**EFFECT OF PROCESS PARAMETER ON SURFACE ROGHNESS IN WIRE EDM**

A major thesis submitted

In partial fulfillment for the requirements of the award of degree

of

**Master of Engineering**

In

**Production Engineering**

Submitted by

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Under the Guidance of

**Dr. VIPIN**



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**YEAR 2010-11**

**CANDIDATE’S DECLARATION**

I hereby declare that the work which being present in the major thesis entitled

― **Effect Of Process Parameter On Surface Roughness In Wire EDM** in the partial fulfillment for the award of degree of MASTER of ENGINEERING with specialization in ―PRODUCTION ENGINEERING submitted to Delhi College of Engineering, University of Delhi, is an authentic record of my own work carried out under the supervisions of Dr. VIPIN, Asstt. Prof. Department of Mechanical Engineering, Delhi College of Engineering, University of Delhi. I have not submitted the matter in this dissertation for the award of any other Degree or Diploma or any other purpose what so ever.

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**CERTIFICATE**

This is to certify that the above statement made by **SUNIL KAKRAN** is true to the best

of my knowledge and belief.

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**Abtract**

The demand for alloy materials having high hardness, toughness and impact strength are increasing in this competitive scenario. As these materials pose severe difficulty to be machined by conventional methods, Wire-cut Electric Discharge Machining (Wire EDM) machines are employed to machine them. The ultimate requirement of any machining process being fine surface finish is accurately satisfied by wire-cut EDM process. Hence this present study aims at obtaining the best surface finish by optimizing various process parameters affecting the machining conditions. With the assistance of Central Composite Design, various numbers of experiments will be conducted by varying the process parameters at various levels. The output response variable being surface roughness will be measured for all the number of experiments conducted.

The output response from experiments were used to obtain mathematical relation between surface roughness and wire EDM process parameters (feed, ton and gap voltage) with the help of Minitab software using regression analysis method. From this method optimum parameter combination has been analysed to give lowest surface roughness as the lowest value of surface roughness indicates the best surface finish. These optimized values of various parameters would then be used in performing machining operation in order to obtain desirable outputs.

**Chapter 1**

**INTRODUCTION**

The development of harder & difficult to machine metals & alloys such as tungsten, tantalum, beryllium, hast alloy, nitralloy, wasp alloy, nimonics, carbide, stainless steels and many other high strength temperature resistant (HSTR) alloys. These materials find wide application in aerospace, nuclear engineering and other industries going to their high strength to weight ratio, hardness and heat resisting qualities. The rapid developments in the field of materials has given an impetus to the modern manufacturing technology to develop, modify and is cover newer technological processes with a view to achieve results that are far beyond the scope of the existing conventional or traditional manufacturing processes. With the developments in the field of materials it has become essential to develop cutting tool materials and processes which can safely and conveniently machine such new materials for sustained productivity, high accuracy and versatility at automation. Consequently, non traditional techniques of machining are providing effective solutions to the problems imposed by the increasing demand for high strength temperature resistant alloys, the requirement of parts with intricate and compacted shapes and materials so hard as to defy machining by conventional methods. The processes are nontraditional `or non-conventional in the sense that they don’t employ a conventional or traditional tool for material removal, instead, they directly utilize some form of energy for metal machining. Conventional machining methods always produce some stress in the metal being cut. Newer methods have been developed that are essentially stress free. Very thin metals can be cut without distortion or stress.

The industries always face problems in manufacturing of components because of several reasons. This may be because of the complexity of the job profile or may be due to surface requirements with higher accuracy and surface finish or due to the strength of the materials. This challenge has been accepted and may new materials and unconventional methods of machining have been developed to suit the requirements of industry. The word unconventional means that the metals are such that they cannot be machined by conventional methods, but require some special techniques.

Wire EDM is a method to cut conductive materials with a thin electrode that follows a programmed path. The electrode is a thin wire. As the wire feeds from reel to reel, it uses sparks of electrical energy to progressively erode an electrically conductive work-piece along a path determined by the relative motion of the machine's axis. Typical wire diameters range from .004" - .012" although smaller and larger diameters are available. The hardness of the work piece material has no detrimental effect on the cutting speed. There is no physical contact between the wire and the part being machined. Rather, the wire is charged to a voltage very rapidly. This wire is surrounded by de-ionized water. When the voltage reaches the correct level, a spark jumps the gap and melts a small portion of the work piece. The de-ionized water cools and flushes away the small particles from the gap.



Fig. 1.1 Schematic representation of Wire EDM cutting process

Wire EDM can be accurate to +/-.0001". No burrs are generated. Since no cutting forces are present, wire EDM is ideal for delicate parts. No tooling is required so delivery times are short. Pieces over 16" thick can be machined. Tools and parts are machined after heat treatment so dimensional accuracy is held and not affected by heat treat distortion.

Today, wire EDM is considered a mainstream metalworking process and it is not unusual to find a wire machine in the average job shop or typical tool room. Although the basic principle of wire EDM has not changed, the process has advanced dramatically in the size, complexity, speed and accuracy of the metal-cutting it can perform even as the equipment has become more affordable, more reliable, and easier to operate.

**Chapter 2**

**LITERATURE REVIEW**

Apart from the important role that Micromachining and Ultraprecision machining has provided to the development of improved or innovative miniaturized products, these techniques have also attracted the interest of the researchers to obtain the highest accuracy and a thorough analysis of the principles governing the material removing mechanisms.

These studies have been briefly discussed for the variations observed experimentally.

**Wire Electric Discharge Machine WEDM**

Swarup S. Mahapatra and Amar Patnaik [2006] studied Parametric Optimization of Wire Electrical Discharge Machining (WEDM) Process using Taguchi Method. They have outlines the development of a model and its application to optimize WEDM machining parameters. Kao *et al* [2006] they have investigates the dry wire electrical discharge machining (EDM) on thin workpieces. This study also observed the deposition of debris in the groove cut by dry wire EDM. For a thick workpiece, the groove was totally blocked.

Herreroa *et al* [2007]. This present article exposes the theoretical analysis of some aspects of the thin WEDM that drop the process accuracy in terms of minimum machinable slot or corner over/undercutting. The scaled electrode dimensions and the reduced power supply with respect to the normal process causes a different influence of the process variables and contribute to obtain complementary information about the WEDM process. The different force components contributing to the wire deformation are discussed and some of them are analyzed from a theoretical point of view presenting analytical calculations to evaluate their expected magnitude and pointing out the difficulties to obtain an experimental characterization of each phenomenon.

J. T. Huangy and Y. S. Lioaz [2000] this paper proposed a prototype ANN-based expert system for the maintenance schedule and fault-diagnosis of Wire-EDM. Owing to the advantages of ANN algorithm and expert system, this system is a powerful development tool for a complicated consulting system such as a Wire-EDM process. The system developed will help operators, even for novices and trainees in Wire- EDM, to maintain machines well, and eliminate faults sooner. Hence, the operating time can be minimized and the cost can be lowered. In the future, more examples will be provided so that the inferring reliability and accuracy of the system can be improved.

Huang *et al* [2005] they have studied how finish surface can be obtained in Wire EDM. Many Wire-EDM machines have adopted the pulse generating circuit using low power for ignition and high power for machining. However it is not suitable for finishing process since the energy generated by the high voltage sub-circuit is too high to obtain a desired fine surface, no matter how short the pulse on time is assigned. For the machine used in this research, the best surface roughness Ra after finishing process is about 0.7μm. In order to obtain good surface roughness, the traditional circuit using low power for ignition is modified for machining as well. With the assistance of Taguchi quality design, ANOVA and F-test, machining voltage, current-limiting resistance, type of pulse generating circuit and capacitance are identified as the significant parameters affecting the surface roughness in finishing process. In addition, it is found that a low conductivity of dielectric should be incorporated for the discharge spark to take place. After analyzing the effect of each relevant factor on surface roughness, appropriate values of all parameter are chosen and a fine surface of roughness Ra equals to 0.22μm is achieved. The improvement is limited because finishing process becomes more difficult due to the occurrence of short circuit attributed to wire deflection and vibration when the energy is gradually lowered.

Qu *et al* [2006]. The feasibility of applying the cylindrical wire EDM process for high MRR machining of free-form cylindrical geometries was demonstrated in this study. The mathematical model for the MRR of cylindrical wire EDM of free-form surfaces was derived. Two experimental configurations designed to find the maximum MRR in cylindrical wire EDM were proposed. Results of each test configurations match each other, which validates the concept. The maximum MRR for the cylindrical wire EDM was higher than that in 2D wire EDM of the same work-material. This indicates that the cylindrical wire EDM is an efficient material removal process. The surface integrity and roundness of cylindrical wire EDM carbide and brass parts were investigated. Experiments demonstrated that good surface finish and roundness could be achieved in the cylindrical wire EDM process. The craters, recast layers, and heat-affected zones were observed, and their sizes were estimated using the SEM.

