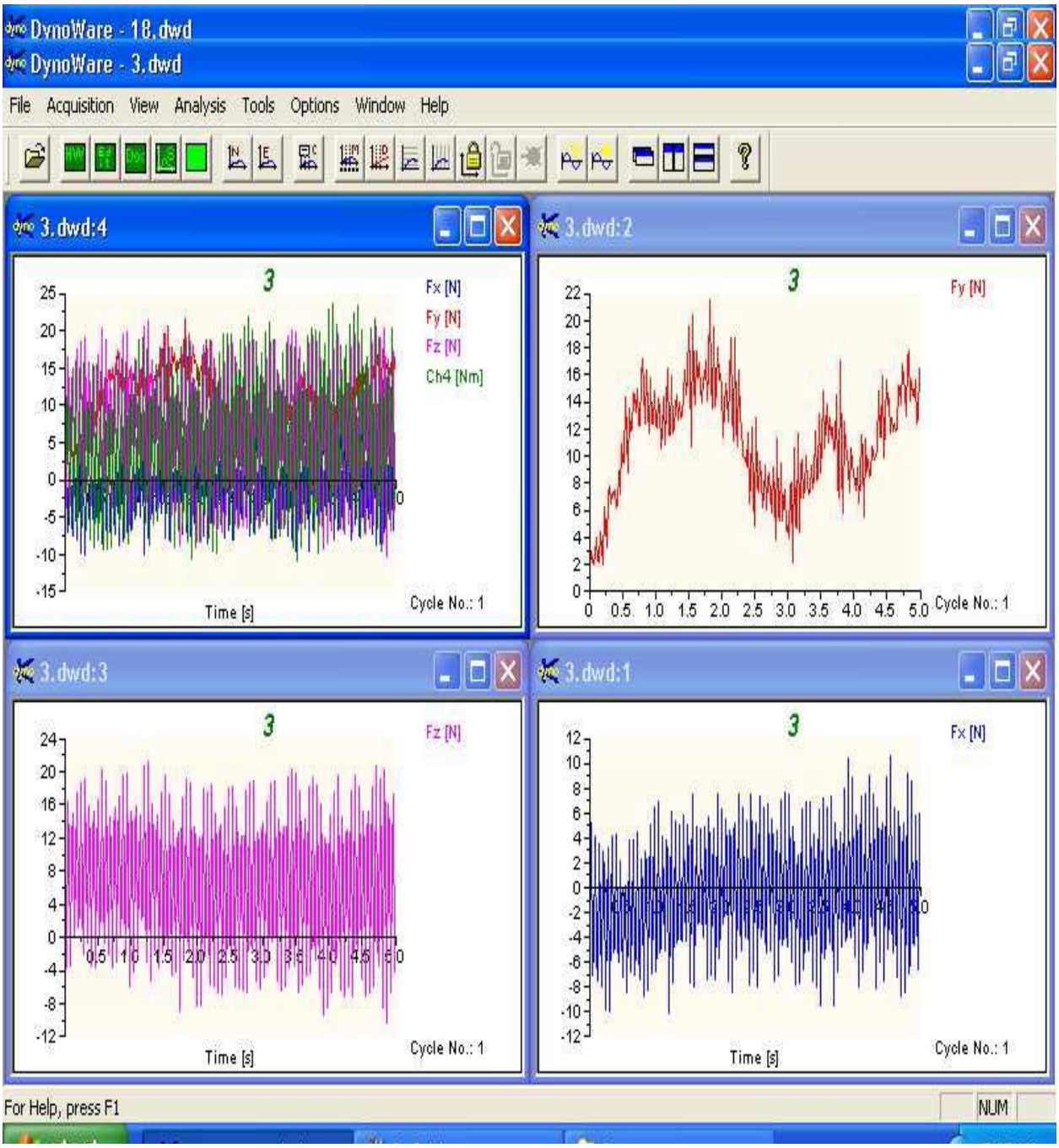


Figure 3.23 Experiment No. 18
(Depth of Cut, DOC = 12 mm, Feed = 0.6 mm/rev, Speed = 900 rpm)

CHAPTER – 4

MATHEMATICAL MODELING AND ANALYSIS

4.1 Introduction

The cutting forces and torque exerted by the cutting tool on the work piece during a machining action to be identified in order to determine the hole quality. Modeling of cutting force and torque in drilling is often needed in machining automation. The objective of this study is to predict the effects of cutting parameters on the variations of cutting forces and torque during drilling operation of Glass fiber reinforced plastic. Cutting forces and torque are measured by varying feed rates, cutting speed and point angle. The average cutting forces are determined at different feed rates in tangential, radial, and axial directions. A comparison between modeling and experiment is presented. Anova has been performed for different experiments to analyse the value of F-test whether it is increasing or decreasing for different factors.

4.2 Taguchi Method

Taguchi method is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipment, and facilities. These improvements are aimed at improving the desired characteristics and simultaneously reducing the number of defects by studying the key variables controlling the process and optimizing the procedures or design to yield the best results. The method is applicable over a wide range of engineering fields that include processes that manufacture raw materials, sub systems, products for professional and consumer markets. In fact, the method can be applied to any process be it engineering fabrication, computer-aided design, banking and service sectors etc. Taguchi method is useful for 'tuning' a given process for 'best' results.

4.3 ANOVA

In statistics, analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance is partitioned into components due to different sources of variation. In its simplest form ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes Student's two sample *t*-test to more than two groups. ANOVAs are helpful because they possess a certain advantage over a two-sample t-test.

The purpose of the statistical analysis of variance (ANOVA) is to investigate which design parameter significantly affects the material removal rate and hardness. Based on the ANOVA,the relative importance of the machining parameters with respect to material removal rate and hardness is investigated to determine more accurately the optimum combination of the machining parameters.

Two types of variations are present in experimental data:

1. Within treatment variability
2. Observation to observation variability

So ANOVA helps us to compare variabilities within experimental data. In my thesis ANOVA table is made with help of MINITAB 15 software. When performance varies one determines the average loss by statistically averaging the quadratic loss. The average loss is proportional to the mean squared error of Y about its target T. F-distribution as part of the test of statistical significance .

Various formulas for ANNOVA are:
• Sum of square
• Total sum of square deviation

4.4 Signal Noise ratio

Noise factors are those that are either too hard or uneconomical to control even though they may cause unwanted variation in performance. It is observed that on target performance usually satisfies the user best, and the target lies under acceptable range of product quality are often inadequate. If Y is the performance characteristic measured on a continuous scale when ideal or target performance is T then according to Taguchi the loss caused L(Y) can be modeled by a quadratic function as shown in equation (4.1)

$L(Y) = K(Y-T2)$……(4.1)

where L(Y)=loss caused, Y = performance characteristics, T = target performance, K = constant.

The objective of robust design is specific; robust design seeks optimum settings of parameters to achieve a particular target performance value under the most noise condition. Suppose that in a set of statistical experiment one finds a average quality characteristic to be μ and standard deviation to be σ. Let desired performance be $\mu 1$ .Then one make adjustment in design to get performance on target by adjusting value of control factor by multiplying it by the factor. Since on target is goal the loss after adjustment is due to variability remaining from the new standard deviation. Loss after adjustment shown in equation (4.2)

$K(\mu/\mu)^2 \sigma^2$……..(4.2)

where μ = mean, σ = variance, K = constant.

The factor μ^2/σ^2 reflects the ratio of average performance (which is the signal) and (the variance of performance) the noise. Maximizing or S/N ratio therefore become equivalent to minimizing the loss after adjustment. Finding a correct objective function to maximize in an engineering design problem is very important. Depending upon the type of response, the following types of S/N ratios are employed in practice:

• In my thesis work Thrust force is considered as smaller is better. Values of thrust force are measured by dynamometer which gives direct reading.

• Torque values are also considered as smaller is better. Torque values are also measured on dynamometer.

4.5 Taguchi Orthogonal Array Design

Orthogonal array used is L18 with three factors taken and number of experiments are 18 for one set. Three sets has been taken for different materials of drill.

Different Interactions AB, AC, BC has been taken for different parameters like Depth of Cut, feed rate and speed.

Where
A is considered as depth of cut,
B is considered as feed rate,
C is considered as speed

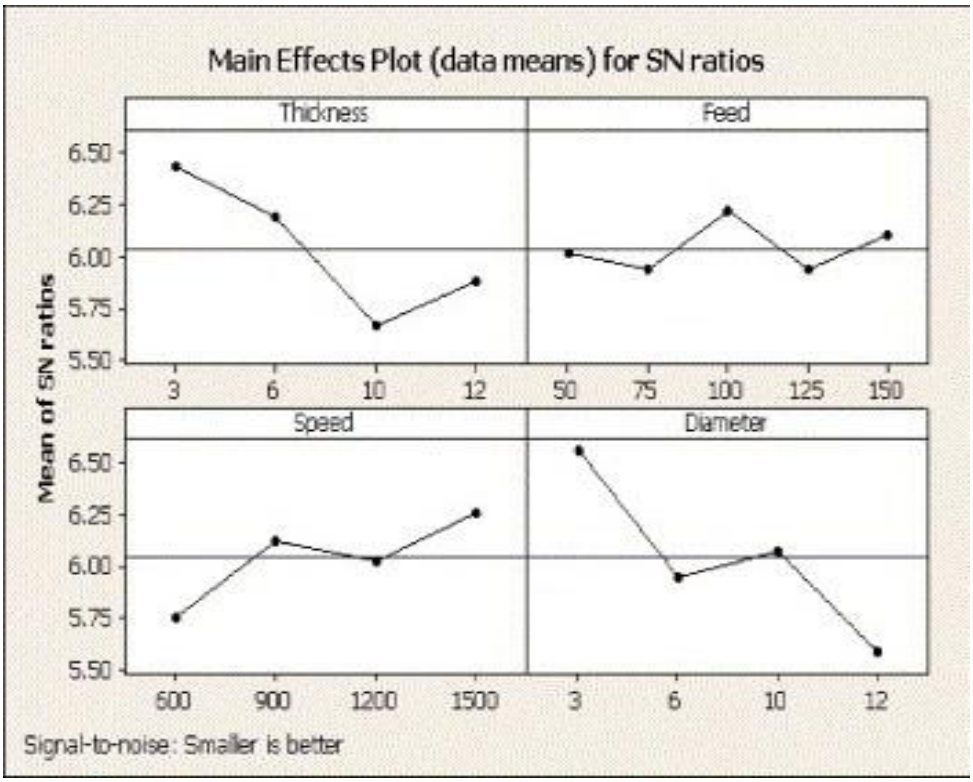


Fig. 4.1 Evaluation of Optical parameter setting

Taguchi creates a standard orthogonal array to accommodate this requirement. Depending on the number of factors, interactions and their level, an orthogonal array is selected by the user. Taguchi has used signal–noise [*S/N*] ratio as the quality characteristic of choice. *S/N* ratio is used as measurable value instead of standard deviation due to the fact that as the mean decreases, the

standard deviation also deceases and vice versa. In other words, the standard deviation cannot be minimized first and the mean brought to the target. In practice, the target mean value may change during the process development. Two of the applications in which the concept of *S/N* ratio is useful are the improvement of quality through variability reduction and the improvement of measurement. The *S/N* ratio characteristics can be divided into three categories given by Eqns. (3), (4) and (5), when the characteristic is continuous.

Nominal is the best characteristic: $\frac{S}{N} = 10 \log \frac{\bar{y}}{s_y^2}$ (4.3)

Smaller the better characteristic: $\frac{S}{N} = -10 \log \frac{1}{n}\left(\sum y^2\right)$ (4.4)

and larger the better characteristic: $\frac{S}{N} = -\log \frac{1}{n}\left(\sum \frac{1}{y^2}\right)$ (4.5)

where $\bar{y}$ is the average of observed data, s_y^2 the variation of *y*, *n* the number of observations, and *y* the observed data. For each type of the characteristics, with the above *S/N* ratio transformation, the higher the *S/N* ratio the better is the result.

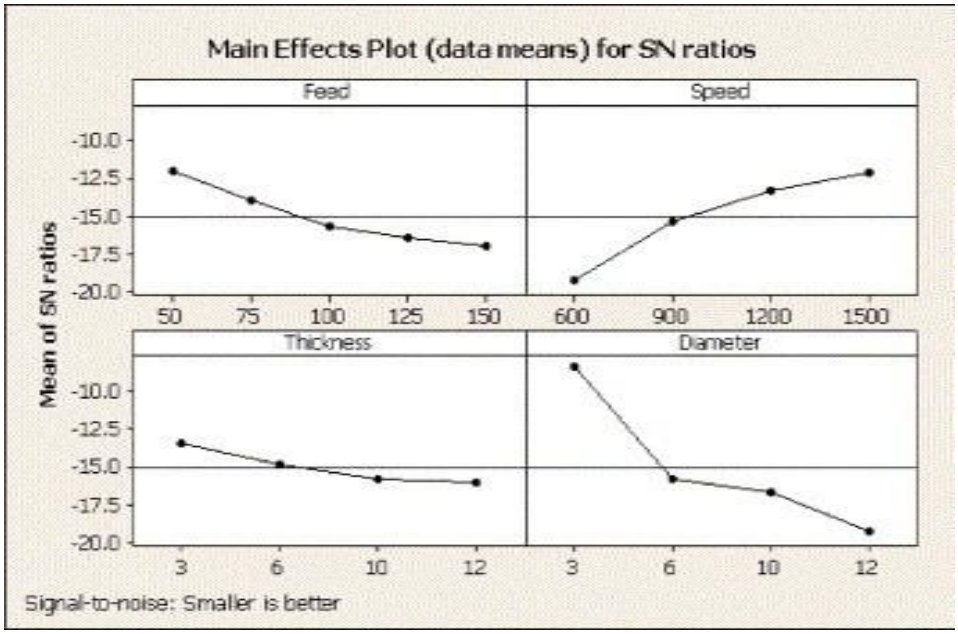


Fig. 4.2 Evaluation of Optical parameter setting

Table 4.1 Analysis of variance for *S/N* ratios (torque)

Source	DF	Seq SS	Adj SS	Adj MS	*F*	*P*
Thickness	3	27.16	27.156	9.0519	2.83	0.039
Feed	4	3.66	3.664	0.9159	0.29	0.887
Speed	3	11.03	11.029	3.6763	1.15	0.330
Diameter	3	38.38	38.381	12.7937	4.00	0.008
Thickness * feed	12	63.23	63.229	5.2691	1.65	0.079
Thickness * speed	9	61.57	61.566	6.8407	2.14	0.027
Thickness * diameter	9	127.73	127.730	14.1922	4.44	0.000
Feed * speed	12	49.48	49.484	4.1236	1.29	0.225
Feed * diameter	12	46.02	46.015	3.8346	1.20	0.284
Speed * diameter	9	40.16	40.159	4.4621	1.40	0.191
Residual error	243	777.10	777.101	3.1979		

By looking at ANOVA Table we observe that F-value for cutting force has large value that's why it has maximum effect on torque but feed rate also showing significant value of F- test which also show effect on torque value.

Hence it can been seen from above all graphs that with increasing cutting force and feed rate, and interactions of two feed rate and cutting force, the thrust forces and torque value increasing significantly. From the predictions of anova table we can see that F-test value show significant results which show that its only the cutting force which effect most to the thrust forces and torque value.

An **F-test** is any statistical test in which the test statistic has an F-distribution under the null hypothesis. It is most often used when comparing statistical models that have been fit to a data set, in order to identify the model that best fits the population from which the data were sampled. Exact F-tests mainly arise when the models have been fit to the data using least squares. The name was coined by George W. Snedecor, in honour of Sir Ronald A. Fisher. Fisher initially developed the statistic as the variance ratio in the 1920s.

Examples of F-tests include:

- The hypothesis that the means of several normally distributed populations, all having the same standard deviation, are equal. This is perhaps the best-known F-test, and plays an important role in the analysis of variance (ANOVA).
- The hypothesis that a proposed regression model fits the data well. See Lack-of-fit sum of squares.

- The hypothesis that a data set in a regression analysis follows the simpler of two proposed linear models that are nested within each other.

- Scheffé's method for multiple comparisons adjustment in linear models.