H. Singh, R. Garg [2009] studied effects of process parameters on material removal rate in WEDM. For their studied they have to these conclusions that: The parameters wire feed (WF) and wire tensions (WT) have no effect on the material removal rate. The pulse on time parameter has direct effect on the material removal rate, as we increase the pulse on time the material removal rate also increases. When the pulse off time is increased the material removal rate decreases. When peak current is increased the material removal rate increases. Material removal rate decreases with increase in the servo voltage. They have come to the conclusion that the wire feed and wire tensions are neutral input parameters. The material removal rate (MRR) directly increases with increase in pulse on time (TON) and peak current (IP) while decreases with increase in pulse off time (TOFF) and servo voltage (SV).

S. K. Hargrove1 and James M. Ngeru [2008] they have approach a neural network approach for determining Wire-EDM cutting parameters and the thermal effect on workpiece surface layers. Surface quality damage due to machine operations is directly related to the amount of energy used to remove the material. The main factors, which influences machining in Wire-EDM includes: electrical parameters and dielectric fluid. Due the nature of wire EDM machine, which is a spark erosion process, there is modification of surface layers structure, which is unfortunate phenomenon and is considered a serious flaw in workpiece which reduces the longevity of the part useful life and material strength. Such phenomenon can be observed in high strength steel metals such as AISI 4330, which is commonly used in aerospace structures, that requires strength and materials free of flaw. As observed from the results, high values of pulse duration, no load voltage, increase the depth of affected layer while a high value of dielectric flushing pressure, reduces the size. Therefore, low values of pulse duration and no load voltage and high value of dielectric flushing pressure will result to minimum thermal surface effect.

Ali *et al* [2008] In this research, conventional WEDM was used for micro/meso fabrication. The influence of discharge current and pulse-on time were studied to achieve high surface finish. Using the optimized process parameters miniaturized spur gears were fabricated with 1-2% dimensional accuracy and about 1 μm *Ra* surface finish.

Hassan *et al* [2009] Study of the Surface Integrity of AISI 4140 Steel in Wire Electrical Discharge Machining. In this project, the relative importance of two main machining parameter variables in WEDM has been identified. Based on the obtained findings, the SEM can be successfully applied to obtain a two-dimensional image with a nanometer scale. The surface roughness of the machined surface can be determined by examine the specimen using pethometer recorder. AISI 4140 steel was cut into nine specimens with different machining parameters which are pulsed current and pulse-on duration. From the data collected and analyzed, it can be concluded that the pulse-on duration has major influence in defining the WEDM surface texture as compared to the pulsed current. Moreover, the interaction effect between pulsed current and pulse-on duration on the 2D surface roughness parameters is relatively small. Through analysis on SEM and calculation, it has been observed that the value of surface roughness, depth of micro-cracks and micro-voids slightly increased with time taken. The higher discharge energy caused more frequent melting expulsion, leading to the formation of a deeper and larger crater on the surface of the workpiece, and resulted in a poorer surface finish. Based on the obtained formula, the values of surface roughness, depth of micro-cracks and micro-voids produced by the WEDM could be evaluated. Moreover, the effect of the magnitude of the pulse-on duration on the surface texture of the specimen was more dominant than the pulsed current. Overall, there are a few steps that can be done more details to produce a good surface finish such as the WEDM machining parameters should be set at low pulsed-current and small pulse-on duration. Once the specimens have been cut, it must be examined instantly to avoid corrosion at the surface which is leads to the bad surface finish. Besides that, the perthometer recorder should be use gently so that the readings can be obtained accurately due to its high sensitivity.

Friedhelm Altpeter, Roberto Perez [2004] studied relevant topics in wire electrical discharge machining control. Their objective is to establishment a relationship between the dynamics of the wire electrode and the state of the art in WEDM control. These results are to be used for identifying promising R&D directions in terms of customer convenience, and set up cost reduction by an improved process mastering.

Mu-Tian Yan, Yi-Peng Lai [2007] have worked for Surface quality improvement of wire-EDM using a fine- finish power supply. In this study, a transistor-controlled RC-type fine-finish power supply for wire-EDM has been developed. The developed power supply using anti-electrolysis circuitry and CPLD-based pulse control circuit can provide low discharge energy pulses with a frequency of 500 kHz. Discharge duration as short as 150 ns and peak current as low as 0.7A can be obtained through the adjustment of the capacitance and current-limiting resistance in the discharge circuit, respectively. Higher value of capacitance results in higher discharge energy and thus contributes to longer discharge duration. The peak current increases slightly with the increase of the pulse on-time. A higher current-limiting resistance results in a lower peak current. Experimental results demonstrate that the developed fine-finish power supply can reduce the recast layer, can eliminate rusting and bluing in titanium and reduce cobalt depletion in tungsten carbide than a standard DC power supply. A fine surface finish of 0.22 mm Ra can be achieved by means of four finish machining operations with proper machining settings.

Muhammad Akram [2002] wrote his Doctor of philosophy thesis on the topic “Central Composite Designs Robust to Third Missing Observation”. First he has explained about design of experiment then about response surface methodology. He has thoroughly explained about CCD and all its aspects in detail. He has also thoroughly explained about the design with the missing observation.

Kamoun *et al* [1999] worked on the topic “Application of a rotatable orthogonal central composite design to the optimization of the formulation and utilization of an useful plasticizer for cement”. Black liquor (BL), a by-product of Alfa pulping industry, is mixed with small amounts of sulfonated naphthalene formaldehyde polymer (SNF) to give useful cement dispersant having a durable action. In order to check the effect of three variables (the ratio water/cement, % black liquor, % SNF) on two properties of the cement grout (cement plasticity and cement plasticity loss), a rotatable orthogonal central composite design is set up. It is concluded from response surface and isoresponse curve studies that the level of plasticity is governed by the percentage of SNF while its durability is ensured by the percentage of the black liquor.

Sathavornvichit *et al* [2006]Central Composite Design in Optimization of the Factors of Automatic Flux Cored Arc Welding for Steel ST-37. The purpose of this research is to determine the optimal factors of Flux Cored Arc Welding process for Steel ST37. The process variables current, voltage, stick out and angle of welding are use in the study of optimization of tensile of weldment by response surface methodology follow a central composite design. A four-factors, three-level Central Composite design was use to determine the optimal factors of Flux Cored Arc welding process for Steel ST37. The central composite design (CCD) with a quadratic model was employed Current(A) ,voltage(V), stick out (mm), angle(degree) are takes as the parameter to carry out the experiment three values taken to carry out experiment .The result indicated that the optimum conditions are 300 ampere of current, 30 volt of voltage, 45 millimeter of stick out and 60 degree of angle.

Kusmiyati, Nor Aishah Saidina Amin [2007] **“**Application of Central Composite Design (CCD) and Response Surface Methodology (RSM) in the Catalytic Conversion of Methane and Ethylene into Liquid Fuel Products”. The effect of operating conditions i.e. temperature, feed composition, and catalyst loading on the reaction of a mixture of methane and ethylene to produce C5+ hydrocarbons was investigated by employing the design of experiment. A central composite design combined with response surface methodology was used to determine the optimum operating condition on the production of C5+ hydrocarbons from a mixture of methane and ethylene. A mathematical model that is able to predict the effect of independent variables towards the responses i.e. the selectivity to C5+ hydrocarbons product was established by multiple regression analysis. Temperature, feed composition, and catalyst weight are taken as parameters to carry out the experiment.

**Chapter 3**

**EXPERIMENTAL SETUP**

In wire electrical discharge machining (WEDM), or wire-cut EDM, a thin single-strand metal wire, usually brass, is fed through the workpiece, typically occurring submerged in a tank of dielectric fluid, which is typically deionised water. This process is not typically used to produce complex 3D geometries. It is instead typically used to cut plates as thick as 300mm and to make punches, tools, and dies from hard metals that are too difficult to machine with other methods. The wire, which is constantly fed from a spool, is held between upper and lower diamond guides. The guides move in the *x*–*y* plane, usually being [CNC](http://en.wikipedia.org/wiki/CNC) controlled and on almost all modern machines the upper guide can also move independently in the *z*–*u*–*v* axis, giving rise to the ability to cut tapered and transitioning shapes (circle on the bottom square at the top for example) and can control axis movements in *x*–*y*–z-*u*–*v*. This gives the wire-cut EDM the ability to be programmed to cut very intricate and delicate shapes. The wire is controlled by upper and lower diamond guides that are usually accurate to 0.004 mm, and can have a cutting path or *kerf* as small as 0.12 mm using Ø 0.1 mm wire, though the average cutting kerf that achieves the best economic cost and machining time is 0.335 mm using Ø 0.25 brass wire. The reason that the cutting width is greater than the width of the wire is because sparking occurs from the sides of the wire to the work piece, causing erosion. This "overcut" is necessary, for many applications it is adequately predictable and therefore can be compensated for (for instance in micro-EDM this is not often the case). Spools of wire are typically very long. For example, an 8 kg spool of 0.25 mm wire is just over 19 kilometers long. Today, the smallest wire diameter is 20 micrometers and the geometry precision is not far from +/- 1 micrometer. The wire-cut process uses water as its dielectric with the water's resistivity and other electrical properties carefully controlled by filters and [de-ionizer](http://en.wikipedia.org/wiki/Ion) units. The water also serves the very critical purpose of flushing the cut debris away from the cutting zone. Flushing is an important determining factor in the maximum feed rate available in a given material thickness, and poor flushing situations necessitate the reduction of the feed rate.

Along with tighter tolerances multiaxis EDM wire-cutting machining center have many added features such as: Multiheads for cutting two parts at the same time, controls for preventing wire breakage, automatic self-threading features in case of wire breakage, and programmable machining strategies to optimize the operation.

Wire-cutting EDM is commonly used when low residual stresses are desired. Wire EDM may leave residual stress on the workpiece that are less significant than those that may be left if the same workpiece were obtained by machining. In fact in wire EDM there are not large cutting forces involved in the removal of material. Yet, the workpiece may undergo to a significant thermal cycle, whose severity depends on the technological parameters used. Possible effects of such thermal cycles are the formation of a recast layer on the part and the presence of tensile residual stresses on the workpiece. If the process is set up so that the energy/power per pulse is relatively little (typically in finishing operations), little change in the mechanical properties of a material is expected in wire-cutting EDM due to these low residual stresses, although material that hasn't been stressed relieved can distort in the machining process.

# EZEE CUT PLUS –WIRE CUT EDM



**Fig 3.1 EZEECUT PLUS WIRE EDM**

**Main Features of CNC WIRE –CUT EDM:**

* The highly precise machine tool includes high precision ball screw, wire rolling guide, high –peed wire –feed mechanism.
* Tension controllable wire driving system keeps constant wire tension.
* Simples to use software PRAPT. Features include DXF file interface, built-in utility packages for gears and curves, Built-in function like move, rotate, copy, mirror, scale reverse mirror, multi cavity program generation.
* Automatic center-find, edge find, pause at wire breaks, pause at short circuit and gap short recovery, program can be restarted after power failure from the same point where power was interrupted.
* X, Y, U, V table displacement and profile displayed on CRT screen.
* Automatic stop after of job.
* Automatic wire radius compensation ensures work-pieces accuracy.
* Auto gap short retrace.
* Dry run & Spark mode switchover.
* Back to origin through shortest path as well as along programmed profile.
* Program can be reversed.
* Sleep mode feature switch off the control panel.
* Multi pass feature gives the better finish for job.
* Machining parameter can be by E-code.
* Unique feature: Wire is reused which drastically reduces machining cost.

**TECHANICAL SPECIFICATION FOR WIRE-CUT EDM:**

|  |  |
| --- | --- |
| **TECHANICAL SPECIFICATIONS** | |
|  | |
| **Machine Tool** | **Ezeecut Plus** |
| Max. work piece size | 360 x 600 mm |
| Max. Z height | 400 mm |
| Max. work piece weight | 300 kg |
| Main table traverse (X, Y) | 320, 400 mm |
| Auxiliary table traverse (u, v) | 25, 25 mm |
| Machine Tool Size(L\*W\*H) | 1500\*1250\*1700 |
| Max. taper cutting angle | ± 3°/100 mm |
| Machine Tool Weight | 1400kg. |
| Max dry run speed | 25mm/min. |
| Best surface Finish (Ra) | 1-1.5µm. |
| Wire diameter | 0.2 to 0.25 mm (Brass) 0.12 to 0.25 mm(Molybdenum) |
| **Control Panel** | **EZ-01** |
| Control Mode | CNC close loop |
| Display | 15" VGA color CRT |
| Control panel size (L\*W\*H) | 1150\*650\*1830 |
| Input program format | G code |
| Min. input command | 0.001mm |
| Min. increment | 0.001mm |
| Interpolation function | Linear & Circular |
| Simultaneously controlled axes | X, Y, U, V |
| Min. resolution for X, Y, u, v | 0.001mm |
| Data Input / Output | 1.44 MB floppy disc, pen drive |
| Input power supply | 3 phase, 415V\* AC, 50Hz |
| Connected load | 1.5 kVA |

**FEATURES ELABORATION:**

**a)MULTICAVITY:**

Number of profiles can be clubbed under one program .prepare the profile in RPAPT part programming system. Make the RRW file of a Profile. On the screen observe the dotted line indicates the joining of two different profiles. At the end of first profile, on the screen the message appears “Remove wire & press enter for rapid traverse”. Here remove the wire from one end. Press enter key table will move to the assigned position. Put the wire & proceed as per the normal procedure.

**b) SPARK MODE & DRY RUN MODE SWICTH OVER:**

This is one of the great features. It make possible to switch over either from Dry run to spark mode or vice versa.

Consider machine is running in spark mode. To enter in dry run, press ’S’ key to stop sparking. Pressss’F5’ key to enter in dry run mode, again press ‘F5’ key. Machine will run in dry run. To come back to Spark mode, press ’F5’ key to stop dry run operation .press ’S’ to enter in Spark mode , again press ‘S’ key to start the sparking.

**c) BACK OPERATION:**

Returns back to the origin along the same path as profile has traveled. This operation is used in spark mode as well as in dry run. In case of wire break in mid way & not possible to lay the new wire from the same point press ‘F1’- BACK key and ‘F2’- BLOCK STEP key. Pressing ‘F1’ while returning back aborts operation.

**d) PROGRAM RESTART:**

While sparking, if it is required to come out of spark mode, program can be restarted by pressing ‘F6’ from the same point where it was stopped.

**e) PROFILE DIRECTION CHECK:**

This function is very useful to know to direction of cut path of profile. Press ‘F3’ key to lock the servomotors. Press ‘F5’ key for dry run. Keep sensitivity at 10 position. On screen you will come to know the direction of cut path.

**f) E-Code:**

Machine parameter can be set by E-code. The range E-code is 0-9999. E-code is set by programmer in part programming. At the time of machining E-code is automatically recalled by software.

**INTERLOCK:**

1. **WIRE BREAK:**

Indicates wire break condition. If wire break sensor is enabled wire break condition turns off wire feed motor.

1. **GAP SHORT:**

Indicates gap short condition.

**INDICATORS**

1. **TRIP:**

Indicates machine is in trip condition. Check for one of the following-

1. Heck input three phase voltages. Over-voltage or under –voltage condition trips the machine.
2. Emergency OFF switch on front panel trips the machine.
3. Mechanical limit switch for wire feed motor assembly trips the machine. This condition occurs if wire feed direction control sensor fails to operate.
4. **VOLTMETER:**

This meter indicates average machining voltage. Minimum gap voltage is 5.5 volts for stable machining.

1. **CURRENT METER:**

This meter indicates averages machining current from 0 to 3 amps.

1. **BLOCK:**

This block is located at the right bottom corner of the screen. This block gives the current position of program.

**SWITCHES:**

1. **EMERGENCY OFF SWITCH:**

Pressing this switch turns off mains power and trip LED on font panel glows.

1. **FEED SWITCH:**

Feed switch is located on machine tool near wire drum assembly. Wire feed can be made ON/OFF either from control panel or machine tool.