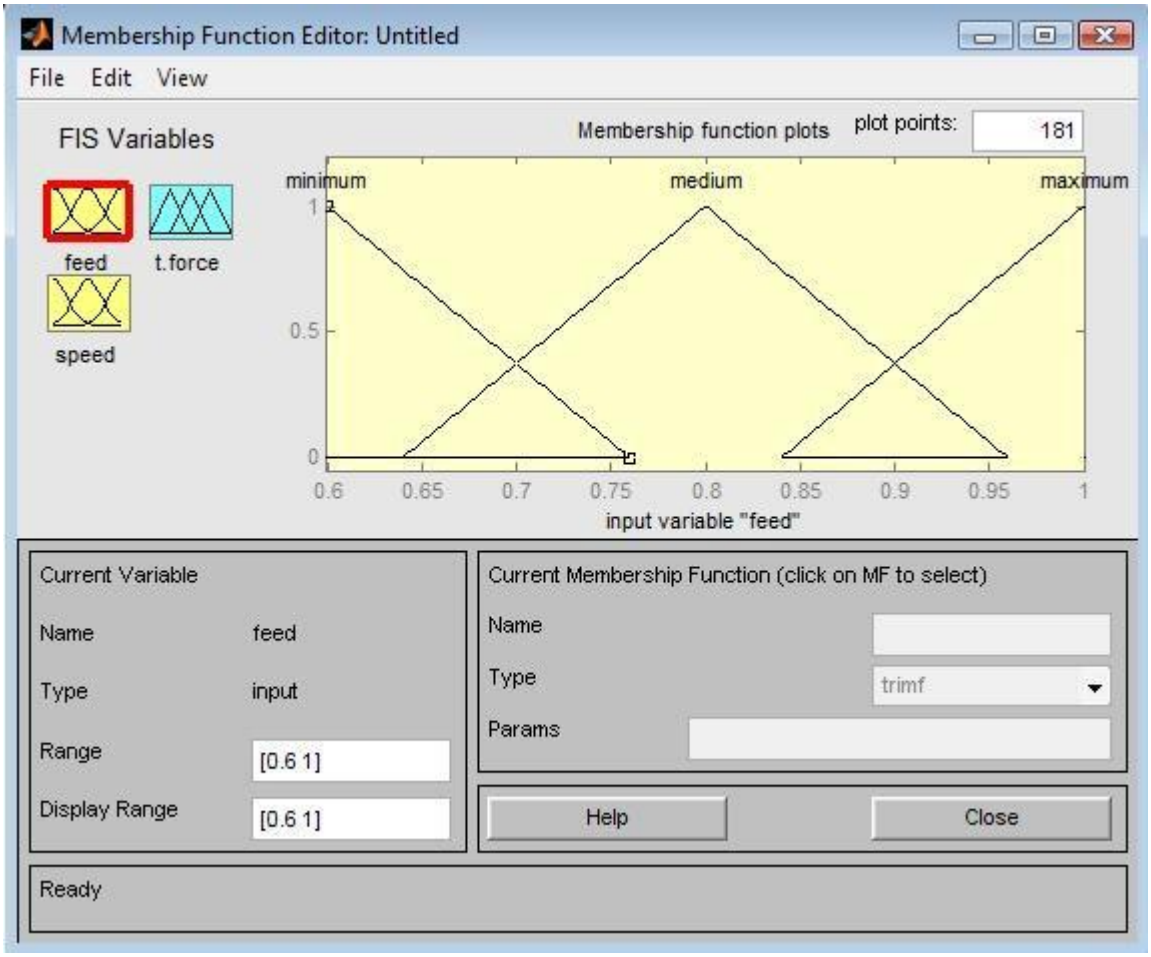


Fig. 4.3 Input Membership Function

4.6 Membership Functions

The different values of feed such as 0.6 mm, 0.8 mm and 1.0 mm are taken and shown as minimum, medium and maximum respectively in the above figure 4.3. The membership function of a fuzzy set is a generalization of the indicator function in classical sets. In fuzzy logic, it represents the degree of truth as an extension of valuation. Degrees of truth are often confused with probabilities, although they are conceptually distinct, because fuzzy truth represents membership in vaguely defined sets, not likelihood of some event or condition. Membership functions were introduced by Zadeh in the first paper on fuzzy sets (1965).For any set X, a membership function on X is any function from X to the real unit interval [0,1].

Membership functions on X represent fuzzy subsets of X. The membership function which represents a fuzzy set $\tilde{A}$ is usually denoted by μ_A. For an element x of X, the value $\mu_A(x)$ is called themembership degree of x in the fuzzy set $\tilde{A}$. The membership degree $\mu_A(x)$ quantifies the grade of membership of the element x to the fuzzy set $\tilde{A}$. The value 0 means that x is not a member of the fuzzy set; the value 1 means that x is fully a member of the fuzzy set. The values between 0 and 1 characterize fuzzy members, which belong to the fuzzy set only partially.

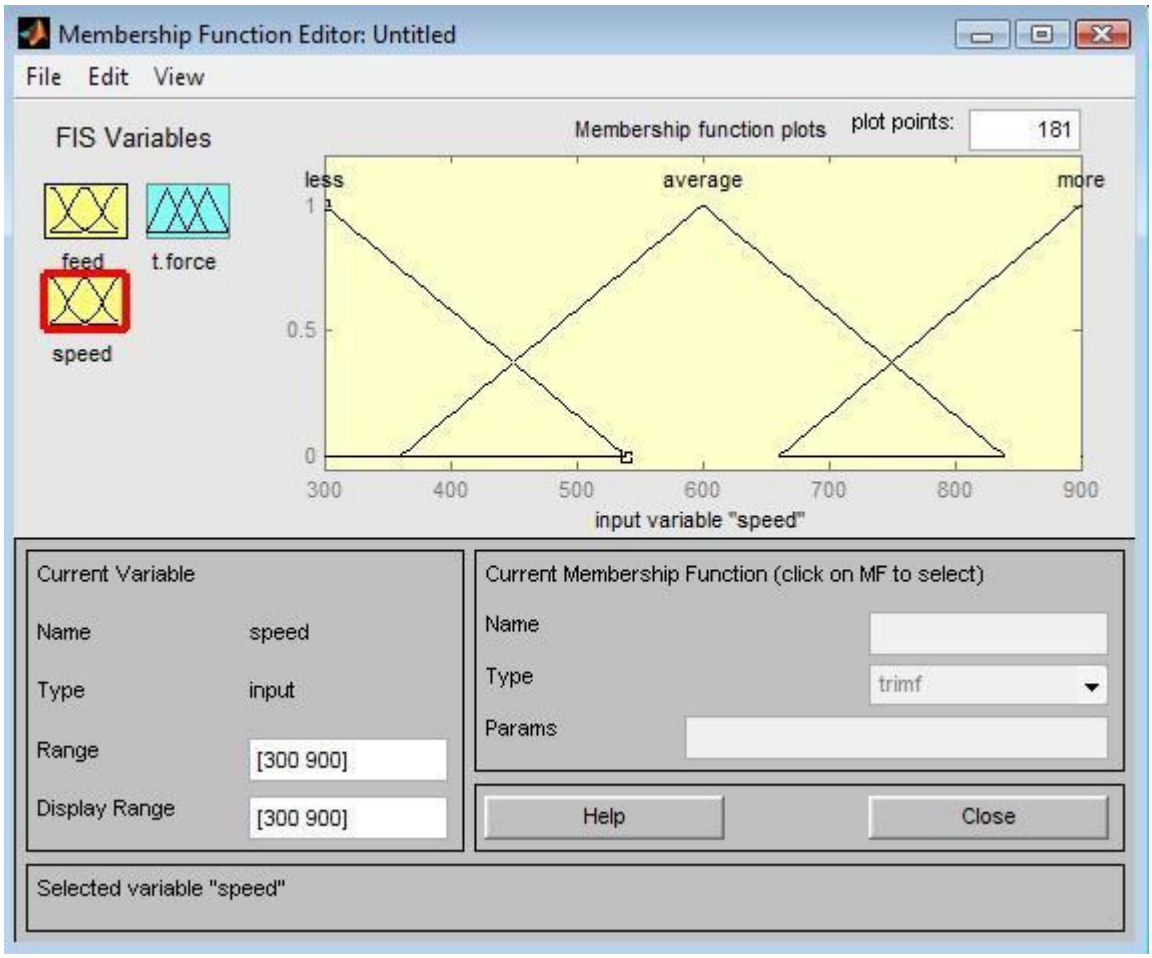


Fig. 4.4 Input Membership Function

Sometimes, a more general definition is used, where membership functions take values in an arbitrary fixed algebra or structure L; usually it is required that L be at least a poset or lattice. The usual membership functions with values in [0, 1] are then called [0, 1]-valued membership functions. One application of membership functions is as capacities in decision theory.

In decision theory, a capacity is defined as a function, ν from **S**, the set of subsets of some set, into [0,1], such that ν is set-wise monotone and is normalized

(i.e. $\nu(\emptyset) = 0, \nu(\Omega) = 1)$. Clearly this is a generalization of a probability measure, where the probability axiom of countability is weakened. A capacity is used as a subjective measure of the likelihood of an event, and the "expected value" of an outcome given a certain capacity can be found by taking the Choquet integral over the capacity.

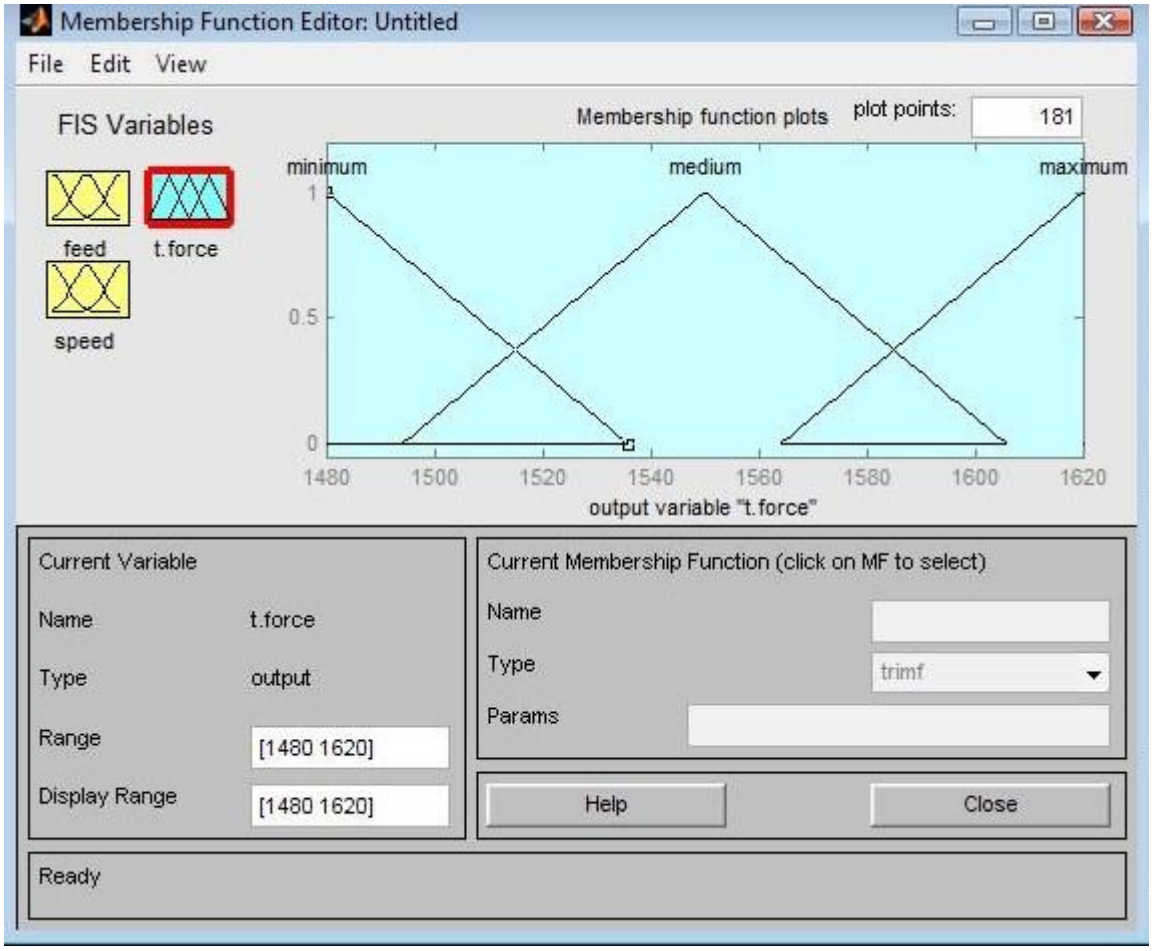


Fig. 4.5 Output Membership Function

4.7 Defuzzification

It is the process of producing a quantifiable result in fuzzy logic, given fuzzy sets and corresponding membership degrees. It is typically needed in fuzzy control systems. These will have a number of rules that transform a number of variables into a fuzzy result, that is, the result is described in terms of membership in fuzzy sets. For example, rules designed to decide how much pressure to apply might result in "Decrease Pressure (15%), Maintain Pressure (34%), Increase Pressure (72%)". Defuzzification is interpreting the membership degrees of the fuzzy sets into a specific decision or real value.

The simplest but least useful defuzzification method is to choose the set with the highest membership, in this case, "Increase Pressure" since it has a 72% membership, and ignore the others, and convert this 72% to some number. The problem with this approach is that it loses information. The rules that called for decreasing or maintaining pressure might as well have not been there in this case.

A common and useful defuzzification technique is *center of gravity*. First, the results of the rules must be added together in some way. The most typical fuzzy set membership function has the graph of a triangle. Now, if this triangle were to be cut in a straight horizontal line somewhere between the top and the bottom, and the top portion were to be removed, the remaining portion forms a trapezoid. The first step of defuzzification typically "chops off" parts of the graphs to form trapezoids (or other shapes if the initial shapes were not triangles). For example, if the output has "Decrease Pressure (15%)", then this triangle will be cut 15% the way up from the bottom. In the most common technique, all of these trapezoids are then superimposed one upon another, forming a single geometric shape. Then, the centroid of this shape, called the *fuzzy centroid*, is calculated. The *x* coordinate of the centroid is the defuzzified value.

Fuzzy logic is widely used in machine control. The term itself inspires a certain skepticism, sounding equivalent to "half-baked logic" or "bogus logic", but the "fuzzy" part does not refer to a lack of rigour in the method, rather to the fact that the logic involved can deal with fuzzy concepts—concepts that cannot be expressed as "true" or "false" but rather as "partially true". Although genetic algorithms and neural networks can perform just as well as fuzzy logic in many cases , fuzzy logic has the advantage that the solution to the problem can be cast in terms that human operators can understand, so that their experience can be used in the design of the controller. This makes it easier to mechanize tasks that are already successfully performed by humans.

Fuzzy logic was first proposed by Lotfi A. Zadeh of the University of California at Berkeley in a 1965 paper. He elaborated on his ideas in a 1973 paper that introduced the concept of "linguistic variables", which in this article equates to a variable defined as a fuzzy set. Other research followed, with the first industrial application, a cement kiln built in Denmark, coming on line in 1975.

Work on fuzzy systems is also proceeding in the US and Europe, though not with the same enthusiasm shown in Japan. The US Environmental Protection Agency has investigated fuzzy control forenergy-efficient motors, and NASA has studied fuzzy control for automated space docking: simulations show that a fuzzy control system can greatly reduce fuel consumption. Firms such as Boeing, General Motors, Allen-Bradley, Chrysler, Eaton, and Whirlpool have

worked on fuzzy logic for use in low-power refrigerators, improved automotive transmissions, and energy-efficient electric motors.

In 1995 Maytag introduced an "intelligent" dishwasher based on a fuzzy controller and a "one-stop sensing module" that combines a thermistor, for temperature measurement; a conductivity sensor, to measure detergent level from the ions present in the wash; a turbidity sensor that measures scattered and transmitted light to measure the soiling of the wash; and a magnetostrictive sensor to read spin rate. The system determines the optimum wash cycle for any load to obtain the best results with the least amount of energy, detergent, and water. It even adjusts for dried-on foods by tracking the last time the door was opened, and estimates the number of dishes by the number of times the door was opened.

Research and development is also continuing on fuzzy applications in software, as opposed to firmware, design, including fuzzy expert systems and integration of fuzzy logic with neural-network and so-called adaptive "genetic" software systems, with the ultimate goal of building "self-learning" fuzzy control systems.