**CONTROL PANEL DESCRIPTION**

**KEYS**

* **‘F1’ – CNT FND**: Used for center finding operation. Wire must be threaded through hole/cavity for which center find operation is to be performed.
* **‘F2’- DG FND**: Used for edge finding operation. wire must be loaded before performing this operation. Press F2 and then arrow keys or pendent keys to move table in that direction. Edge find operation gets terminated whenever gap short condition is detected.
* **‘F3’- SERVO DISABLE**: X, Y, U, V motor supply gets disabled. This is particularly useful for machines with hand-wheel provision for manual X, Y table movement. When this function key is not enabled X, Y, U, V motors remains in hold/lock condition.
* **‘F4’-WBRK EN**: Wire break sensor enable key. If selected wire feed motor turned off when wire break gets detected.
* **‘F5’- DRY RUN**: Use this key for dry run operation. File must be loaded before performing this operation. Use sensitivity control for increasing or decreasing dry run speed.
* **‘F6’- PROGRAM RESTRAT**: While sparking, if it is required to come out of spark mode, program can be restarted by pressing ‘F6’ from the same point where it was stopped.
* **‘F7’- NO BUZZ**: If selected buzzer will not sound.
* **‘F8’-ROTATE/MIRROR**: Use +/- keys to rotate selected profile by + / - 90 degrees. Use X or Y key to mirror selected profile about X or Y axis. At a time only one operation i.e. rotate or mirror about X or mirror about Y operation is possible.
* **‘F9’- DRO**: If selected X, Y, U, V co-ordinate can be manually updated. Disabled in spark and dry run mode. Use ‘up/down’ arrows keys to select particular axis. We can make X or Y half by pressing ‘h’ keys.
* **‘F10’- PROGRAM REVERSE**: Use this key to reverse the path of a program. This operation is very useful when wire gets at the nearest end position of program.

**OTHER KEYS FUNCTIONS:**

* **‘ALT-F’**: User data file related operations are possible. it has following submenus

**OPEN**- Used for loading user data files stored in \dwg\_data directory. These files have RRW extension.

If file name is known user can press ‘M’ key for manual entry. Type file name without extension and press ‘Enter’ key when OPEN is highlighted. New window is opened listing file names. User can scroll up/down by pressing ‘up/down arrow’ or ‘Page Up/Page Down’ keys. Highlighted file can be loaded by pressing ‘Enter’ key.

**COPY** – When highlighted press ‘Enter’ key to select this option. Used for copying files from removable drive to \dwg\_data directory where user program /data files are stored.

**DRIVE** – When highlighted press ‘Enter’ key to select this option. Used for selecting removable drive this is required in the file-copy option.

* **‘R’-SPRK TIME RESET**: Press for resetting sparking time (SPKG TIME) to 0. Disabled in the spark mode.
* **‘F’ - FEED**: Press for altering wire feed speed. Press ‘F’ again or ‘Enter’ key to come out from this mode. Minimum to maximum limits are 0 to 100 No’s respectively. This setting controls the speed of wire feed motor. Keys ‘+’ or ‘-’ are used to increase or decrease the feed speed.
* **‘G’- GAP**: Press for altering gap voltage setting. Press ‘G’ again or ‘Enter’ key to come out from this mode. Minimum to maximum limits are 1 to 100 No’s respectively. This setting controls the gap voltage. Keys ‘+’or ‘-’ are used to increase or decrease the gap voltage.
* **‘E’ - SEN**: Minimum to maximum limits are 1 to 10 No’s respectively. This setting controls the speed of stepper motor in spark & dry run mode. Keys ‘+’ or ‘-’ are used to increase or decrease the bed speed.
* **‘N’ - Ton**: This is ON time pulse width in µSec. minimum to maximum limits are 1 to 99 No’s. Keys ‘+’ or ‘-’ are used to increase or decrease the machining pulse width.
* **‘O’- Toff**: This is OFF time interval of machining pulse. Minimum to maximum limits are 1 to 15 No’s. Keys ‘+’ or ‘-’ are used to increase or decrease the time interval of machining pulse.
* **‘I’- I peak**: This setting controls the current selection stage. Minimum to maximum limits are 0 to 4 No’s. Keys ‘+’ or ‘-’ are used to increase or decrease the number of active current stages.
* **‘U’ - Group Pulse**: The range of group pulse is 0, 5 to 15 µSec. keys ‘’or ‘’ are used to increase or decrease the setting. 0 disables group pulse avoids wire breakages. To activate group pulse, Ton setting must be greater than (group pulse x 2)
* **‘S’ - SPARK**: Press for making spark On\Off.
* **‘P’- PUMP**: Press for making coolant pump On\Off.
* **‘W’- WIRE FEED**: Press for making wire feed motor On\Off.
* **‘Alt-W’**: Used for wire vertically adjustment. For reference use wire verticality block provided with machine. There are two modes for wire verticality operation.
* **Visual Mode** – press ‘F3’ function kept for servo disable. Make machine lamp on. Press Alt-W and move X, Y, U, V motors manually for wire verticality. Press any key to exit from this mode.
* **Spark Mode** – make pump switch off. Make pump, wire feed ON. Press ALT- W, then arrow keys to move U/V motor and pendent keys to move X/Y motor.

There should be uniform spark from top to bottom on wire verticality block. Key other than arrow keys exits this mode.

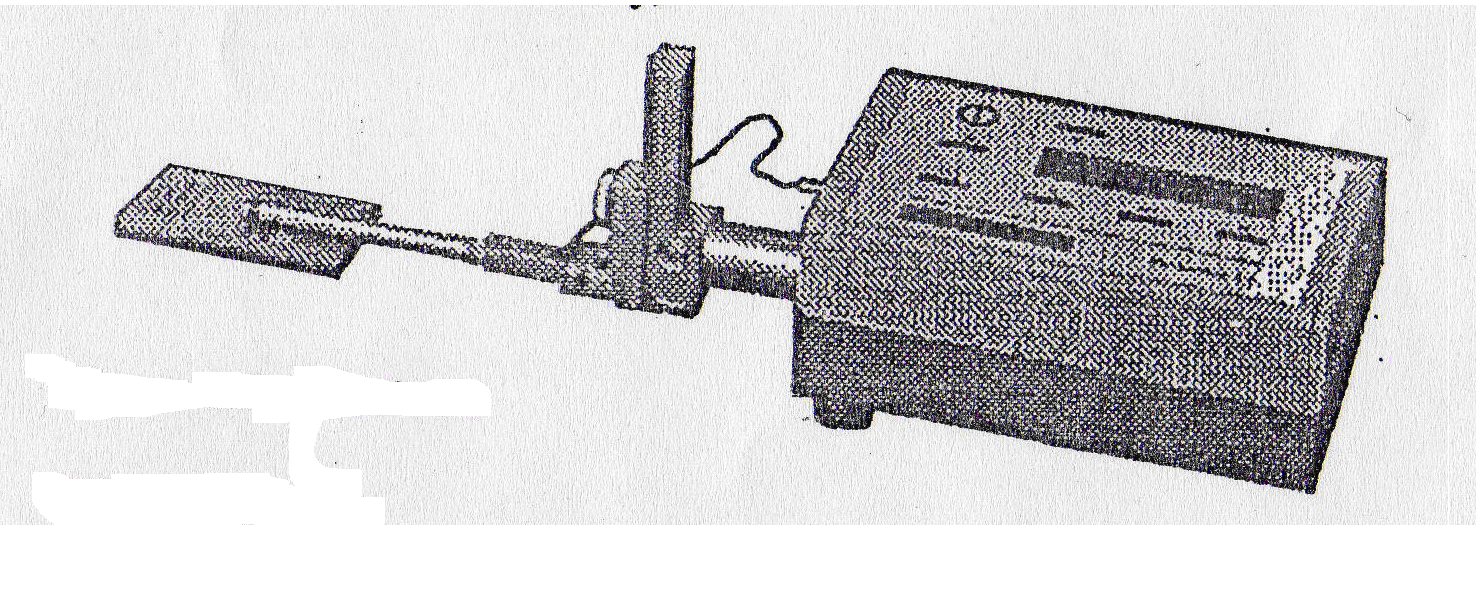
* **’Alt -E’**: Used to access the E-code, which set the machining parameters.
* **‘Alt-X ’**: Exit from EzeeCut menu /screen and come to command prompt.
* **‘Esc’**: used to come out from spark mode, dry run mode or from file selection menu

**Surface Roughness Measuring Instrument**

The Surtronic 3+ is a portable, self-contained instrument for the measurement of surface texture and is suitable for use in both the workshop and laboratory. Parameters available for surface texture evaluation are: Ra, Rq, Rz, Ry, Rt and Sm.

The parameters evaluations and other functions of the instrument are microprocessor based. The measurement results are displaced on an LCD screen and can be output to an optional printer or another computer for further results.

The instrument is normally powered by an alkaline non-rechargeable battery. If preferred, a Ni-Cad rechargeable battery can be used.

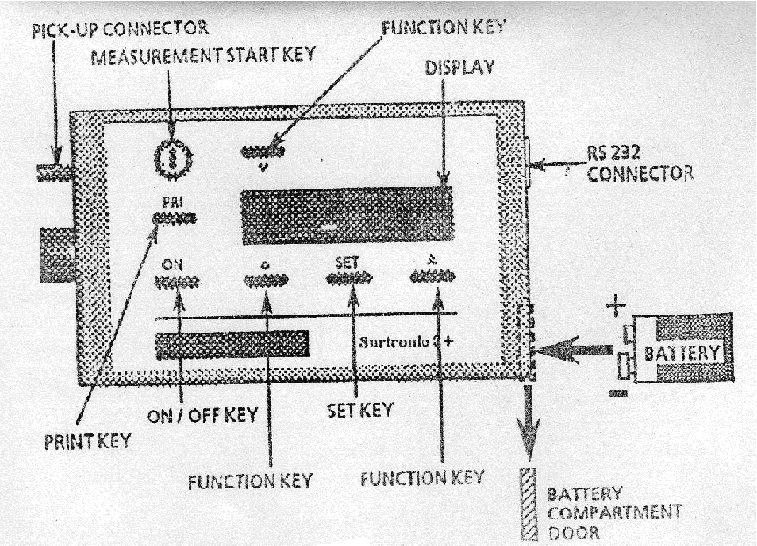


**Fig.: 3.2** Surface roughness measurement apparatus (Referred from Instrument Manual)

**Display-Transverse Unit**

The top panel of the display-traverse unit carries a membrane type control panel and a liquid crystal display. The unit houses the electronics for controlling the measurement sequence, computing the measurement data and outputting the results to the display, or to the RS232 port for use with a printer( when included) or to a computer for further analysis.

The unit also contains a drive motor which traverses the pickup across the surface to be measured. The measuring stroke always starts from the extreme outward positions. At the end of the measurement the pick up returns to this position ready for the next measurement. The traverse length is determined from selections of cut-off (Lc) or length (Ln).

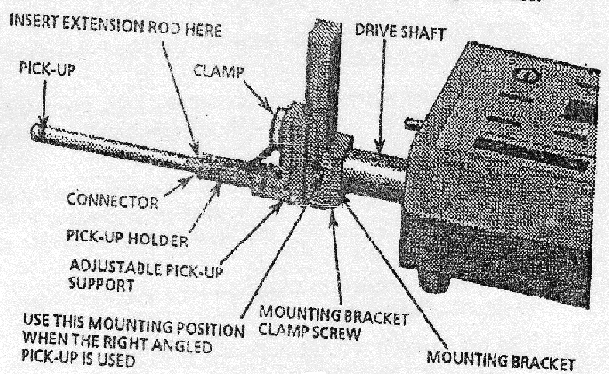


**Fig.: 3.3** Display Transverse Unit (Referred from Instrument Manual)

**Pick-Up Mounting Components**

The pick-up is fastened to the drive shaft by the following means:

**Mounting Bracket**: This is clamped to the drive shaft by means of a knurled knob. Although normally used upright, it can be turned to angle the pick-up or to take it off the centre line. It can also be mounted sideways on the drive shaft, when the right-angle pick-up is in use.



**Fig.: 3.4** Mounting Bracket (Referred from Instrument Manual)

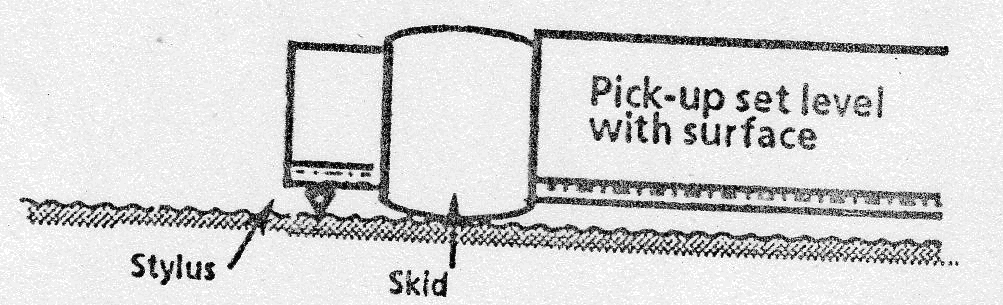
**Adjustable Support**: this can be clamped at any positions on the slide of the mounting bracket to provide pick-up height adjustment.

**Pick-up Holder**: This fits into the crutch of the pick-up support and is held in place by a spring plunger.

**Connector**: The connector of the pick-up lead is screwed into the end of pick-up and is then inserted into the end of the pick-up holder, with the lead coming out through the slot in the holder. It is advisable to connect the lead to the display-traverse unit first and then to the pick-up. When the extension rod is used, the short pick-up is not required and the end of the rod itself is inserted into the holder.

**DIP switch settings**: The instrument default settings, when powering up with a new battery, are set via DIP switches housed inside the display-traverse unit. The selections can be changed by menu/pushbuttons operations. The DIP switches are accessed by unscrewing the three feet from the base of the display-traverse unit, then removing the screws which were partly covered by the feet.

**Pick-up**:The pickup is a variable reluctance type transducer which is supported on the surface to be measured by a skid, a curved support projecting from the underside of the pickup in the vicinity of the stylus. As the pickup traverses across the surface, movements of the stylus relative to the skid are detected and are converted into a proportional electrical signal. The radius of curvature of the skid is much greater than the roughness spacing. This enables it to ride across the surface almost unaffected by the roughness, and provides a datum representing the general form of the surface. Even so, where the waviness is widely spaced it will be necessary to use the pickup with shoe, in conjunction with the 2.5mm (0.1 in) cut-off.



**Fig.: 3.5** Pick-up (Referred from Instrument Manual)

**Specifications of Roughness Measurement Instrument:**

Make : Taylor/Hobson (Supplied from England)

Battery**:** Alkaline: Minimum 600 Measurements of 4mm Lengths.

Ni-Cad: Minimum 200 Measurement of 4mm Length

Size: 6 LR 61 (USA/Japan), Fixed Battery

External Charger (Ni-Cad Only)

110/240V, 50/60 Hz

Traverse Unit: Traverse Speed: 1mm/Sec

Measurement: Metric/Inch Preset by DIP-Switch

Cut-Off Values: 0.25mm, 0.8mm, and 2.50mm

Traverse Length: 1, 3, 5, 10, Or 25.4 + 0.2mm At 0.8mm Cut-Off.

Display: LCD-Matrix. 2lines \* 16 Characters

Keyboard: Membrane Switch Panel Tactile.

Filters: Digital Gauss Filters or 2CR Filter (ISO) Selectable By DIP-Switch.

Parameters: Ra, Rq, Rz (DIN), Ry and Sm.

Calculations Time: Less Than Reversal Time Or 2 Sec Which Ever Is The Longer.

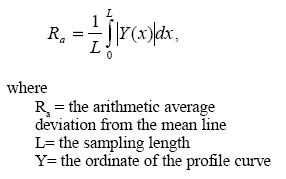
**Measurement of Surface Roughness**

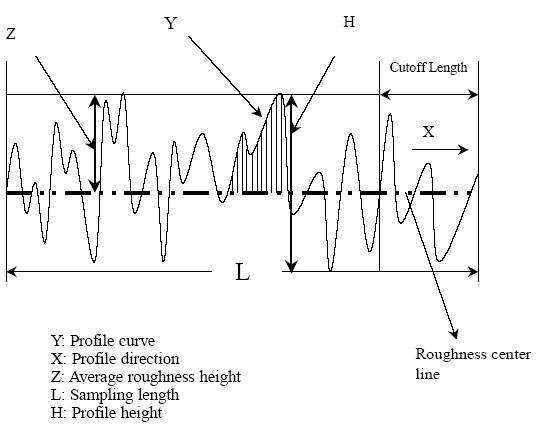
Inspection and assessment of surface roughness of machined work pieces can be carried out by means of different measurement techniques. These methods can be ranked into the following classes:

* [Direct measurement methods](http://www.mfg.mtu.edu/cyberman/quality/metrology/surface.html#para21#para21)
* [Comparison based techniques](http://www.mfg.mtu.edu/cyberman/quality/metrology/surface.html#para22#para22)
* [Non contact methods](http://www.mfg.mtu.edu/cyberman/quality/metrology/surface.html#para23#para23)

**Direct Measurement Methods**

Direct methods access surface finish by means of stylus type devices. Measurements are obtained using a stylus drawn along the surface to be measured. The stylus motion perpendicular to the surface is registered. This registered profile is then used to calculate the roughness parameters. The parameter Ra is used here.