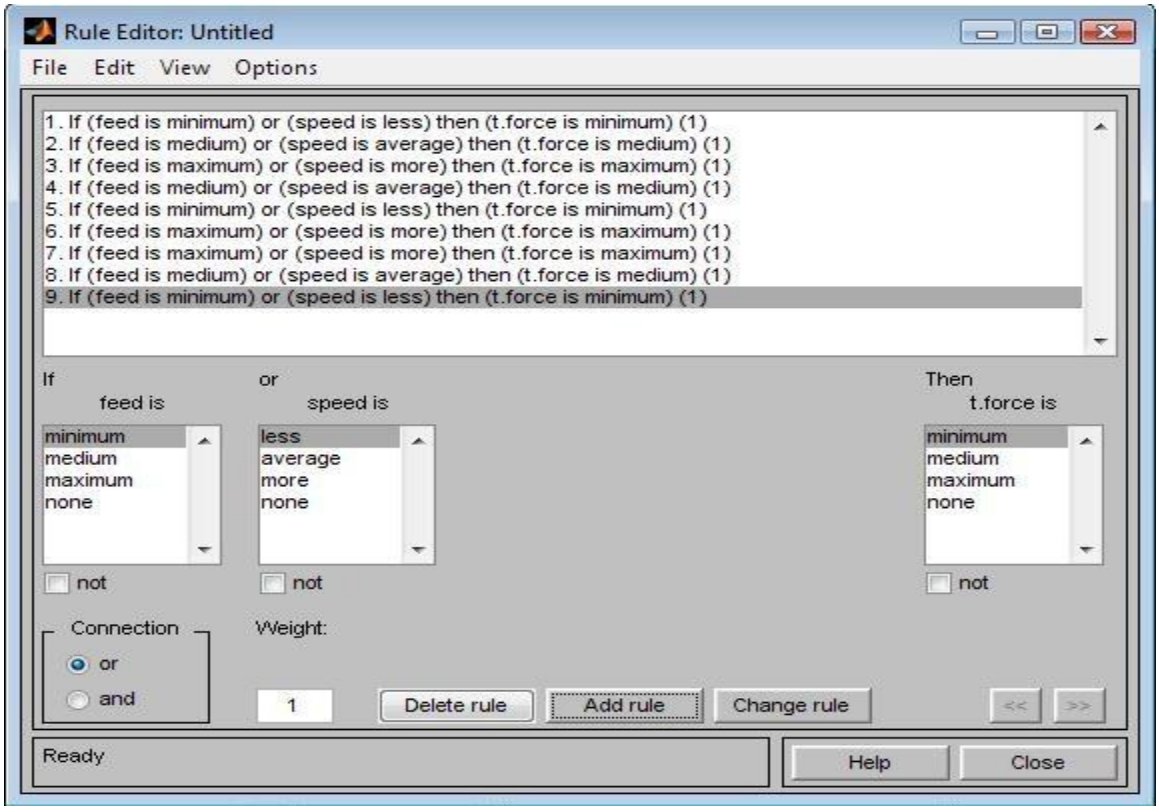


Fig. 4.6 Rule Editor

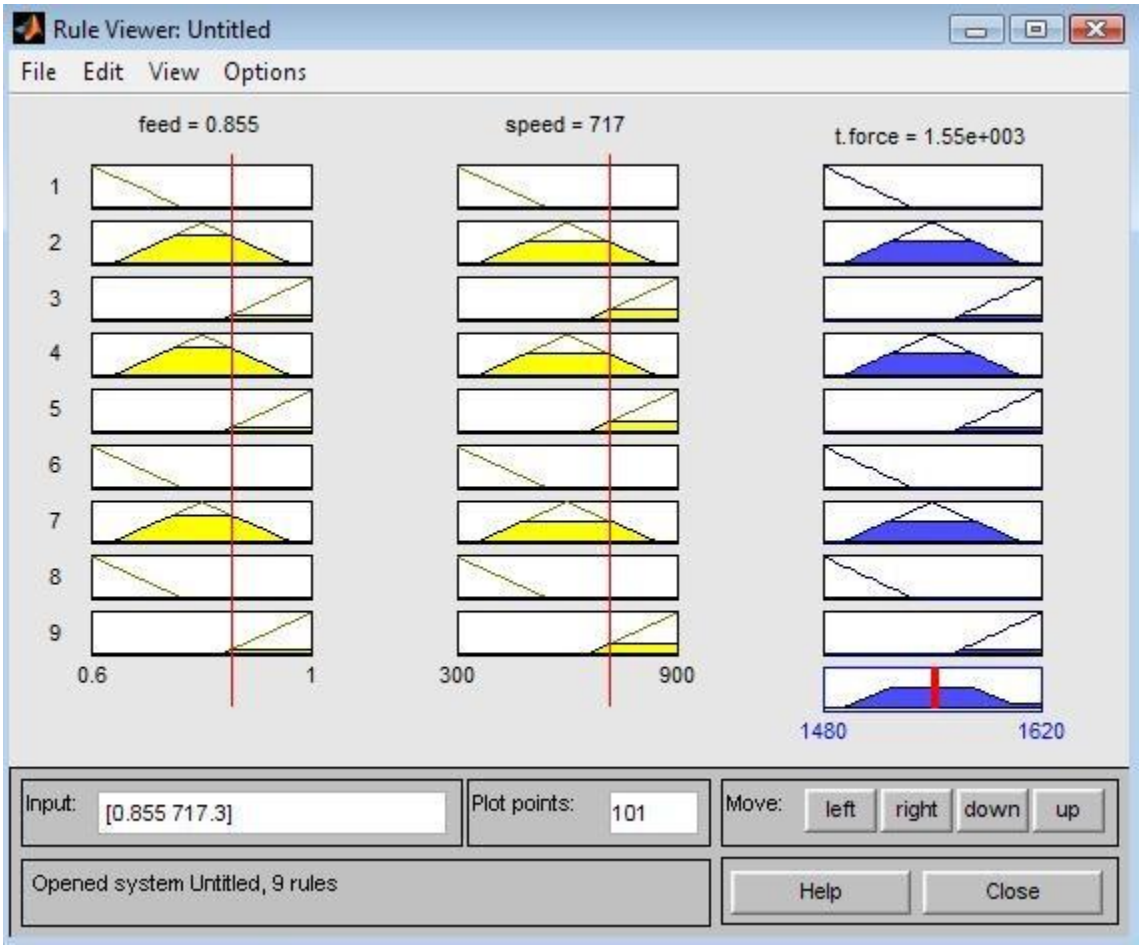


Fig. 4.7 Rule Viewer

The fuzzy logic toolbox facilitates the users with a rule viewer shown in figure 4.7. The rule viewer shows the nine rules used for the construction of the system. It also shows the numerical ranges of the input variables and the output variable. The rule viewer provides a platform for the modelers where one can enter the crisp input values and obtain a crisp output value.

Input Values: 1. Feed

2. Speed

Ouput Value: Thrust Force

By changing the input parameters feed & speed by moving the vertical lines, we can easily note the change in the behavior of the output parameter, i.e. Thrust Force.

The value of the thrust force keep on increasing with the increase in the feed or speed parameter.

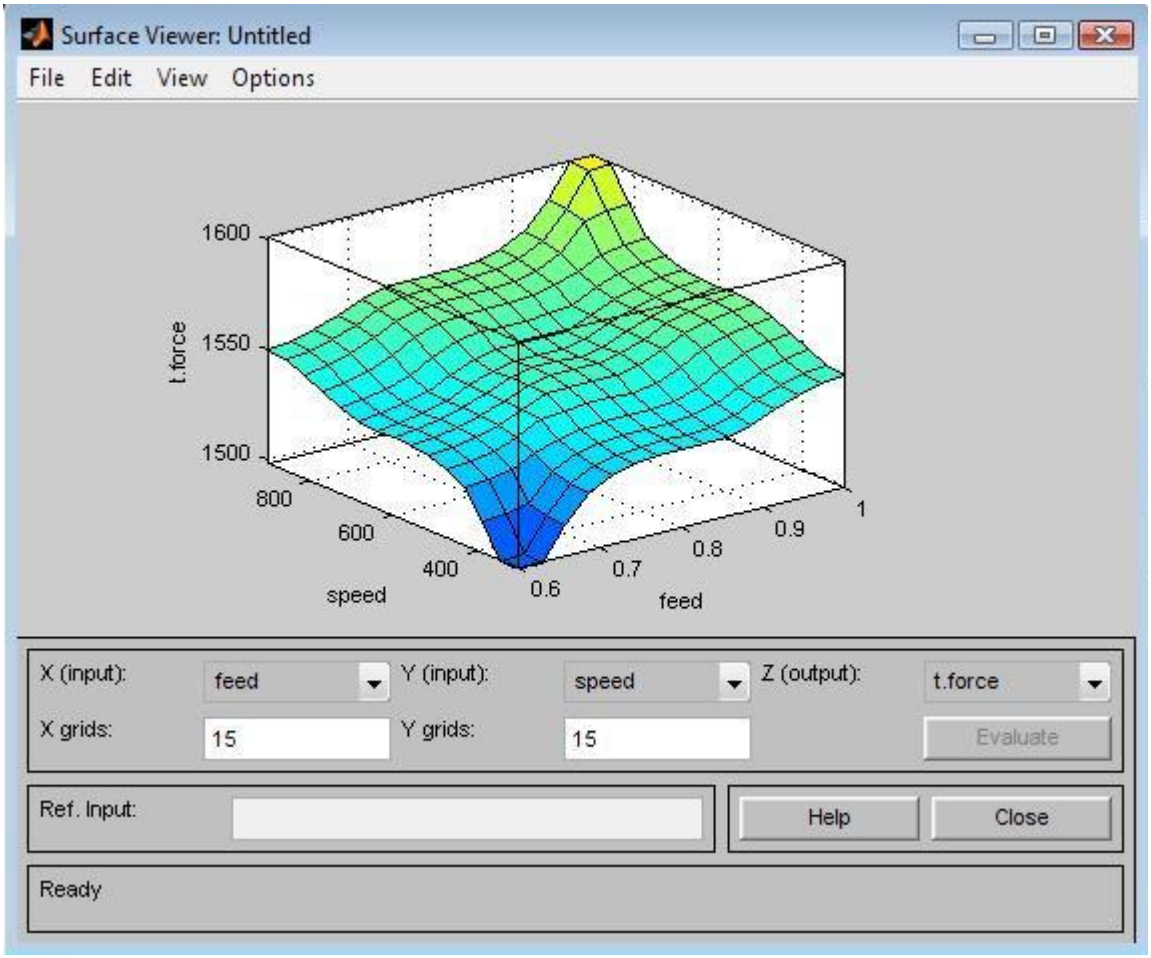


Fig. 4.8 Surface Viewer

Upon opening the Surface Viewer, we are presented with a 3-dimensional curve that represents the mapping from input to output. Since this is a two-input one-output case, we can see the entire mapping in one plot. Two-input one-output systems work well, as they generate three-dimensional plots that MATLAB can adeptly manage. Accordingly, the Surface Viewer is equipped with pop-up menus that let you select any two inputs and any one output for plotting. Just below the pop-up menus are two text input fields that let you determine how many x-axis and y-axis grid lines you want to include. This allows you to keep the calculation time reasonable for complex problems. Clicking the Evaluate button initiates the calculation, and the plot comes up soon after the calculation is complete. To change the x-axis or y-axis grid after the surface is in view, simply change the appropriate text field, and click either X-grids or Y-grids, according to which text field you changed, to redraw the plot. The Surface Viewer has a special capability that is very helpful in cases with two (or more) inputs and one output: you can actually grab the axes and reposition them to get a different three-dimensional view on the data. The Ref. Input field is used in situations when there are more inputs required by the system than the surface is mapping. Suppose you have a four-input one-output system and would like to see the output surface. The Surface Viewer can generate a three-dimensional output surface where any

two of the inputs vary, but two of the inputs must be held constant since computer monitors cannot display a five-dimensional shape.

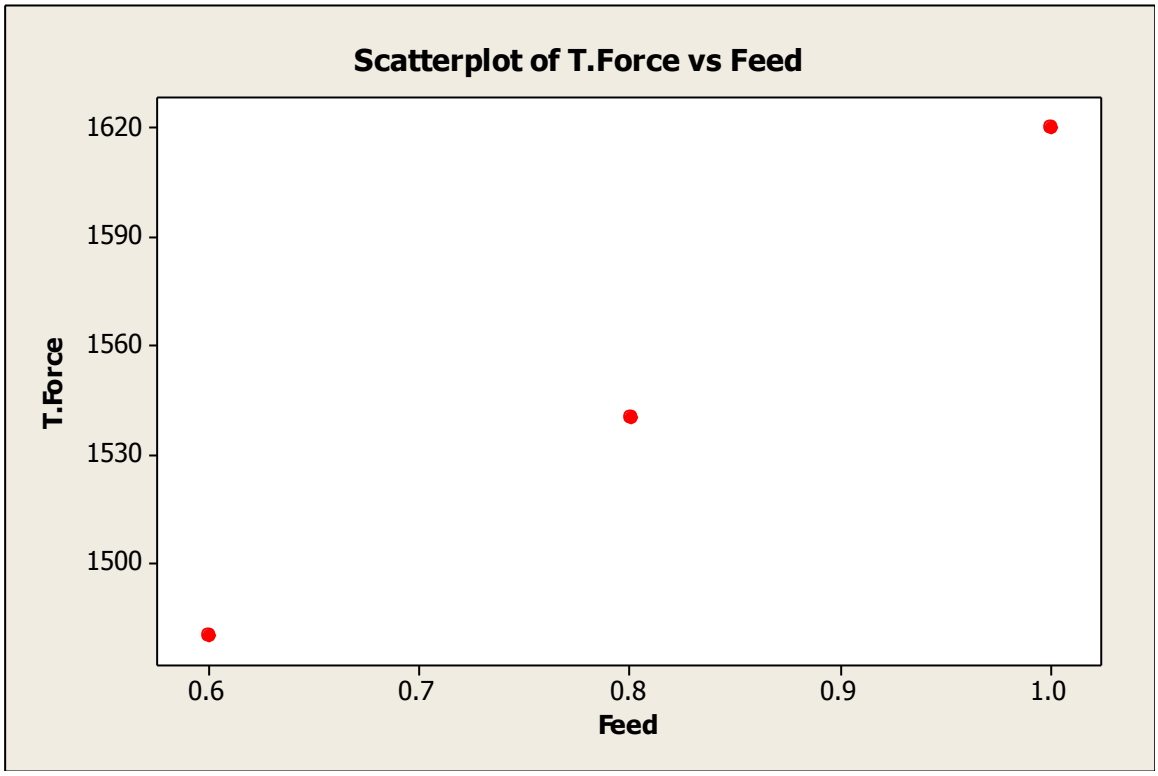


Fig. 4.9 Scatter Plot or Graph

The feed follows a linear path with the increase of thrust force as shown in the above graphical representation. A **scatter plot** or **scattergraph** is a type of mathematical diagram using Cartesian coordinates to display values for two variables for a set of data.The data is displayed as a collection of points, each having the value of one variable determining the position on the horizontal axis and the value of the other variable determining the position on the vertical axis. This kind of plot is also called a scatter chart, scattergram, scatter diagram or scatter graph. A scatter plot is used when a variable exists that is under the control of the experimenter. If a parameter exists that is systematically incremented and/or decremented by the other, it is called the control parameter or independent variable and is customarily plotted along the horizontal axis. The measured or dependent variable is customarily plotted along the vertical axis. If no dependent variable exists, either type of variable can be plotted on either axis and a scatter plot will illustrate only the degree of correlation (not causation) between two variables. One of the most powerful aspects of a scatter plot, however, is its ability to show nonlinear relationships between variables. Furthermore, if the data is represented by a mixture model of simple relationships, these relationships will be visually evident as superimposed patterns. The scatter

diagram is one of the basic tools of quality control. No universal best-fit procedure is guaranteed to generate a correct solution for arbitrary relationships. A scatter plot is also very useful when we wish to see how two comparable data sets agree with each other. In this case, an identity line, *i.e.*, a $y=x$ line, or an 1:1 line, is often drawn as a reference. The more the two data sets agree, the more the scatters tend to concentrate in the vicinity of the identity line; if the two data sets are numerically identical, the scatters fall on the identity line exactly. The analysis of variance has been studied from several approaches, the most common of which use a linear model that relates the response to the treatments and blocks. Even when the statistical model is nonlinear, it can be approximated by a linear model for which an analysis of variance may be appropriate. To test the hypothesis that all treatments have exactly the same effect, the F-test's p-values closely approximate the permutation test's p-values: The approximation is particularly close when the design is balanced. Such permutation tests characterize tests with maximum power against all alternative hypotheses, as observed by Rosenbaum. The anova F–test (of the null-hypothesis that all treatments have exactly the same effect) is recommended as a practical test, because of its robustness against many alternative distributions. The Kruskal–Wallis test is a nonparametric alternative that does not rely on an assumption of normality. And the Friedman test is the nonparametric alternative for a one-way repeated measures ANOVA. The separate assumptions of the textbook model imply that the errors are independently, identically, and normally distributed for fixed effects models, that is, that the errors are independent.

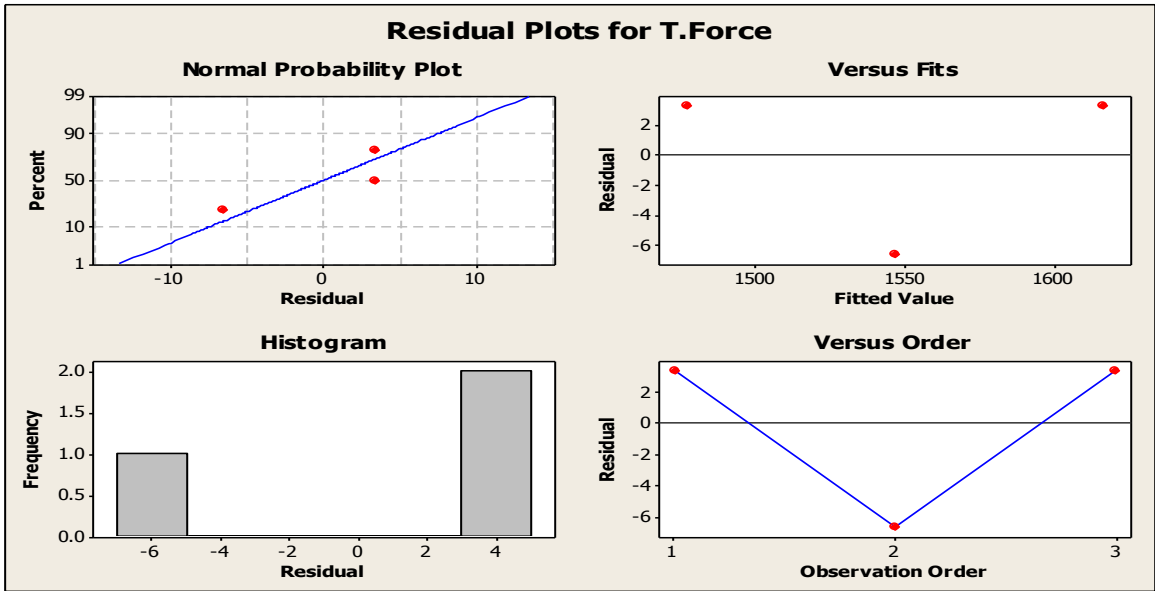


Fig. 4.10 Residuals Plots

The residuals from a fitted model the differences between the responses observed at each combination values of the explanatory variables and the corresponding prediction of the response computed using the regression function. If the model fit to the data were correct, the residuals would approximate the random errors that make the relationship between the explanatory variables and the response variable a statistical relationship. Therefore, if the residuals appear to behave randomly, it suggests that the model fits the data well. On the other hand, if non-random structure is evident in the residuals, it is a clear sign that the model fits the data poorly. The next section details the types of plots to use to test different aspects of a model and give guidance on the correct interpretations of different results that could be observed for each type of plot.

4.8 Graphical analysis of residuals

There are many statistical tools for model validation, but the primary tool for most modeling applications is graphical residual analysis. Different types of plots of the residuals from a fitted model provide information on the adequacy of different aspects of the model.

1. sufficiency of the functional part of the model: scatter plots of residuals versus predictors
2. non-constant variation across the data: scatter plots of residuals versus predictors; for data collected over time, also plots of residuals against time
3. drift in the errors (data collected over time): run charts of the response and errors versus time
4. independence of errors: lag plot
5. normality of errors: histogram and normal probability plot

Graphical methods have an advantage over numerical methods for model validation because they readily illustrate a broad range of complex aspects of the relationship between the model and the data.

4.9 Quantitative analysis of residuals

Numerical methods for model validation, such as the R^2 statistic, are also useful, but usually to a lesser degree than graphical methods. Numerical methods for model validation tend to be narrowly focused on a particular aspect of the relationship between the model and the data and often try to compress that information into a single descriptive number or test result. Numerical methods do play an important role as confirmatory methods for graphical techniques, however. For example, the lack-of-fit test for assessing the correctness of the functional part of the model

can aid in interpreting a borderline residual plot. There are also a few modeling situations in which graphical methods cannot easily be used. In these cases, numerical methods provide a fallback position for model validation. One common situation when numerical validation methods take precedence over graphical methods is when the number of parameters being estimated is relatively close to the size of the data set. In this situation residual plots are often difficult to interpret due to constraints on the residuals imposed by the estimation of the unknown parameters. One area in which this typically happens is in optimization applications using designed experiments. Logistic regression with binary data is another area in which graphical residual analysis can be difficult. Unfortunately, a high R^2 (coefficient of determination) value does not guarantee that the model fits the data well. Use of a model that does not fit the data well cannot provide good answers to the underlying engineering or scientific questions under investigation. However to increase the precision of the R^2, some statisticians suggest that you should use the adjusted R^2 to reflect both the number of independent variables in the model and sample size. This is only useful for multiple regression.

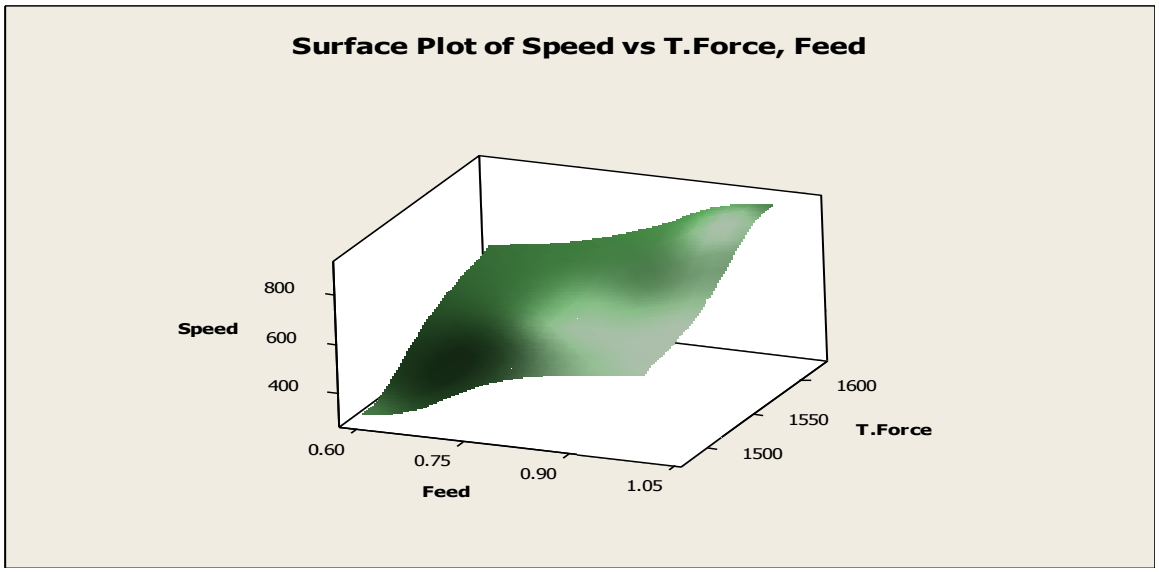


Fig. 4.11 Surface Plot

The surface plot for corresponding changes of feed and thrust force is shown in the above figure that shows linear distribution with the change of speed. A (topological) surface is a nonempty second countable Hausdorff topological space in which every point has an open neighbourhood homeomorphic to some open subset of the Euclidean plane $\mathbf{E}^2$. Such a neighborhood, together with the corresponding homeomorphism, is known as a (coordinate) chart. It is through this chart that the neighborhood inherits the standard coordinates on the

Euclidean plane. This coordinates are known as local coordinates and these homeomorphisms lead us to describe surfaces as being locally Euclidean.

4.10 Software Analysis

More generally, a (topological) surface with boundary is a Hausdorff topological space in which every point has an open neighbourhood homeomorphic to some open subset of the upper half-plane $\mathbf{H}^2$. These homeomorphisms are also known as (coordinate) charts. The boundary of the upper half-plane is the x-axis. A point on the surface mapped via a chart to the x-axis is termed a boundary point. The collection of such points is known as the boundary of the surface which is necessarily a one-manifold, that is, the union of closed curves. On the other hand, a point mapped to above the x-axis is an interior point. The collection of interior points is the interior of the surface which is always non-empty. The closed disk is a simple example of a surface with boundary. The boundary of the disc is a circle.

The term surface used without qualification refers to surfaces without boundary. In particular, a surface with empty boundary is a surface in the usual sense. A surface with empty boundary which is compact is known as a 'closed' surface. The two-dimensional sphere, the two-dimensional torus, and the real projective plane are examples of closed surfaces.

The Möbius strip is a surface with only one "side". In general, a surface is said to be orientable if it does not contain a homeomorphic copy of the Möbius strip; intuitively, it has two distinct "sides". For example, the sphere and torus are orientable, while the real projective plane is not (because deleting a point or disk from the real projective plane produces the Möbius strip).

In differential and algebraic geometry, extra structure is added upon the topology of the surface. This added structures detects singularities, such as self-intersections and cusps, that cannot be described solely in terms of the underlying topology.

In mathematics, specifically in topology, a **surface** is a two-dimensional topological manifold. The most familiar examples are those that arise as the boundaries of solid objects in ordinary three-dimensional Euclidean space $\mathbf{R}^3$ — for example, the surface of a ball. On the other hand, there are surfaces, such as the Klein bottle, that cannot be embedded in three-dimensional Euclidean space without introducing singularities or self-intersections.

To say that a surface is "two-dimensional" means that, about each point, there is a coordinate patch on which a two-dimensional coordinate system is defined. For example, the surface of the Earth is (ideally) a two-dimensional sphere, and latitude and longitude provide two-dimensional coordinates on it (except at the poles and along the 180th meridian).

The concept of surface finds application in physics, engineering, computer graphics, and many other disciplines, primarily in representing the surfaces of physical objects. For example, in analyzing the aerodynamic properties of an airplane, the central consideration is the flow of air along its surface. Historically, surfaces were initially defined as subspaces of Euclidean spaces. Often, these surfaces were the locus of zeros of certain functions, usually polynomial functions. Such a definition considered the surface as part of a larger (Euclidean) space, and as such was termed extrinsic.

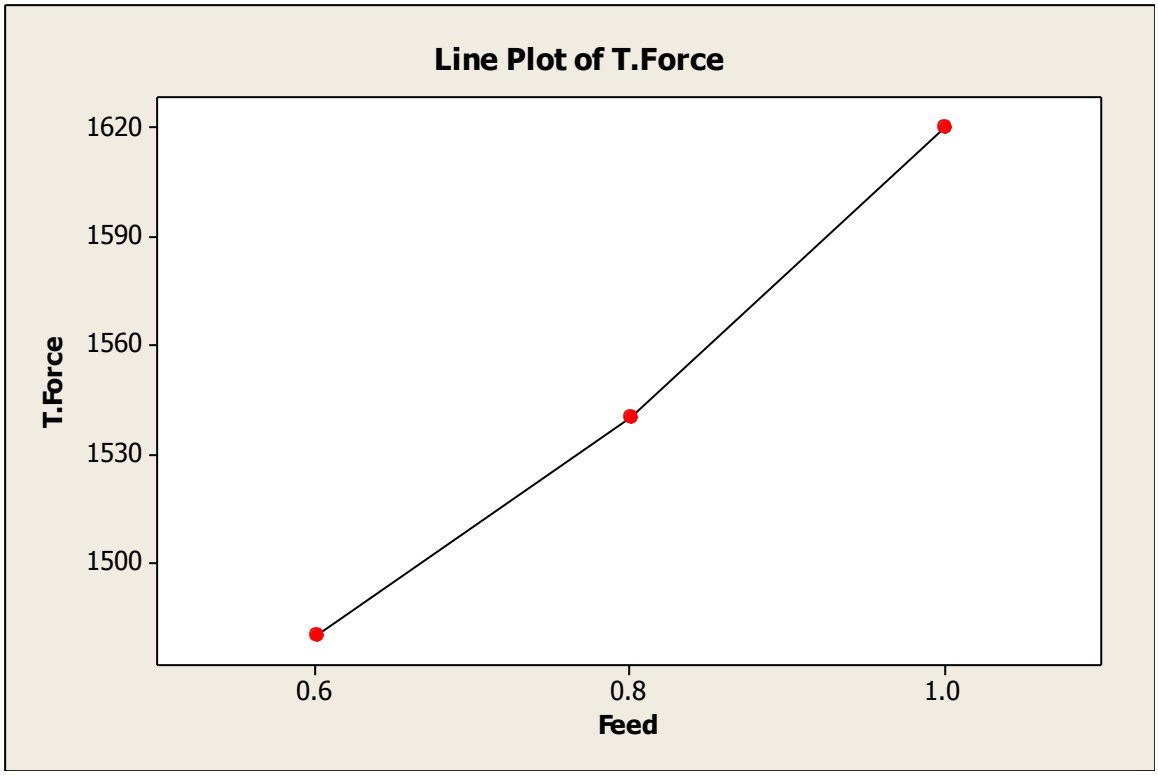


Fig. 4.12 Line Plot

From the line plot, it is clear that the thrust force follows a non – linear slope with the change of feed. A line plot is a graph of the transfer function of a linear, time-invariant system versus frequency, plotted with a log-frequency axis, to show the system's frequency response. It is usually a combination of a line magnitude plot, expressing the magnitude of the frequency response gain, and a line phase plot, expressing the frequency response phase shift. A line phase plot is a graph of phase versus frequency, also plotted on a log-frequency axis, usually used in conjunction with the magnitude plot, to evaluate how much a signal will be phase-shifted. For example a signal described by: $A\sin(\omega t)$ may be attenuated but also phase-shifted. If the system attenuates it by a factor x and phase shifts it by $-\Phi$ the signal out of the system will be $(A/x)\sin(\omega t - \Phi)$. The phase shift Φ is generally a function of frequency. The magnitude and phase Bode plots can seldom be changed independently of each other — changing the amplitude response of the system will most likely change the phase characteristics and vice versa.

For minimum-phase systems the phase and amplitude characteristics can be obtained from each other with the use of the Hilbert transform. The horizontal frequency axis, in both the magnitude and phase plots, can be replaced by the normalized (non dimensional) frequency ratio $\frac{\omega}{\omega_c}$. In such a case the plot is said to be normalized and units of the frequencies are no longer used since all input frequencies are now expressed as multiples of the cutoff frequency ω_c.