**Fig. 3.6** (Measurement of Surface roughness by Stylus)

**Comparison Based Techniques**

Comparison techniques use specimens of surface roughness produced by the same process, material and machining parameters as the surface to be compared. Visual and tactile senses are used to compare a specimen with a surface of known surface finish. This method is useful for surface roughness Ra>1.6 micron.

**Non Contact Methods**

In it a rough surface is illuminated by a monochromatic plane wave with an angle of incidence with respect to the normal to the surface.  The photo sensor of a camera placed in the focal plane of a Fourier lens is used for recording speckle patterns. Then the surface roughness can be defined and calculated

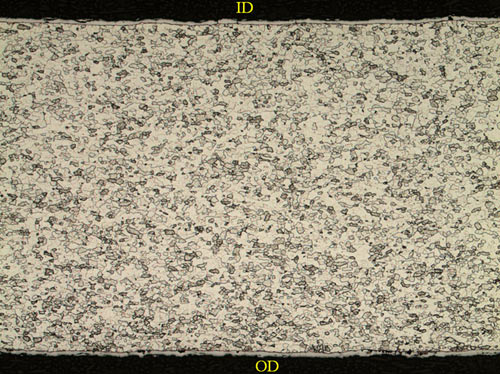
In these experiments direct measurement method has been used i.e. stylus type surface roughness meter was used to measure the surface roughness of the specimen. There were two main reasons behind selecting stylus type surface roughness; one is its easy availability and other is the ease with which it can be operated. The instrument used in these experiments is a product of precision devices

**Work Piece EN-31**

The workpiece for conducting experiment is EN31 which also known as high Carbon alloy Steel. En 31 is an alloyed and heat treated bearing steel with similar composition to that of SAE 52100 steel.  High carbon alloy steel which achieves a high degree of hardness with compressive strength and abrasion resistance.

The composition of EN31 workpiece as shown below:

|  |  |
| --- | --- |
| Carbon | 090-1.10 |
| Silicon | 0.10-0.35 |
| phosphorus | 0.05max |
| Sulfur | 0.05max |
| Nickel | Nil |
| Chromium | 1.00-1.50 |



**Fig 3.7** Micro Structure of EN31 Material

**Preparation of Work Piece**

**Dry Polishing**

Many industrial metallic items are required to have a smooth shining surface in order to have a metallic aesthetic appearance or service required.

In this, no coolant is used. It is carried out in an emery paper of progressively fine grade. The first step involves grinding by using coarse 1/10 paper. This step involves removal of outside impurities like salt etc. in the next step emery paper

Of finer grade 2/0 type is used. It is done perpendicular to previous direction. The rough grinding step involves rubbing by finer emery paper, grade 3/0 which is perpendicular to previous direction.

Ht final polishing paper is 4/0. The grade is an indication of the abrasive grain size. Thereafter, iron & steel samples are polished by means of a rotating cloth impregnated with suitable polishing medium. The cloth cares a hard rotating polishing dis. A suspension of polishing medium powder of alumina is suspended on pad and is wetted after this polished specimen is used against rotating pad using slight pressure of the fingers. This is called polishing.

**Wet Polishing**

After the specimen is dry polish using emery paper, its polished by rotating disc covered with broad cloth and which a very finely powdered alumina () is applied (continuously added). The finished micro section is examined before etching to remove non-metallic inclusion in CI- microstructure with a special agent called steel and cast-iron are usually etched with alcoholic solution. Etching is done to reveal grain boundaries in microstructure.

Procedure is as follows:

* Prepare polishing solution by mixing alumina powder in water on the machine rotor.
* Now start the machine and star polishing the specimen that has been already dry polished using different grades of emery paper. Move the piece slowly from centre to periphery without applying much pressure.
* After wet polishing apply the etchant 0.8%) and 0.2%, so as to reveal the grain boundaries.
* Microstructure is ready to be examined under microscope.

**Brinell Hardness Test**

Hardness is defined as the ability of a material to resist scratching, abrasive, cutting, indentation or penetration.

The hardness determination tests are based on the determination of

1. Resistance to permanent deformation under static or dynamic loading.
2. Resistance to scratching.
3. Energy absorption under impact loading.
4. Wear resistance.
5. Resistance to cutting or drilling.
6. Since these phenomenon are not same, the results of various tests often don’t correlate with one another. the method used for hardness determination are as follows:
7. **Conventional Method**
8. Sclerscope test b)Mohr’s Scale

**Sclerscope Test**: this test is based on rebounding a diamond tipped hammer against the surface whose hardness is to be measured. The height to which it rebounds gives an indication of energy absorption which can be calibrated in terms of hardness.

**Mohr’s Scale**: in this method, two surfaces are rubbed against each other. The surface of wear hardness will wear out, so materials were arranged in order of hardness such that any material in scale would scratch any material between diamonds has index of 10, white talc has 1.

**2) Indention Analysis**

Basic emphasis is on the indentation procedure on the specimen by an indenter. When the indenter is pressured in to the surface under a static compressive load, large amount of plastic deformation takes place locally. The material thus deformed flows out in all direction. The region affected extends to a distance approximately 3 times the radius of indention taking into account principle of constant volume during the plastic deformation .the surface surrounding the impressing bulges out slightly to account for the volume of metal displaced under the indenter. In some cases, metal bulges out around the indentation. This is called ridging. This is obtained in cold worked alloys. While in some cases the metal bulges out at the ends resulting in sinking at the impression. Sinking takes place in case of annealed metals. Methods used for this type analysis are Brinell hardness test, Victor hardness test, Rockwell hardness test.

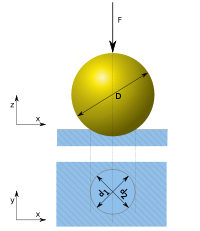
\mbox{BHN}=\frac{2P}{\pi D ({D-\sqrt{(D^2-d^2)})}}

Where:

P = applied force (kgf)

D = diameter of indenter (mm)

d = diameter of indentation (mm)

[](http://en.wikipedia.org/wiki/File:BrinellHardness.svg)

**Fig 3.8** Brinell Hardnees Test

Test is done workpiece

P = 750kg

D = 5mm

d = 2.02mm

\mbox{BHN}=\frac{2P}{\pi D ({D-\sqrt{(D^2-d^2)})}}

=235 BHN

**Chapter 4**

**DESIGN OF EXPERIMENT**

Response surface methodology is concerned with a set of statistical and mathematical techniques that are useful for designing, developing, improving and optimizing the process under study. RSM has widely been used in the field of industry and chemical engineering to study the yield or output of a system as it varies in response to the changing levels of one or more applied factors. The development of RSM was originated by Box and Wilson and was followed by Box (1952, 1954). The main emphasis was on the use of designs of experiments and regression analysis to investigate a particular response produced by a given set of input variables over a specified region of interest; to explore the level of input variables that give the stationary of a specified response and to model the information in adequate functional form so that the shape of responses surface at the its optimum point is indentified. Mead and Pike (16975) have explored the use of RSM in agricultural and biological sciences, Smith and Rose (1963) has demonstrated its application in food science by using sensory measurement to the develop products recipes. Many recent application of RSM in the field of scientific experimentation may be found in Box and draper (1987), Khuri and Cornel (1996) Myers and Montgomery (1995).

The role of RSM is to work as a set of techniques that consists of the following steps:

1. Determination a sequence of experiments that provide adequate and reliable values of the response variable understudy.
2. Finding the form of the relationship between the response and a suitable independent factor (variables).
3. Locating optimum response of the process by changing the levels of the input variables that can be viewed as design variables.

**Factors (or Experimental Variables) and levels**

Factors are processing conditions or input variables whose values (or levels) can be controlled experiment e.g. temperature, feed, time and voltage etc. The word level means the value of input variables or factors examined in the experiment are called levels.

**Response**

“The quantitative output (performance measure) of a trial based on a given set of treatment (factors set at their levels in an experiment run) is called the response corresponding to the set of treatments”. The response may be the yield, the purity of the products, cost and viscosity. For example, in an agricultural experiment, the response is the yield of the crop, measures in units of kgs per hector. The response variable is the measured quantity of the output of a trial whose value is assumed to be affected by changing the levels of the factors. The true value of the response corresponding to any particular combinations of the levels of the factors under study and in the absence of experiment discrepancy is represented by η. The response variable is often represented as y where as the factors are represented as .

**Response Surface Model**

The mathematical expression η = Ф () which represents the specific relationship between true response η and input variables (factors) is called the response surface model. For K=2 the relationship between response variable and two input variables can be shown graphically. For each value of there is a corresponding value of response variable thus the values of the variables may be viewed as a surface lying above the plane. That is why the term RSM was coined. Because of the geometrical constraints, the case for more than two input variables can be visualized than attempting to draw.