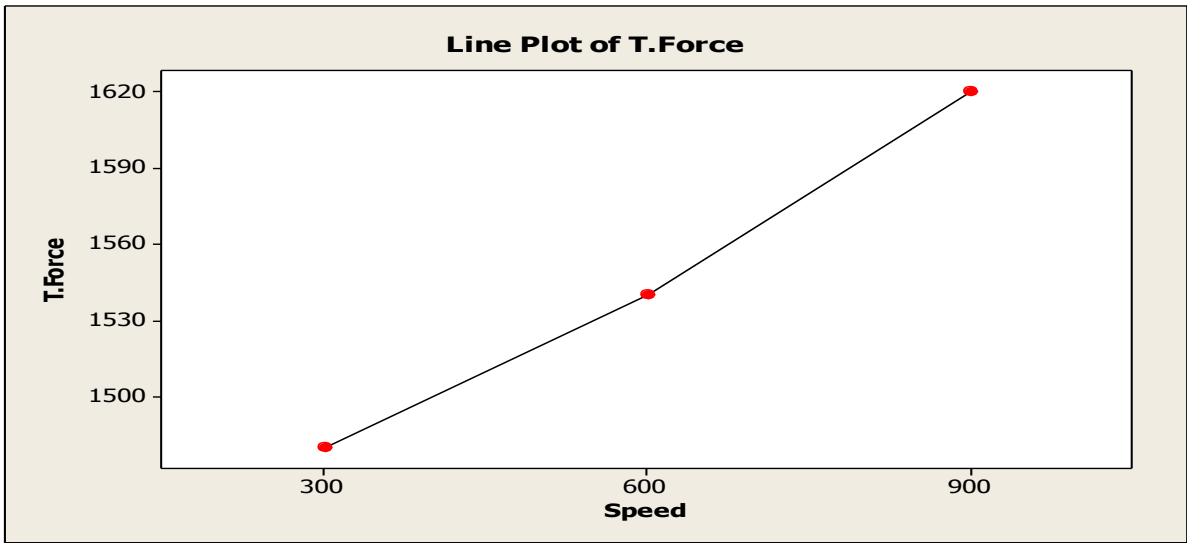


Fig. 4.13 Line Plot

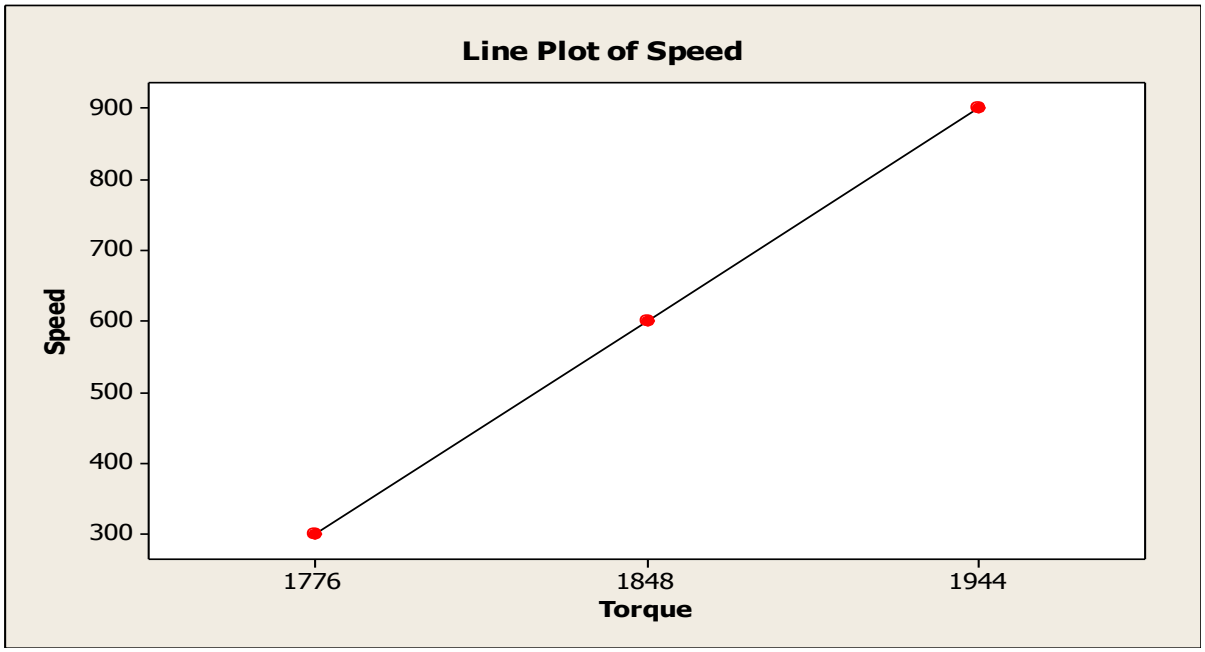


Fig. 4.14 Line Plot

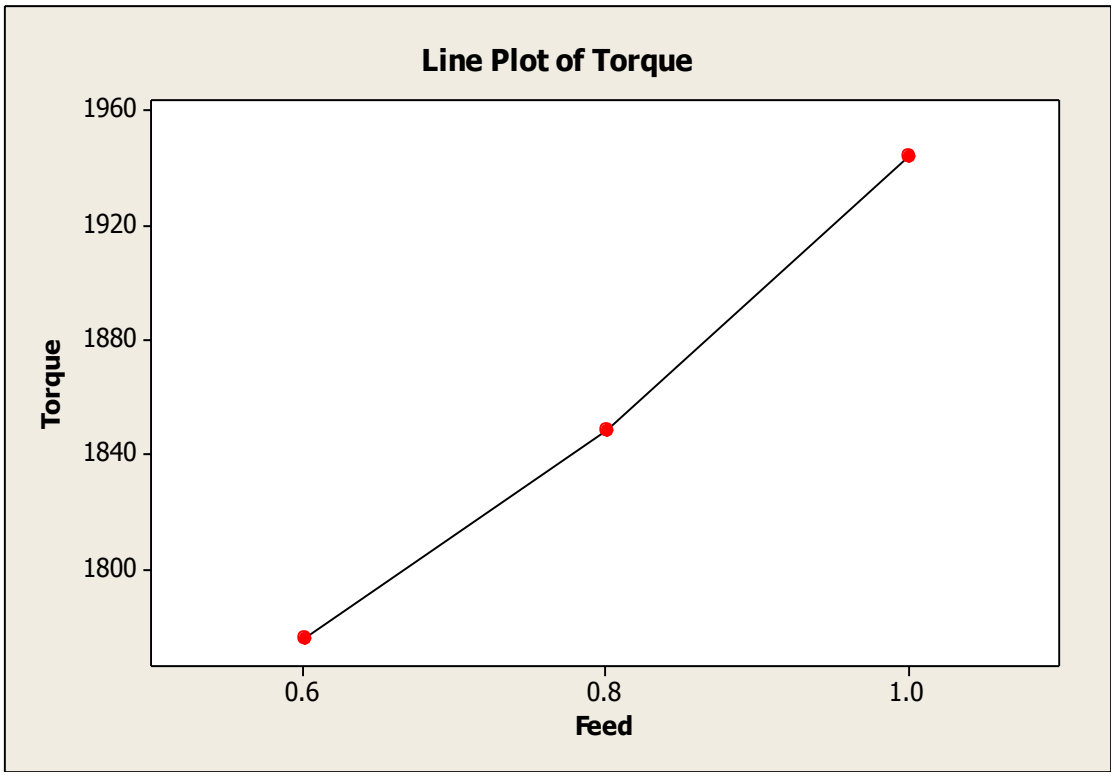


Fig. 4.15 Line Plot

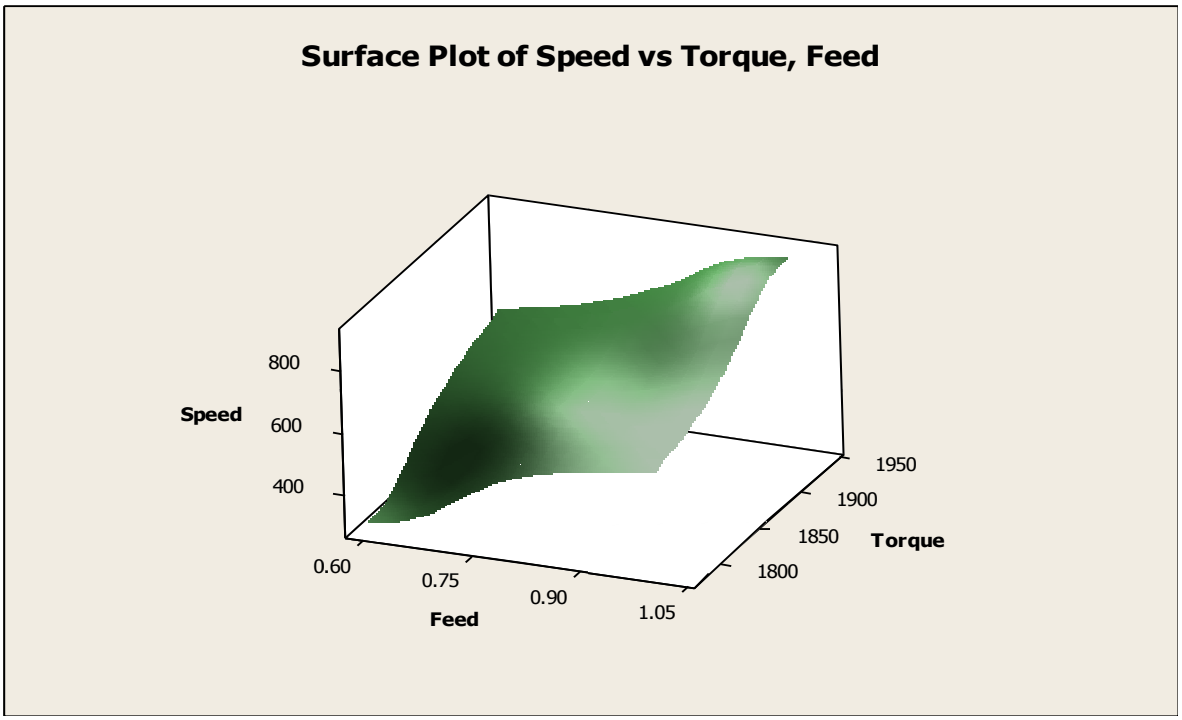


Fig. 4.16 Surface Plot

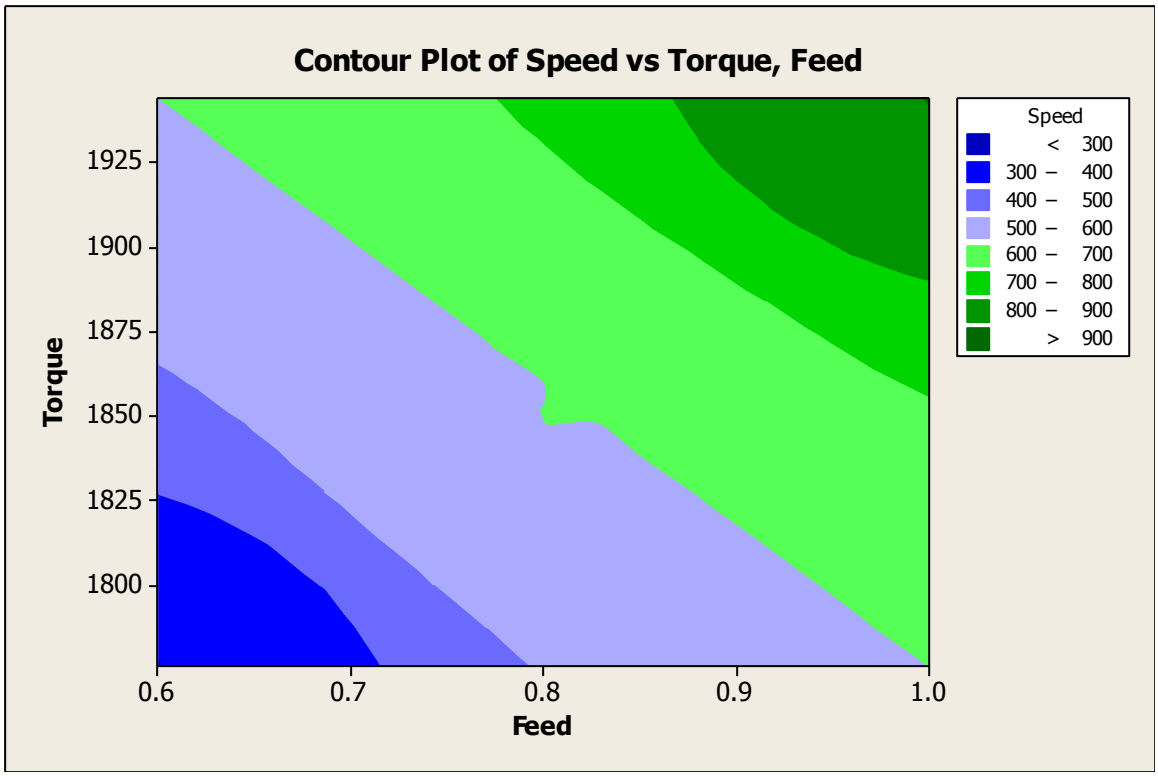


Fig. 4.17 Contour Plot

The speed at the range of 500-600 rpm has much effect on torque and feed because the plot shows a considerable changes with higher area of occupance at 500-600 rpm of speed. A contour line (also isoline or isarithm) of a function of two variables is a curve along which the function has a constant value. In cartography, a contour line (often just called a "contour") joins points of equal elevation (height) above a given level, such as mean sea level. A contour map is a map illustrated with contour lines, for example a topographic map, which thus shows valleys and hills, and the steepness of slopes. The contour interval of a contour map is the difference in elevation between successive contour lines. More generally, a contour line for a function of two variables is a curve connecting points where the function has the same particular value. The gradient of the function is always perpendicular to the contour lines. When the lines are close together the magnitude of the gradient is large: the variation is steep. A level set is a generalization of a contour line for functions of any number of variables. Contour lines are curved or straight lines on a map describing the intersection of a real or hypothetical surface with one or more horizontal planes. The configuration of these contours allows map readers to infer relative gradient of a parameter and estimate that parameter at specific places. Contour lines may be either traced on a visible three-dimensional model of the surface, as when a photogrammetrist viewing a stereo-model plots elevation contours, or interpolated from estimated

surface elevations, as when a computer program threads contours through a network of observation points of area centroids. In the latter case, the method of interpolation affects the reliability of individual isolines and their portrayal of slope, pits and peaks.

Table 4.2 Experimental Value of Torque

Exp. No.	Torque
1	1776
2	1776
3	1776
4	1848
5	1848
6	1848
7	1944
8	1944
9	1944
10	1848
11	1848
12	1848
13	1944
14	1944
15	1944
16	1776
17	1776
18	1776

The experimental values of the torque are recorded as given in the above table in accordance with the feed, speed parameters. The torque follows a linear change with the increase in feed, speed parameters & graph shown previously illustrates the straight line behavior of the torque.

Torque, also called **moment** or **moment of force** (see the terminology below), is the tendency of a force to rotate an object about an axis, fulcrum, or pivot. Just as a force is a push or a pull, a torque can be thought of as a twist.

Loosely speaking, torque is a measure of the turning force on an object such as a bolt or a flywheel. For example, pushing or pulling the handle of a wrench connected to a nut or bolt produces a torque (turning force) that loosens or tightens the nut or bolt.

The terminology for this concept is not straightforward: In the US, in physics it is usually called "torque" and in mechanical engineering it is called "moment". However outside the US this varies. In the UK for instance, most physicists will use the term "moment". In mechanical

engineering, the term "torque" means something different, described below. In this article the word "torque" is always used to mean the same as "moment".

The symbol for torque is typically τ, the Greek letter tau. When it is called moment, it is commonly denoted M.

The magnitude of torque depends on three quantities: the force applied, the length of the lever arm connecting the axis to the point of force application, and the angle between the force vector and the lever arm. In symbols:

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F} \text{.....(4.7)}$$

$$\boldsymbol{\tau} = rF \sin\theta \text{.....(4.8)}$$

where

τ is the torque vector and τ is the magnitude of the torque,

r is the displacement vector (a vector from the point from which torque is measured to the point where force is applied), and r is the length (or magnitude) of the lever arm vector,

F is the force vector, and F is the magnitude of the force, × denotes the cross product,

θ is the angle between the force vector and the lever arm vector.

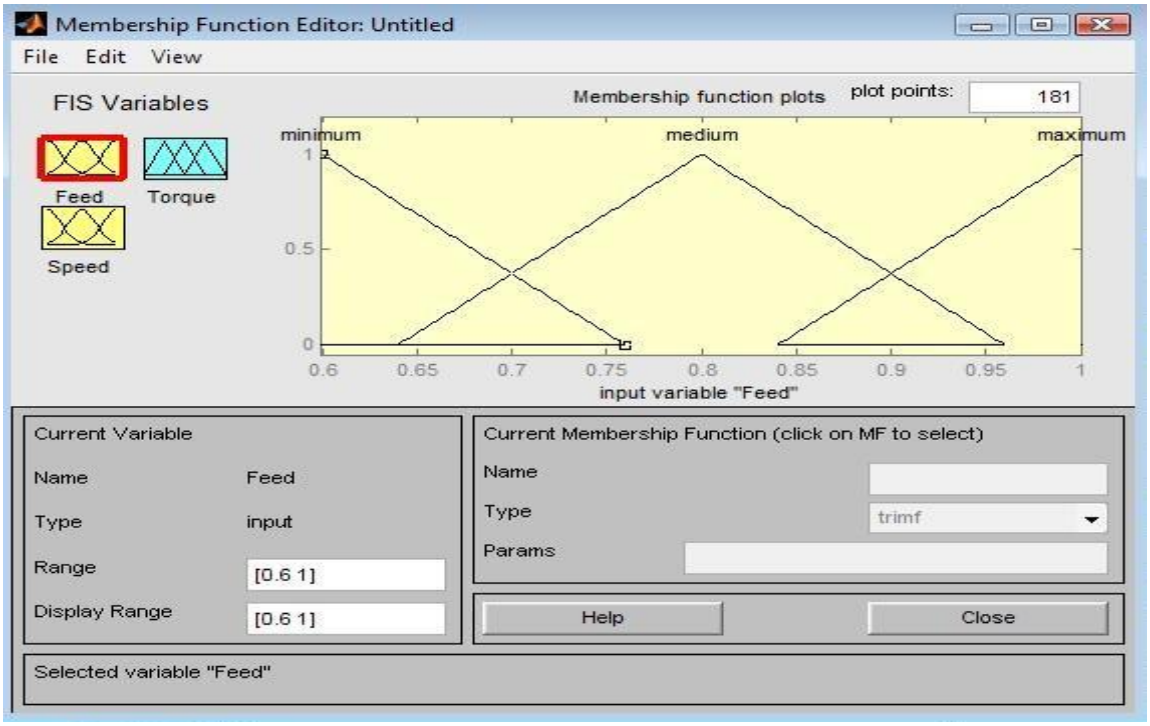


Fig. 4.18 Input Membership Function

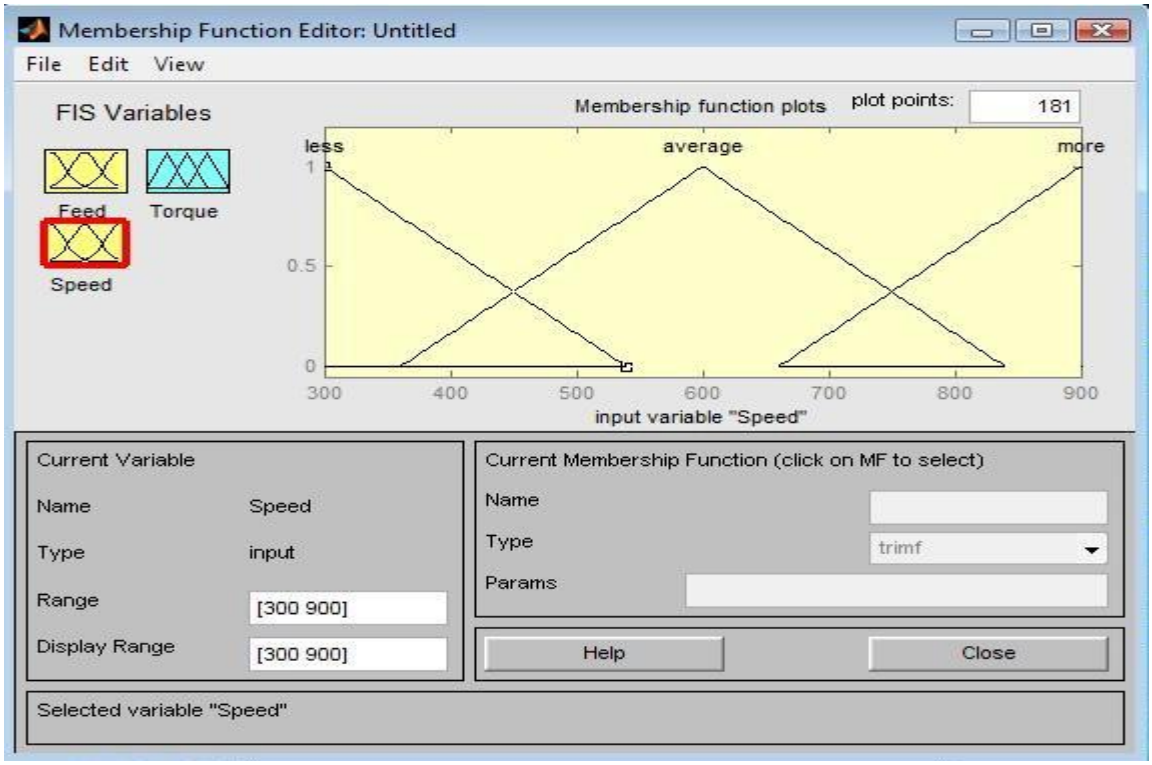


Fig. 4.19 Input Membership Function

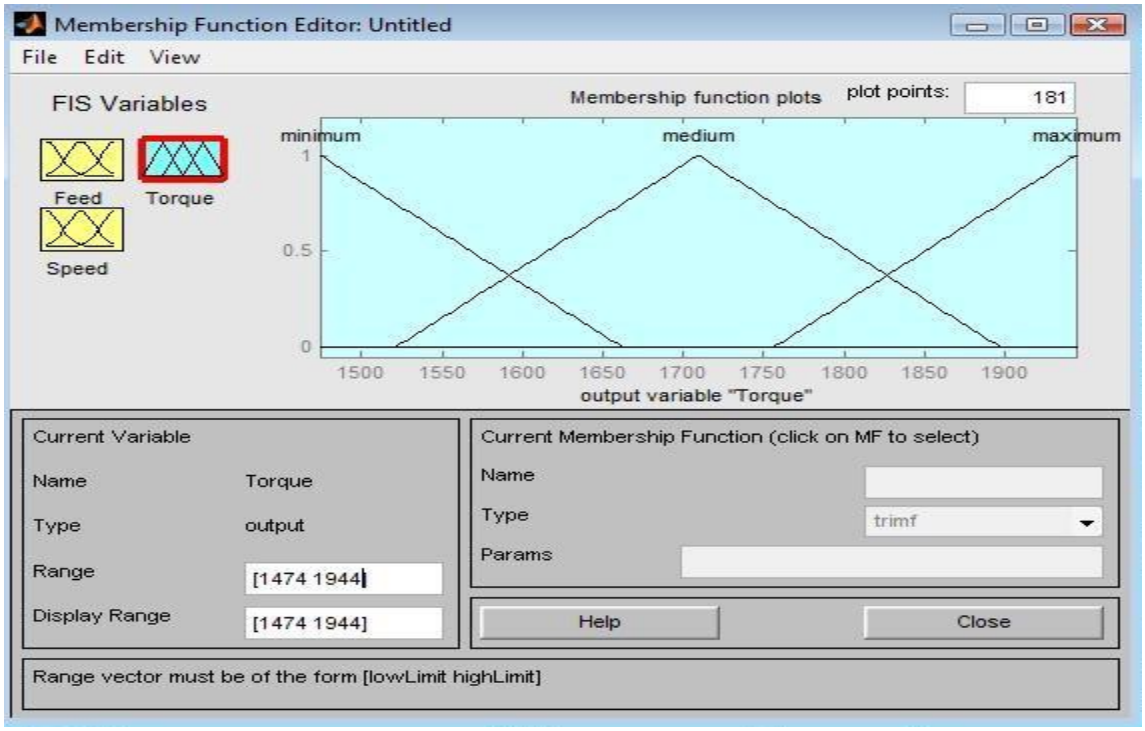


Fig. 4.20 Output Membership Function

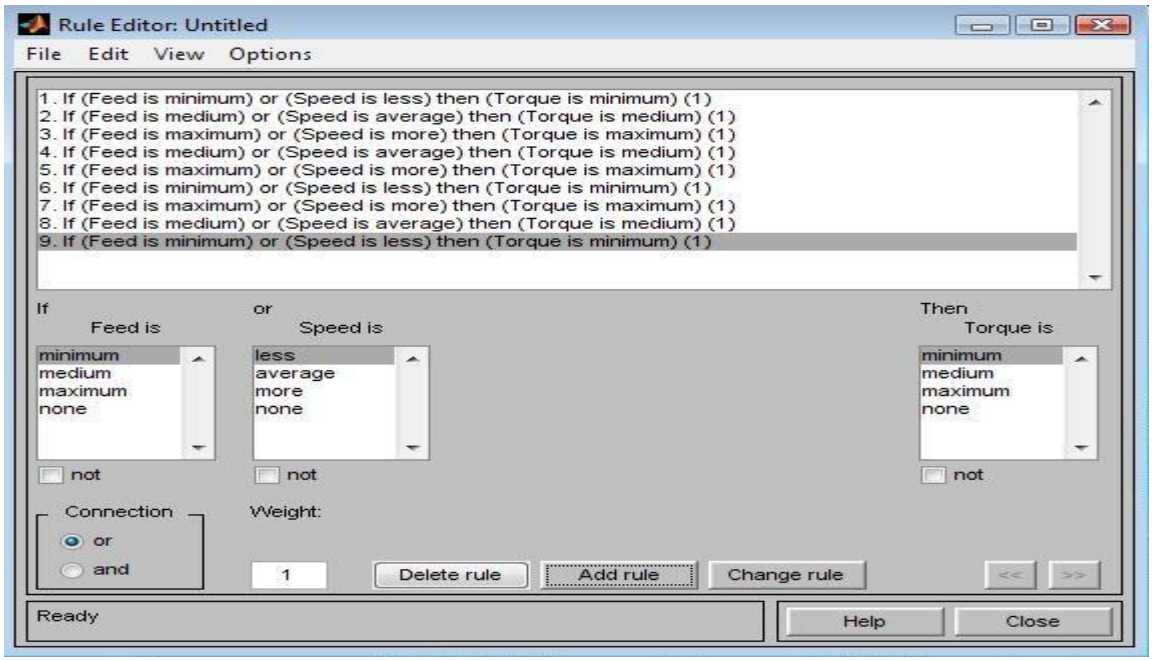


Fig. 4.21 Rule Editor

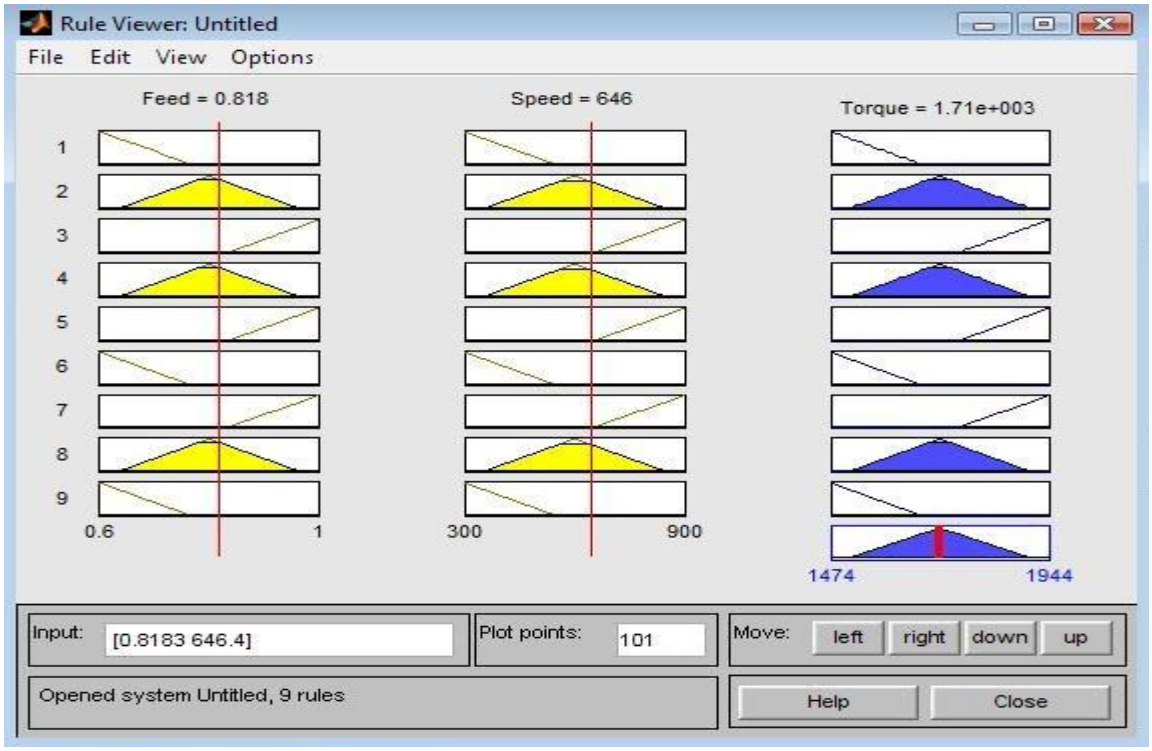


Fig. 4.22 Rule Viewer

The fuzzy logic toolbox facilitates the users with a rule viewer shown in figure 4.22. The rule viewer shows the nine rules used for the construction of the system. It also shows the numerical ranges of the input variables and the output variable. The rule viewer provides a platform for the modelers where one can enter the crisp input values and obtain a crisp output value.

Input Values: 1. Feed

2. Speed

Ouput Value: Torque

By changing the input parameters feed & speed by moving the vertical lines, we can easily note the change in the behavior of the output parameter, i.e. Torque.

The value of the torque keeps on increasing with the increase in the feed or speed parameter.

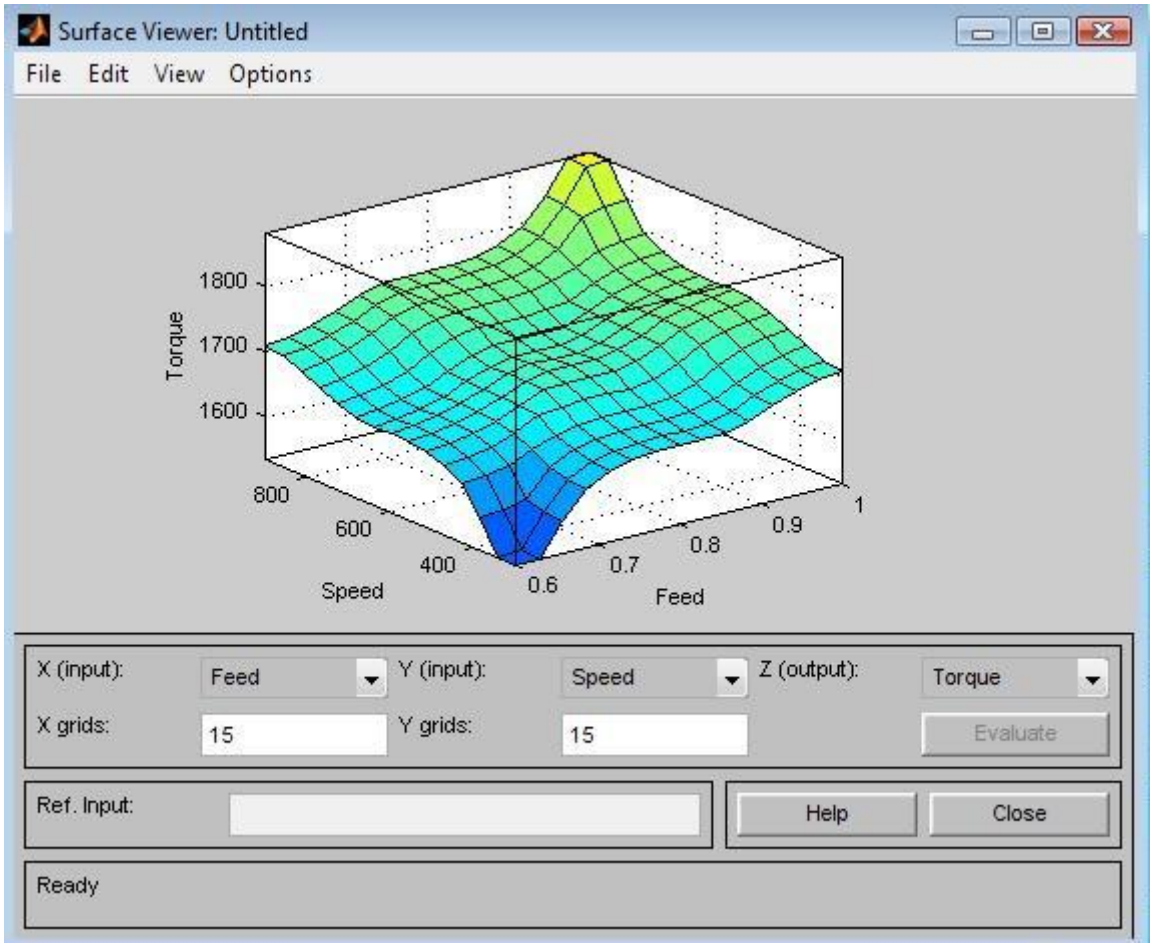


Fig. 4.23 Surface Viewer

CHAPTER – 5

MECHANICIAL MEASUREMENT & TESTING

The thrust force, torque, and tool wear in drilling of mild steel & glass fiber material are investigated. Drilling the mild steel at high speed generates the chip light emission, high tool temperature, and severe tool wear. At low spindle speed, the work-material builds up at the major and margin cutting edges and may break the drill. A range of feasible spindle speed and feed rate for the efficient drilling of workpiece without the detrimental chip light emission and cutting edge work-material build-up has been identified in this study. Under the same drilling condition, the tool generally requires less thrust force and about the same torque than the high-speed steel tool. The progressive wear of the major and margin cutting edges for drilling is examined. Severe drill wear is associated with the bright chip light emission. Without chip light emission, the drill wear is visible but not severe. This study concluded that precision holes in mild steel & glass fiber could be generated with proper selection of tooling and process parameters.

This study extends the previous research on drilling of BMG to the investigation of drilling thrust force, torque, and drill wear. Thrust force and torque determine the energy required for chip generation. In addition, effects of tool wear, drilling process parameters (feed rate and spindle speed), plowing in the drill center chisel edge, chip generation in the major cutting edge, and deformation of tool- and work-materials can be revealed by analyzing the change in thrust force and torque. In this study, mild steel & glass fiber are drilled under the same process conditions and the measured thrust force and torque are compared. Tool wear has a strong effect on hole quality and dimensional accuracy during drilling. Tool wear can reach a threshold level, which causes the catastrophic failure of the drill. Excess tool wear is associated with high cutting forces and can damage the part, fixture, and machine tool. For mild steel, the low thermal conductivity facilitates high chip temperatures, which may trigger the rapid exothermic oxidation of the chip and light emission during drilling. Unlike lathe turning, the chip in drilling is constrained within narrow flutes and makes the constant contact with the drill and workpiece. High temperature chip is expected to damage the drill catastrophically. Such phenomenon is revealed in this study.

One of the goals of this study is to identify feasible drilling process parameters that do not generate the chip light emission and can produce multiple holes with no significant tool wear. The cutting force and tool wear in lathe turning of mild steel has been investigated. Identification of the tool wear mechanisms, such as the chipping and plastic deformation of major and margin cutting edges on the drill, and comparison with drilling are performed. The thrust force, torque, and severe tool wear of drilling associated with the chip light-emission are analyzed. For the drilling without chip light emission, the same analysis procedure is applied to study the thrust force and torque. Finally, progressive tool wear for drilling is presented.

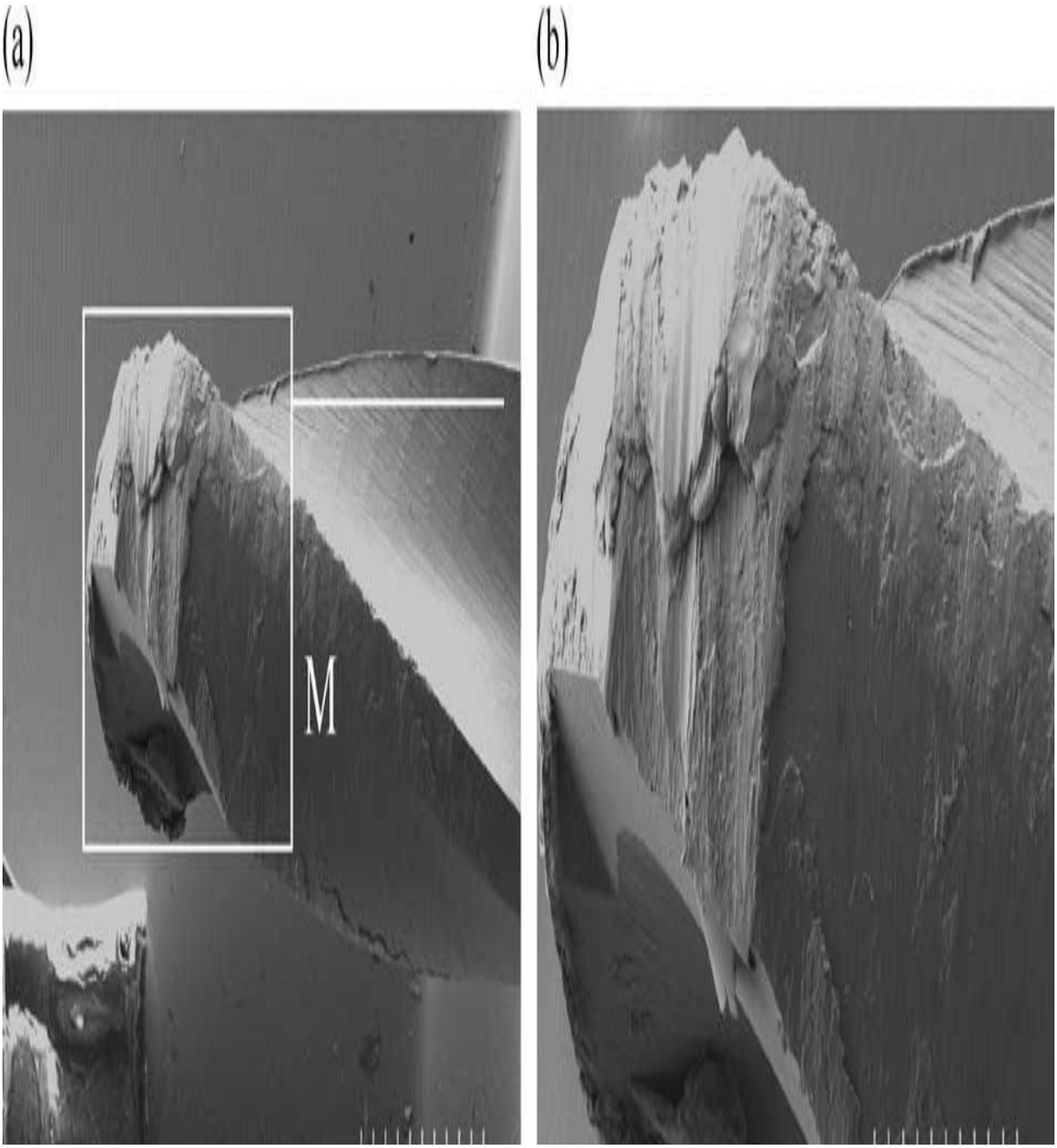


Fig. 5.1. Microscopic Views of the severe wear in 10 mm HSS tool in Exp. III after drilling four holes: (a) 0.6 mm/rev feed rate, (b) close-up view of the drill tip in (a), and (b) drilling with 1.0 mm/rev. (M: margin wear)

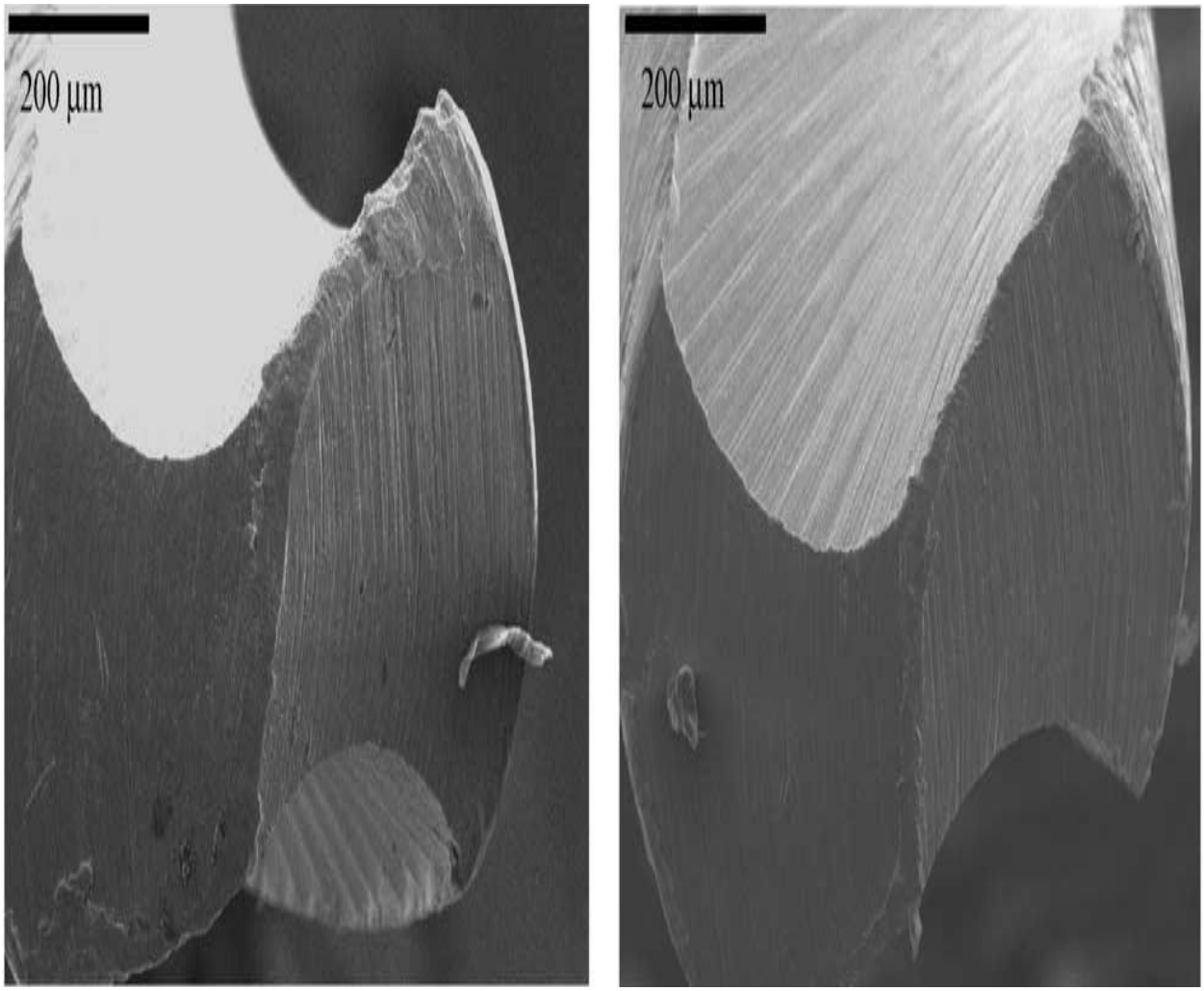


Fig. 5.2. Wear of HSS drill: Exp. II at 600 rpm spindle speed and Exp. II at 900 rpm spindle speed.