**Optimizing the response surface**

If graphical display is possible, optimization of the whole process (i.e. optimization of the response and identification of the factor-level producing it) is straight forward. The graphical displays are not practical in many situations because the response function η = Ф () remains unknown. Thus the scope of RSM should cover:

1. The experimental strategy to explore the response over the ranges of input variables.
2. Empirical statistical modelling to develop an approximation to the true response function and
3. Optimization methods for finding the levels or values of input variables producing optimum response.

**Response function: Approximation thereof**

Generally, the scientists are concerned with a process, product or system involving a response that depends on the levels of the controllable input variables.

The relationship between the true response and k independent variables is defined as

η = Ф ()

Whereas, as similar relation between observed response at the application of the treatment combination and takes the form

= Ф () +

Where, generally referred to as the experiment error, is the difference between the observation and true value η.

The variables in the response function Ф are original variables as they are expressed in their original units of measurement. It is convenient to transform the original variables to their coded counterparts by using the relationship

i=1, 2 ...k.

Where and are suitable location and scale factors respectively. The coded variables are usually dimensionless with mean zero and the same standard deviation.

The true response function, in terms of coded variables can be expressed as

η = Ф ()

The most out of RSM can only be got if the true response function (unknown) Ф can be approximated. Low order polynomial (based on Taylor’s series expansion) in smaller region of factor space could be good starting point. For k=2

Are the first-order models in terms of coded variables without and with interaction respectively. The first model is called main-effect model. Inclusion of the interaction term in the second model improves it provided that interaction exists between, which gives a better sense of surface and curvature. If the surface has stronger curvature the second model needs further improvement and quadratic term are needed to be included. A second order model

If the response obtained under the levels of significantly differs under the levels of then the term can also be added in the above model i.e.

A variables extension to the second order model can be defined as

The order of polynomial approximating the response function and can go higher than two if required, if Taylor series expansion remains the basis for the approximation.

If Y denotes the response variable, then the relationship between response variable and set of input variables is as follow:

Where (u= 1,2.....,n) is the response corresponding to the design point and (i<j)(i,j=1,2,.....,k)are the unknown parameters in the second order polynomial model 𝛆’s are random errors with zero means and a common variance .this model may be written in the matrix over n observation as:

Y=Xβ +𝛆

Where Y is the column vector of ‘n’ response values corresponding to the n design points, 𝛆 is the column vector of the errors, β is the column vector of unknown parameter and X is the design model matrix whose row is

{1,}

**Response Surface Designs**

Experiments, which are particularly designed to explore response surface, are called response surface designs. They are particularly used to predict the model. The form and order of the approximating polynomial depends on the postulated model. The form and order of the approximating polynomial depends on the polynomial depends on the postulated model. Usually first and second order models are used.

Assuming the main criteria of the design is the number of design point ‘n’ which should be large enough to let the parameter with an acceptable efficiency level.

**First Order Design**

The design which enables to estimate the response by first degree polynomial in, are called first order designs and the corresponding model is called the first order model.

A factorial design is often used to fit a first order response surface model and to estimate the factor effect to perform the method of steepest ascent.

Generally the relationship η = Ф () exists between a response η and the levels of k quantitative variables () and the function Ф is assumed to be represented by a polynomial of degree v within a limited region of interest in the space of the k variables. This experiment has n points in k dimensional space chosen so as that from the data obtained by the taking one observation at each of the point, all the coefficients of the polynomial can be estimated. In a polynomial equation of degree v in k variables there are (k+1) terms. When v=1, then this model becomes first order polynomial model so there are (k+1) terms. In the first order polynomial surface, each (i=1, 2....k) appears linearly only. That is the effect of changing the levels of any can be represented by the straight line relationship with the response variables y. It is suggested that the series of factorial design is suitable for the class of first order designs. First order designs can be orthogonal and rotatable, but second or higher order designs cannot orthogonal and rotatable at the time and may not be either. The detail will follow

For k=3 the first order model in terms of the coded variables is

...... (1.1)

This model is also called main effect as it includes only the main effect terms. The 23 factorial design with n=8 design points may be considered as the best response surface design to estimate the four unknown parameters ()

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |
| 1 | -1 | -1 | -1 |
| 1 | 1 | -1 | -1 |
| 1 | -1 | 1 | -1 |
| 1 | -1 | -1 | 1 |
| 1 | 1 | 1 | -1 |
| 1 | 1 | -1 | 1 |
| 1 | -1 | 1 | 1 |
| 1 | 1 | 1 | 1 |

X =

Table 4.1 Coding Table  
Because of the availability of the few extra degrees of freedom in his design we are even able to represent some ‘curvature’ in the response function by including interaction term into it. The model becomes:

...... (1.2)

In RSM the experimenter’s objective is to determine the levels of the independent variables that nearly give the optimum value of response. If the process is operating in some region that is remote from the optimum, the experimenter must determine a set of levels of the process variables that will lead towards optimum. This phase of RSM makes considerable use of the first order model to reach near the optimum and to determine the optimum conditions for the process under study.

The design matrix X of order n\*p has one column of order n for each factor under study. The elements oh the rows of this matrix are values of the standardized (coded) levels to be used in the run of experiment. It is to be noted that all the columns of X. Except the first one, sum to zero and orthogonal to each other.

**Second Order Design**

The design which are set up for the purpose of collecting the observed values of response for estimating the parameters in the second-order model or fitting the second second-order model are called second-order designs. In the design each factor is applied at least at three levels. There is one linear as well as quadratic term for each of the k factor in the model. Experiment designs for fitting a quadratic response surface model of the from as

When each independent experiment variable is defined by an upper and lower bound, the experiment region is a hyper-rectangle, when the ranges of the x’s are scaled (normalized) to a common interval, -1 x1; the experimental region becomes a hypercube. A hyper sphere is a regular region tat “cuts off the corners” of a hypercube.

We consider a matrix D which is referred as the design matrix in the levels of the k input variables of order n\*k having n rows, one fro each experiment point and k columns, one for each factor being examined. The design matrix D is expanded to a n\*p model design matrix X having ‘n’ rows and p columns, one column for each coefficient to be estimated in the model. The X is a matrix constructed from design matrix D according response surface model. For a second order response surface model the number of coefficients is

P= () =1+2k+k (k-1)/2= (k+1) (k+2)/2

i.e. the quadratic model has a constant term, k linear terms (), k quadratic terms () and k (k-1)/2 interaction terms of the form where (i<j, i, j=1, 2,..., k) for the case of two variables, the second order model is

There are many different second order design e.g. Central composite cuboidal design, central composite orthogonal design, central composite rotatable design, central composite minimum variance design, central composite mini-max loss3 design and Box-Behukent design.

The suitability of the second order model is based upon the following:

1. It is a flexible model which can be used to generate the curvilinear response surface and to draw contour plots.

The estimation of parameters is simple which is obtained through ordinary least squares method.

1. The second model is very useful in solving real response surface problems.
2. In the case of missing observations, it is used to measure the losses in central composite designs.

**Central Composite Design**

Research and development are the heart and soul of improvement efforts in manufacturing, and it's fast becoming standard practice to employ design of experiments methods in industrial R&D. In the early stages of their work, experimenters typically use screening experiment designs that normally consist of trials run at the extreme lower- and upper-bound level setting combinations of the variable study ranges. They provide information on the direct additive effects of the study variables and on pair wise (two-variable) interaction effects. Screening designs enable experimenters to select the best materials and equipment from available alternatives and to focus on the correct variables and ranges for further study.

In the later stages of the experimental work, the goal shifts from screening to product and process optimization. The statistical experiment designs most widely used in optimization experiments are termed "response surface designs." In addition to trials at the extreme level settings of the variables, response surface designs contain trials in which one or more of the variables is set at the midpoint of the study range (other levels in the interior of the range may also be represented). Thus, these designs provide information on direct effects, pair wise interaction effects and curvilinear variable effects. Response surface methodology, one approach to product and process optimization work, derives its name from the use of these widely used optimization experiment designs.

Most practitioners of RSM now generate their experiment designs and analyze their data using a statistical software program running on a personal computer. Many of these software programs can generate many classes of RSM designs and, in some cases, offer several varieties of each class. However, the central composite design is the most popular of the many classes of RSM designs due to the following three properties:

* A CCD can be run sequentially. It can be naturally partitioned into two subsets of points; the first subset estimates linear and two-factor interaction effects while the second subset estimates curvature effects. The second subset need not be run when analysis of the data from the first subset points indicates the absence of significant curvature effects.
* CCDs are very efficient, providing much information on experiment variable effects and overall experimental error in a minimum number of required runs.
* CCDs are very flexible. The availability of several varieties of CCDs enables their use under different experimental regions of interest and operability.