The growing demand for higher productivity, product quality and overall economy in manufacturing by machining, grinding and drilling, particularly to meet the challenges thrown by liberalization and global cost competitiveness, insists high material removal rate and high stability and long life of the cutting tools. However, high production machining and grinding with high cutting velocity, feed and depth of cut is inherently associated with generation of large amount of heat and high cutting temperature. Such high cutting temperature not only reduces dimensional accuracy and tool life but also impairs the surface finish of the product. Hole making had long been recognized as the most prominent machining process, requiring specialized techniques to achieve optimum cutting condition. Drilling can be described as a

process where a multi-point tool is used to remove unwanted materials to produce a hole. It broadly covers those methods used for producing cylindrical holes in the work piece. While removal of material in the form of chips new surfaces are cleaved from the work piece accompanied by a large consumption of energy. The mechanical energy necessary for the drilling operation is transformed into heat leading to conditions of high temperature and severe thermal/frictional conditions at the tool- chip interface.

During the drilling process, the most important factor affecting the cutting tool performance and work piece properties is cutting temperature that emerges between drill bit and chip. The temperatures associated with the drilling process are particularly important, because drilling is one of the predominant industrial machining processes and heat effects in drilling are generally more severe than in other metal cutting operations. Drills often experience excessive temperatures because the drill is embedded in the work piece and heat generation is localized in a small area. The resulting temperatures can lead to accelerate tool wear and reduce tool life and they can have profound effects on the overall quality of the machined work piece. Drill designers often select the geometrical features of a drill based on the expected temperature profile in the drill point, so accurate prediction of the temperature distribution is imperative. Temperature not only be exaggerated the tool wear but also affect the surface, hole quality and chip formation. The cutting temperature directly influences hole sensitivity, surface roughness, and tool wear. Worn drills produce poor quality holes and in extreme cases, a broken drill can destroy almost all finished part. A drill begins to wear as soon as it is placed into operation. As it wears, cutting forces will increases, the temperature of the drill rises and this accelerates the physical and chemical processes associated with drill wear and therefore drill wears faster. Thrust and torque depend upon drill wear, drill size, feed rate and spindle speed. Research results shows that tool breakage, tool wear and work piece deflection are strongly related to cutting force. In drilling, the material is removed in the form of chips and evacuated through the drill flutes. It has been found that smaller chips are more easily removed from the drill by the action of the flutes, centrifugal forces, and/or metal working fluids. Long chips can become tangled around the drill, can lead to poor hole quality and are more difficult to manage once outside the hole thereby increasing production costs and lowering productivity. Furthermore, while drilling deep holes friction between the drill flutes and chips causes the chips to be evacuated slower than chips are produced. This leads to chip clogging, which in turn causes sudden increases in torque and thrust that may cause drill breakage.

Improving chip evacuation will lead to less drill breakage, lower production costs, better hole quality, and increased productivity. Currently in industries, this high temperature problem is partially tried to be controlled by reducing heat generation and moving heat from the cutting

zone through optimum selection of machining parameters and geometry of the cutting tools, proper cutting fluid application and using heat resistant cutting tool materials like carbides, coated carbides and high performance ceramics (CBN). The thermal deterioration of the cutting tools can be reduced by using CBN tools. If properly manufactured, selected and used, CBN tools provide much less cutting force, temperature and hence less tensile residual stress. Though CBN tools are extremely heat and wear resistive, those are too expensive and are justified for very special work materials and requirements where other tools are not effective.

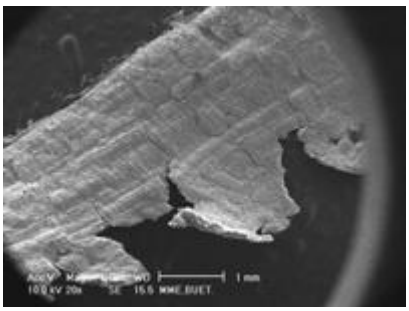
The application of cutting fluid during machining operation reduces cutting zone temperature and increases tool life and acts as lubricant as well. It reduces cutting zone temperature either by removing heats as coolant or by reducing the heat generation as lubricant. In addition, it serves a practical function as a chip-handling medium. However, it has been experienced that lubrication is effective at low speeds when it is accomplished by diffusion through the work piece and by forming solid boundary layers from the extreme pressure additives, but at high speeds no sufficient lubrication effect in evident. The ineffectiveness of lubrication of the cutting fluid at high speed machining is attributed to the inability of the cutting fluid to reach the actual cutting zone and particularly at the chip-tool interface due to bulk or plastic contact at high cutting speed. On the other hand, the cooling and lubricating effects of cutting fluid influence each other and diminish with increase in cutting velocity.

Since the cutting fluid does not enter the chip-tool interface during high speed machining, the fluid action is limited to bulk heat removal only. High-pressure jet of conventional coolant has been reported to provide some reduction in cutting Temperature. Cutting fluids have the dual tasks of cooling the cutting surface and flashing chip. They also help to control cutting-face temperature and this can prolong tool life, improve cut quality, and positively influence part finish. It has the benefit of a powerful stream that can reach onto the cutting area, provides strong chip removal and in some cases, enough pressure to deburr.

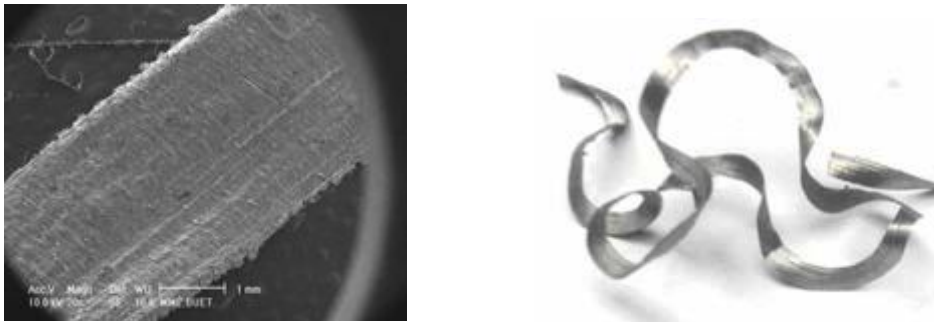
Possibility of controlling high cutting temperature in high production machining by some alternative method has been reported. High-pressure coolant injection technique not only provided reduction in cutting forces and temperature but also reduced the consumption of cutting fluid by 50% .Coolant applied at the cutting zone through a high-pressure jet nozzle could reduce the contact length and coefficient of friction at chip-tool interface and thus could reduce cutting forces and increase tool life to some extant. The main objective of the present work is to make a experimental investigation on the role of high pressure coolant in drilling with HSS drill and overall benefits in respects of cooling capacity of the fluid, chip, roundness deviation of the hole, taper of the hole and tool wear.

5.1 Scanning Electron Microscope (SEM)

A **scanning electron microscope** (**SEM**) is a type of electron microscope that images a sample by scanning it with a high-energy beam of electrons in araster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surfacetopography, composition, and other properties such as electrical conductivity. The types of signals produced by an SEM include secondary electrons, back-scattered electrons (BSE), characteristic X-rays, light (cathodoluminescence), specimen current and transmitted electrons. Secondary electron detectors are common in all SEMs, but it is rare that a single machine would have detectors for all possible signals. The signals result from interactions of the electron beam with atoms at or near the surface of the sample. In the most common or standard detection mode, secondary electron imaging or SEI, the SEM can produce very high-resolution images of a sample surface, revealing details less than 1 nm in size. Due to the very narrow electron beam, SEM micrographs have a large depth of field yielding a characteristic three-dimensional appearance useful for understanding the surface structure of a sample. This is exemplified by the micrograph of pollen shown to the right. A wide range of magnifications is possible, from about 10 times (about equivalent to that of a powerful hand-lens) to more than 500,000 times, about 250 times the magnification limit of the best light microscopes. Back-scattered electrons (BSE) are beam electrons that are reflected from the sample by elastic scattering. BSE are often used in analytical SEM along with the spectra made from the characteristic X-rays. Because the intensity of the BSE signal is strongly related to the atomic number (Z) of the specimen, BSE images can provide information about the distribution of different elements in the sample. For the same reason, BSE imaging can image colloidal gold immuno-labels of 5 or 10 nm diameter which would otherwise be difficult or impossible to detect in secondary electron images in biological specimens. Characteristic X-rays are emitted when the electron beam removes an inner shell electron from the sample, causing a higher energy electron to fill the shell and release energy. These characteristic X-rays are used to identify the composition and measure the abundance of elements in the sample.



(a) Dry condition



(b) High-pressure coolant condition

Figure-5.3. SEM views of chips produced while drilling steel by HSS drill bit under (a) dry and (b) high-pressure coolant condition.

High-pressure coolant (HPC) played very effective role for cooling and provided lubrication between drill bit and chip interface. Figure-5.3 shows the condition of chips during drilling by HSS drill bit under both dry and high-pressure coolant (HPC) condition. The shape of the chip produced under dry conditions was spiral but under high-pressure coolant condition became string. The color of the chips became lighter i.e. metallic from burnt blue due to reduction in drilling temperature by high-pressure coolant condition.

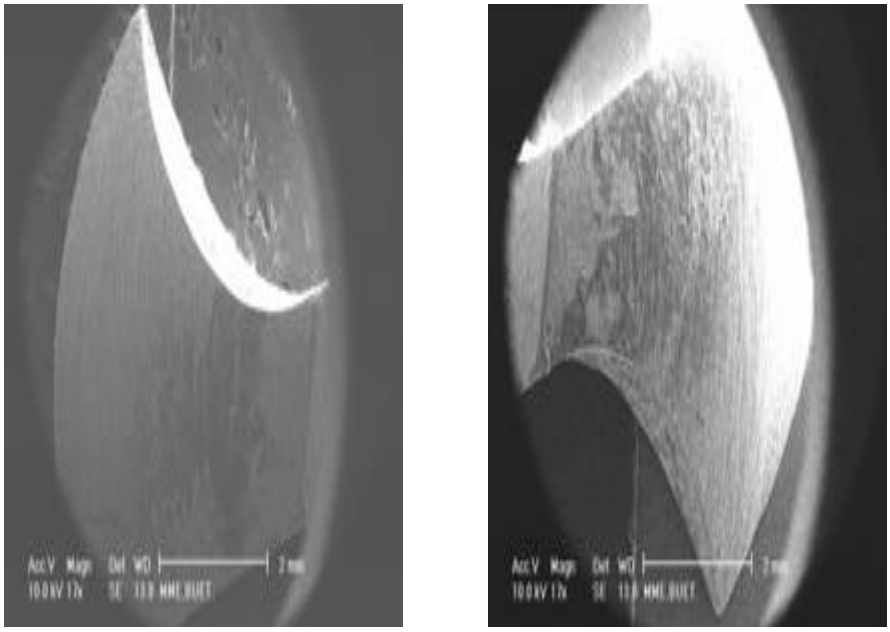


Figure-5.4. SEM view of drill bit under dry condition

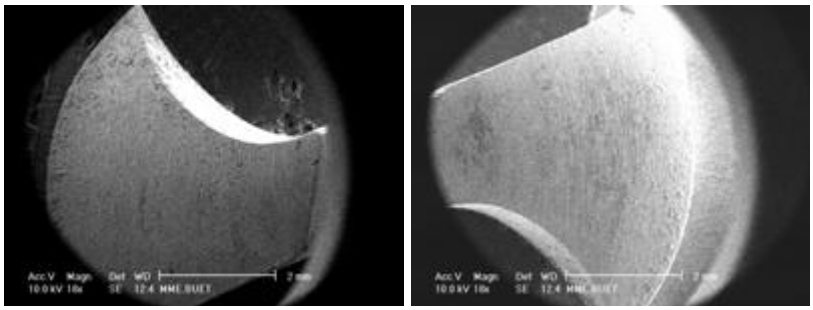


Figure-5.5. SEM view of drill bit under high pressure coolant condition

The formation of chip under HPC condition is more favorable in compare to dry condition because of high lubricant Roundness deviation was smaller at both the entrance and end of the holes under HPC condition in compare to dry condition. When high depth of cut used, the drilling with dry condition was not possible because of poor cooling and lubrication action.

Taper values and their dispersion were smaller under high-pressure coolant condition capacity. Moreover, in both conditions the average taper values were positive i.e., the diameters in the entrance of the holes were bigger than at the end. The beneficial effects of HPC may be attributed to effective lubrication action, which prevents the chip sticking on the tool and makes the cut feasible.

When the tool reached the end of the holes, the diameter decreased, due to the alignment of the tool caused by the hole wall. When high depth of cut is used, the drilling using dry condition is not possible because of high tool wear. The SEM views of the worn out drill bit is shown in Figure 5.4, 5.5. Moreover, the quality of the holes obtained using high-pressure coolant is much better than that obtained using dry condition.

Chip shape is the most important factor for the smoothness of a drilling process. The drilling process will be smooth if chips are well broken. However, most ductile materials do not break during drilling, and instead, form continuous chips. Based on the chip forming mechanisms, continuous chips can be categorized to spiral chips and string chips. When chips are initially generated, because the inner cutting edge moves significantly slower than the outer cutting edge, the inner chip is inherently shorter than the outer chip. This difference in length within the chip forces it flow to the drill center instead of perpendicular to the cutting edge.

Furthermore, the center part of the drill flute forces the chip to curl and form a spiral shape. However, when spiral chips move in the drill flute, in order to maintain its spiral shape, they have to constantly rotate on their own axis. This rotational motion causes the spiral chips to have difficulty maintaining their shape as the hole gets deeper. If chips cannot keep up with the rotational motion, they will either break or be forced to move along the flute without spinning, and form string chips. High-pressure coolant (HPC) played very effective role for cooling and provided lubrication between drill bit and chip interface. The shape of the chip produced under dry conditions was spiral but under high-pressure coolant condition became string. The color of the chips became lighter i.e. metallic from burnt blue due to reduction in drilling temperature by high-pressure coolant condition.

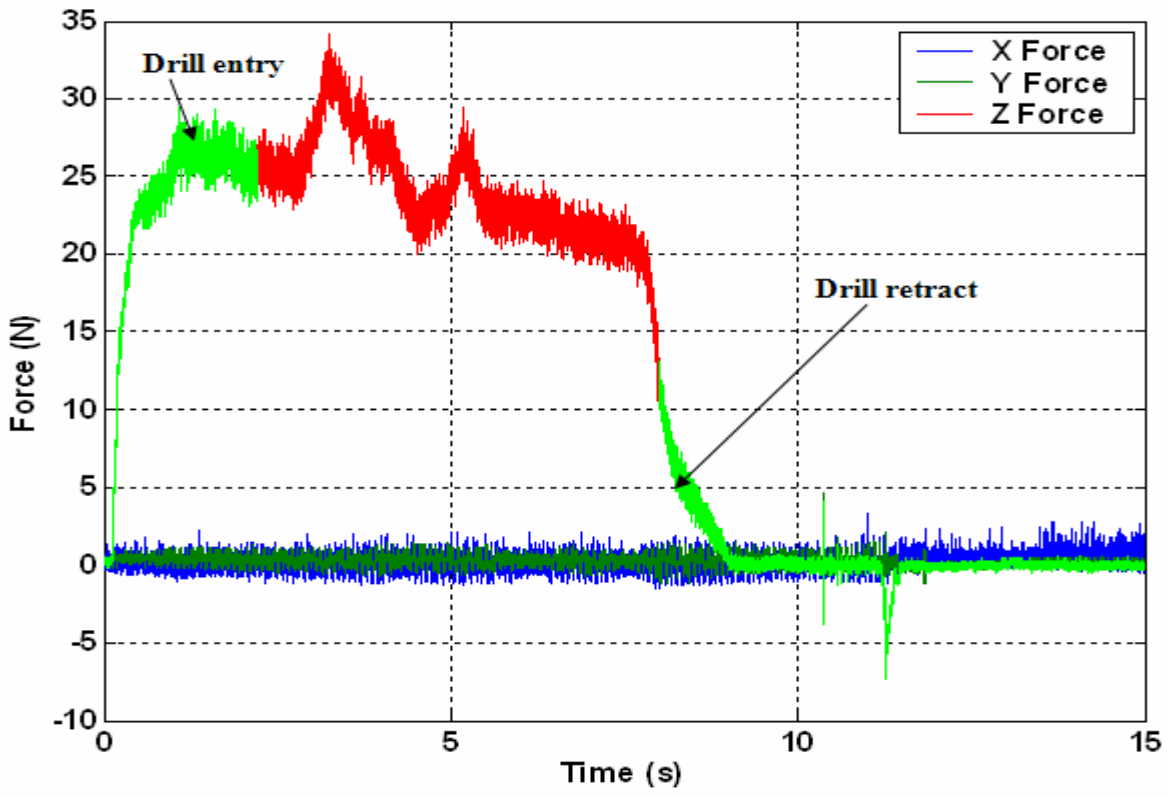


Fig. 5.6 Representation of Cutting Force

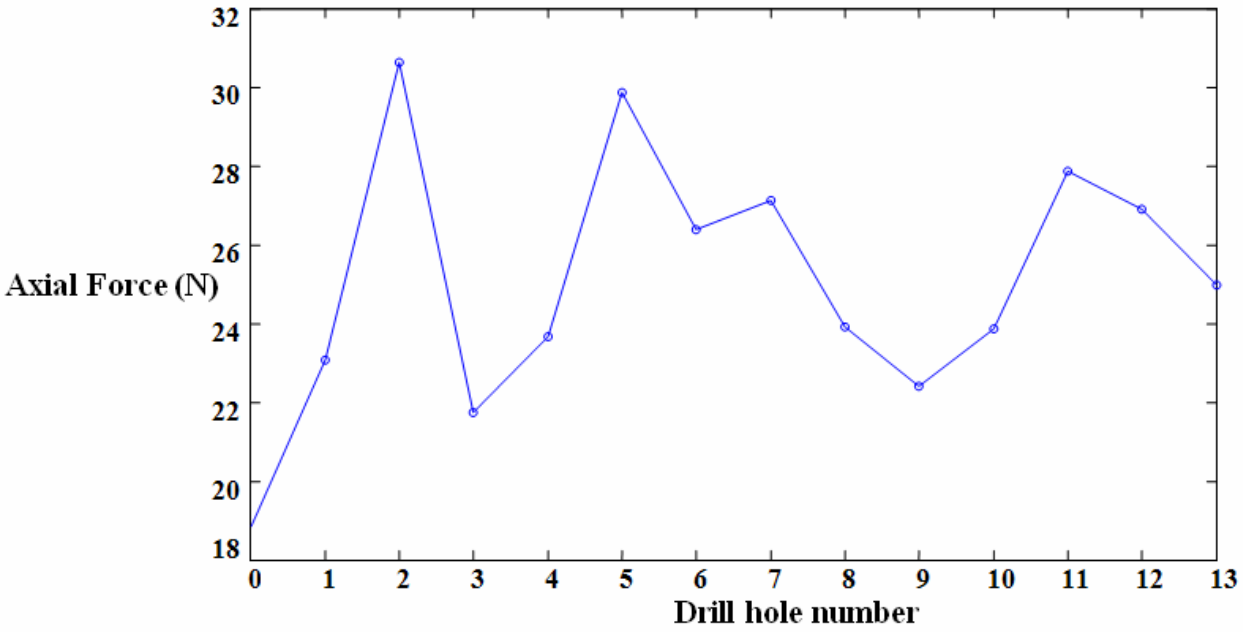


Fig. 5.7 Representation of Axial Force vs Drill Hole number

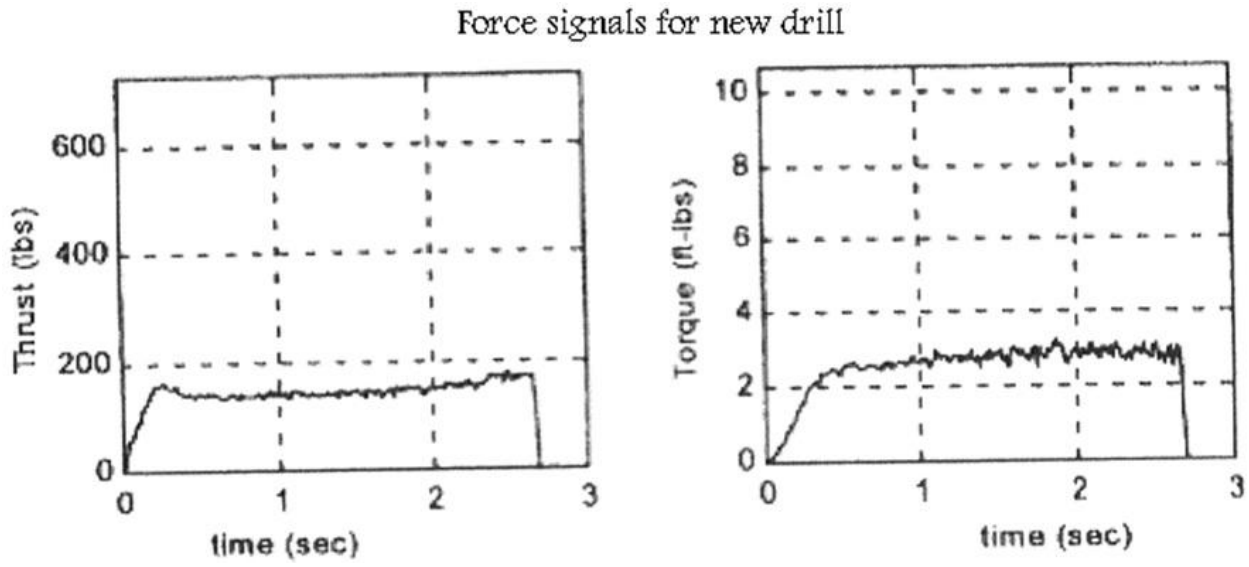


Fig.5.8 Torque & Thrust Force transition in relation to Time

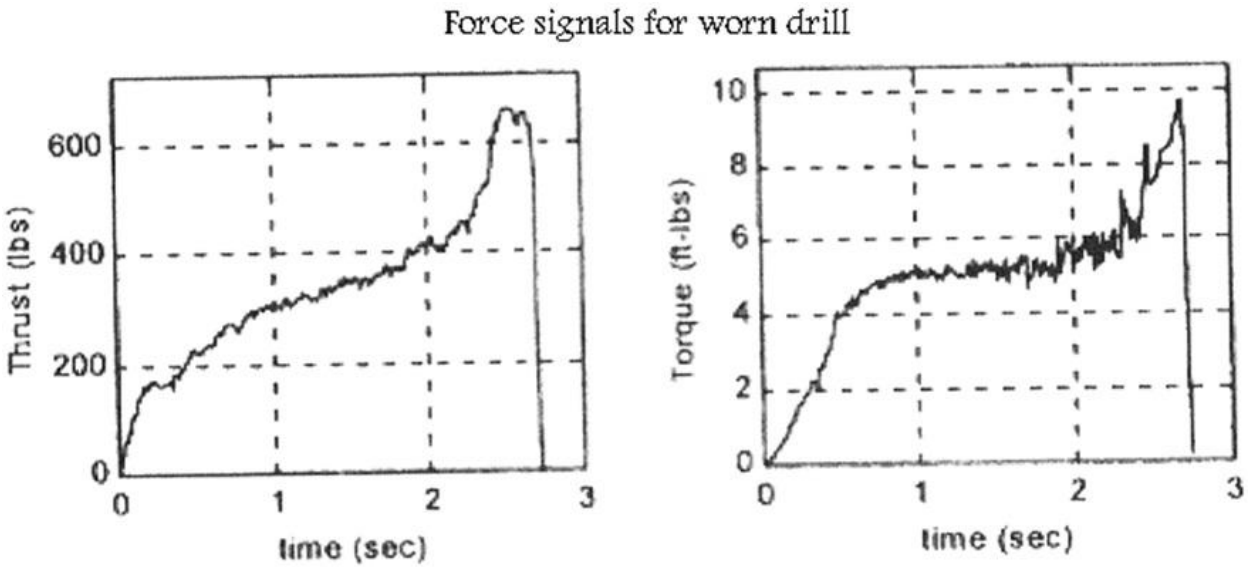


Fig.5.9 Torque & Thrust Force transition in relation to Time

When the machining operation is continued through the machining time tool begins to wear and the force necessary to operation increase. The force act on the lipe edge is consist of two element, one of its elements is created via machining operation (*Fcut*) and the other is created from friction between the tool and workpiece. Therefore the total force is given:

$$F = F_{cut} + kwb \quad \text{.....(5.1)}$$

in the formula.1., *k* is a constant value , *w* is wear and b is cutting lengh.

Among indirect methods the method based on force measurment is one of the most widely methods that has been used to tool condition monitoring. Cutting forces (both thrust and torque) are very useful for drill wear monitoring. Because these forces generally increase as tool wear increases, thus, within the tool wear region cutting forces provide a good assessment of the tool conditions. If the cutting tool cannot withstand the increased cutting forces, catastrophic tool failure becomes inevitable. Consequently tool life which is a direct function of tool wear is best determinded by monitoring both torque and thrust force. In this method the accuracy of tool wear estimation is high than others. Because its measurment process will not be affected by structure of machine tools and the other noises. Therefore the measured dataes will be close to the real figures.The researches have posed thrust force and torque as a function of feed rate, drill diameter and flank wear have been investigated. Based on the experiments done with different material of workpiece, the formulas of torque and thrust force is posed as a function related to brinel hardning of workpiece, drill diameter, feed rate, flank wear and other parameters.

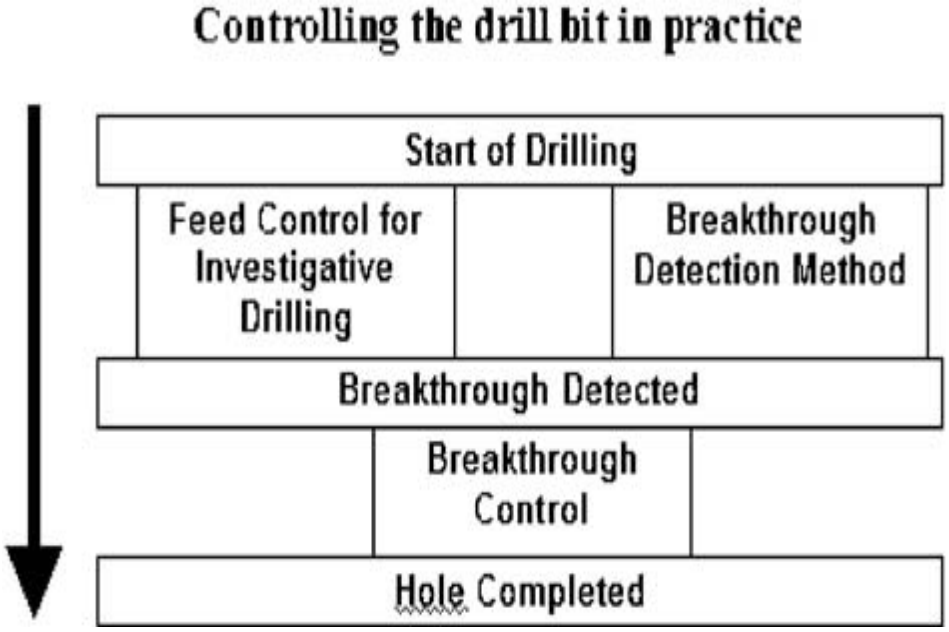


Fig. 5.10 The Stages of Drilling Sequence

CHAPTER – 6

RESULTS AND CONCLUSIONS

This study demonstrated that, when feasible process parameters are selected, Mild Steel & Glass Fiber could be efficiently drilled using either the HSS tool. The HSS tool with better mechanical and thermal properties was proven to be a better choice for drilling mild steel & glass fiber. The chip light emission, associated with high chip and tool temperatures, showed a detrimental effect on the drill life. For drilling without light emission, HSS tools performed well. The analysis of tool wear further confirmed such statement. The research into machining of mild steel is continuing in several fronts, including the micro-milling, grinding, polishing and electrical discharge machining processes. In recent years, new Fe, Al, and Ti based BMG materials have been developed. This has generated needs and opportunities for further study of machining processes to precisely shape these new, advanced engineering materials.

In drilling-induced delamination, the selection of proper tool geometry and operating conditions are important.Twist drill has been found more advantageous than the Core drill. An experimental approach to the evaluation of thrust force in drilling composite laminate by twist drill using Taguchi method was presented in this study. The experimental results show that the speed and feed rate are the main parameters among the four control factors (diameter, depth of cut, feed rate and spindle speed) that influence the thrust force. Large grit size produces low thrust force in drilling, which can reduce the extent of delamination. The correlation between thrust force and cutting parameters was obtained by multi-variable linear regression and compared with the experimental results.

Effect of work-material

The gradual increase of the thrust force and torque that eventually leads to the failure of the HSS drill. Build-up of work-material in cutting and margin edges is the likely cause of drill failure. The HSS tool successfully drilled holes on the mild steel workpiece. When the process parameters are correct, drilling is not difficult. Using the HSS tool, drilling generally requires higher thrust force than that for other workpieces. The torque level is about the same. It can be noted that an austenitic stainless steel, is a difficult-to-drill material with a high strain hardening rate (0.6), high fracture toughness (KIC of 75–100 MPa-m1/2), low thermal 103 conductivity (16 W/m-K) and good ductility (40%). In this regard, when the process conditions are right, is easier to drill.

Effect of tool-material

An HSS drill generally has higher force and about the same torque compared to other drill. A large portion of thrust force, over 50%, is contributed by the plowing in the drill center chisel edge. The harder drill has a higher elastic modulus and produces less wear and deformation in

the drill chisel edges. This leads to more efficient plowing of the work-material compared to the HSS tool.

Effect of Feed rate, Speed & Cause of Delamination:

• Thrust forces and torque value increases when the feed rate of twist drill increases.
• Delamination factor increases when feed and speed values increases.
• Tool wear increases due to increase in feed & speed.

Effect of Thrust Force, Torque on Delamination:

• Delamination factor increases when thrust force and torque values increases.
• Tool wear increases due to increase in thrust force & torque.

Hole Quality & Part Performance:

In the drilling the quality of the cut surfaces is strongly dependent on the appropriate choice of drilling parameters. The aim of this work is to clarify the interaction mechanisms between the drilling tool and material. Drilling tests were carried out using standard HSS tools. Drilling was interrupted at preset depths to study damage development during drilling. The specimens, polished by a metallographic technique, were examined by optical microscopy to identify any damage.

Tool Wear:

The two special wear types occur mostly independent from the geological circumstances:

1.Total wear down, when the bit is worn down to or below the buttons. In such cases one may not be able to definitely recognise the predominant wear process.

2. Widening of flushing holes and flutes is a phenomenon, which in most cases is caused by aggressive flushing fluids or suspended abrasive particles in the flushing. It may even be caused by cavitation alone which means material loss out of the tool surface due to forming and implosion of microscopic vapour bubbles under high velocities of flow.

Self Theory:

The difficult-to-machine fiber-reinforced composite materials inspire the progress of drilling technology for making the structural components without delamination to ensure the product reliability. The HSS drills show different level of the drilling thrust force varying with the feed rate. A feed rate strategy can avoid delamination caused by the thrust in drilling. The comprehensive modeling and analysis of drill bits illustrate that a distributed thrust toward the drill periphery is advantageous. In otherwords, the HSS drill bits can’t be operated at larger feed rate (namely shorter cycle time) without delamination damage. The results well explain the wide acceptance of these tools in industry. The HSS drill and pilot hole reduce the central material removal, which particularly cancels the contribution of chisel edge to the thrust force. The

resulted reduction of drilling thrust therefore significantly avoids the delamination. The back-up plate supports the last laminae and prevents the deformations from leading to exit delaminations. The drilling process then allows for larger critical thrust force and can be operated at larger feed rate free of delamination damage.

CHAPTER – 7

FUTURE SCOPE OF THE WORK

The following recommendations are made for future work:

1. Development of a model to predict the optimal thrust force necessary for drilling of composites without delamination since a very low thrust force is known to cause the fiber pull out & other defects during drilling.

2. Development of similar models for different tool geometries and comparing them to the existing one.

3. Force appears to provide a reasonable metric to rate drill performance. In future work a mechanistic model of drilling force based on the geometry which quantifies the effect of changes in drill geometry on force should be developed. Given that temperature is also a critical issue in drilling success, the mechanistic drilling model could be augmented to perform heat transfer calculations and estimate drilling temperature.

4. It is worthwhile to apply the supervisory control approach to drilling of circuit boards, laminated metals, aramid and glass laminates. However, if the thickness of the specimen is smaller than the point length of the drill, a new dynamic model and new delamination model must be developed.

5. For the successful carrying out of a drilling operation, the optimal speed of feed, speed must be maintained to avoid increase in thrust force, torque & tool wear.

6. Neural network control and fuzzy control are other good strategies for the control of thrust force and torque. The ambiguity of the dynamics and the process mechanism gives some advantage to these relatively new control methods.

7. The use of fuzzy logic must be implemented in every machining operation for the proper & in-depth understanding of behavior of workpiece, cutting tool, process & response parameters.

8. Use of fuzzy logic in industries will help to solve the problems that are difficult to control using conventional approaches.

9. The feed rate and drill diameter are seen to make the largest contribution to the overall performance.

10. The HSS drill bit causes a large delamination compared to other drill bits.

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