Three main varieties of CCD are available in most statistical software programs: face-centered, rotatable and inscribed. Many experimenters are uncertain about the best variety to use in a given study. To make the right selection, the experimenter must first understand the differences between these varieties in terms of the experimental region of interest and region of operability, according to the following definitions.

* *Region of interest* --A geometric region defined by lower and upper limits on study-variable level setting combinations that are of interest to the experimenter

* *Region of operability* --A geometric region defined by lower and upper limits on study-variable level setting combinations that can be operationally achieved with acceptable safety and that will output a testable product

A design which consists of two level factorial or fractional factorial chosen as to allow the estimation of all first –order and two factor interaction terms augmented with further points which allow pure quadratic effects to be estimated is called central composite design(CCD). It is one of the most important and commonly used classes of experiment designs for second model. Theses designs are very useful in industry due to its versatility. Box and Wilson (1951) were who introduced this class of designs. The practical application of CCD usually arises through sequential experimentation. It consists of factorial or fraction of factorial design augmented with 2k axial and centre points.

If we have 5 levels for each of the three factors .i.e () factorial design, there 125 treatment combinations. The corresponding CCD has only ( treatments combinations or design points where represents the factorial points, is the number of axial points and is the number of centre points. The beauty of the CCD is that it eliminates the need for a large number of treatment combinations. Because of the cut down version of factorial design, all is not lost; actually we loose only the non essential information. The volume of information given by CCD is closely matched with the balanced incomplete factorial design. In CCD it is assumed that the response relationship with the k design variables is adequately by the second order polynomial model

If the design used consists of n experiment runs, then the said model in the matrix form may be written as

Where is a vector of n response values, X is an n\*p matrix of rank p with row (u=1,2,....,n)of form

1,.

is p\*1 vector of p unknown parameters and is a vector of random error having normal distribution with mean zero vector and variance-covariance matrix to sum ,CCD consists of three parts:

1. A complete or fractional replication of factorial design points with k factors consisting of = design points of the form () usually called “cube” as it displayed as cube for k=3 and hypercube fork>3. For complete design v=0.
2. A set of =2k axial points with coordinates (0,...,0), (0,0,...,0)........(0,......,0, ),usually called a “star”. where is thedistance of the axial points from the deign centre.
3. A set of centre points at(0,...,0).

If the above three parts are replicated only once, then the total number of design points are

n= i.e n=+2k+

Each of the three parts play the important role .i.e. factorial part provides the estimates of linear terms or linear and two-factor interactions terms, the axial part allows for efficient estimation of pure quadratic term and the method of replicating centre points provide protection against curvature as well independent estimate of error. If be the average of the factorial points and be the average of the centre points, the large of the difference , indicates the presence of curvature.

The choice of parameter, the distance of the axial points from the design centre and number of centre points is important for adequate performance of CCD. The value of specifics the location of the axis, which can be the experimenter to satisfy various conditions. A CCD can be made spherical CCD, rotatable CCD, orthogonal CCD, cuboidal CCD and minimum variance CCD by choosing appropriate values of. Hokes (1974) explained that all these designs are scaled so that the design perimeter is at radius. A graphical layout of 2- variables CCD with =4, =4, and =4 is given in fig 1.1 where there are five levels each of the two variables. The four factorial points are placed on a square with its centre at (0, 0) and four axial points of which two are on axis and two are on axis passing through the centre, at distance (=) from the centre. That is all factorial and axial () design points lie at equal distance on the circle of radius and the centre points lie at the design centre.

**Chapter 5**

**RESULTS AND DISCUSSIONS**

Factors that are chosen to carry out experiment are:

* Feed
* Gap Voltage
* Ton(Pulse on duration)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Level** | Lowest | Low | Medium | High | Highest |
| **Coding** | -√2 | -1 | 0 | 1 | √2 |
| **Feed (mm/min)** | 30 | 35 | 40 | 45 | 50 |
| **Ton(µsec)** | 10 | 15 | 20 | 25 | 30 |
| **Gap Voltage(V)** | 5 | 10 | 15 | 20 | 25 |

Table 5.1 Level of Independent variables

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| S.NO | X1 | X2 | X3 | Feed(mm/min) | Ton(µsec) | Gap Voltage(V) | Surface Roughness(µm) |
| 1 | -1 | -1 | -1 | 35 | 15 | 10 | 4.70 |
| 2 | 1 | -1 | -1 | 45 | 15 | 10 | 5.10 |
| 3 | -1 | 1 | -1 | 35 | 25 | 10 | 5.76 |
| 4 | 1 | 1 | -1 | 45 | 25 | 10 | 6.08 |
| 5 | -1 | -1 | 1 | 35 | 15 | 20 | 4.76 |
| 6 | 1 | -1 | 1 | 45 | 15 | 20 | 4.90 |
| 7 | -1 | 1 | 1 | 35 | 25 | 20 | 5.60 |
| 8 | 1 | 1 | 1 | 45 | 25 | 20 | 5.90 |
| 9 | 0 | 0 | 0 | 40 | 20 | 15 | 5.14 |
| 10 | 0 | 0 | 0 | 40 | 20 | 15 | 5.14 |
| 11 | 0 | 0 | 0 | 40 | 20 | 15 | 5.16 |
| 12 | 0 | 0 | 0 | 40 | 20 | 15 | 5.14 |
| 13 | -√2 | 0 | 0 | 30 | 20 | 15 | 5.11 |
| 14 | √2 | 0 | 0 | 50 | 20 | 15 | 5.78 |
| 15 | 0 | -√2 | 0 | 40 | 10 | 15 | 4.40 |
| 16 | 0 | √2 | 0 | 40 | 30 | 15 | 6.10 |
| 17 | 0 | 0 | -√2 | 40 | 20 | 5 | 5.70 |
| 18 | 0 | 0 | √2 | 40 | 20 | 25 | 5.30 |
| 19 | -√2 | 0 | 0 | 30 | 20 | 15 | 4.90 |
| 20 | √2 | 0 | 0 | 50 | 20 | 15 | 5.66 |
| 21 | 0 | -√2 | 0 | 40 | 10 | 15 | 4.40 |
| 22 | 0 | √2 | 0 | 40 | 30 | 15 | 6.18 |
| 23 | 0 | 0 | -√2 | 40 | 20 | 5 | 5.72 |
| 24 | 0 | 0 | √2 | 40 | 20 | 25 | 5.38 |

Table 5.2 Experiment condition and Results

**Regression Analysis: Surface Roughness (µm)** **versus Feed (mm/min), Ton (µsec), & Gap Voltage (V).**

**The regression equation is**

**Surface Roughness (µm) = 2.43 + 0.0335 Feed (mm/min) + 0.0903 Ton(µsec)- 0.0163 Gap Voltage (V)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Predictor | Coef | SE Coef | T | P | VIF |
| Constant | 2.4321 | 0.2720 | 8.94 | 0.000 |  |
| Feed(mm/min) | 0.03350 | 0.005734 | 5.84 | 0.000 | 1.000 |
| Ton(µsec) | 0.09033 | 0.005734 | 15.76 | 0.000 | 1.000 |
| Gap Voltage(V) | -0.016333 | 0.005734 | -2.85 | 0.010 | 1.000 |

Table 5.3 Regression Table

S = 0.140442 R-Sq = 93.6% R-Sq(adj) = 92.6%

PRESS = 0.550583 R-Sq(pred) = 91.01%

Analysis of Variance

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | DF | SS | MS | F | P |
| Regression | 3 | 5.7295 | 1.9098 | 96.83 | 0.000 |
| Residual Error | 20 | 0.3945 | 0.0197 |  |  |
| Lack of Fit | 11 | 0.3583 | 0.0326 | 8.11 | 0.002 |
| Pure Error | 9 | 0.0362 | 0.0040 |  |  |
| Total | 23 | 6.1240 |  |  |  |

Table 5.4 Analysis of Variance

8 rows with no replicates

|  |  |  |
| --- | --- | --- |
| Source | DF | Seq SS |
| Feed(mm/min) | 1 | 0.6733 |
| Ton(µsec) | 1 | 4.8961 |
| Gap Voltage(V) | 1 | 0.1601 |

Surface

Obs Feed(mm/min) Roughness(µm) Fit SE Fit Residual St Resid

1 35.0 4.7000 4.7963 0.0573 -0.0963 -0.75

2 45.0 5.1000 5.1313 0.0573 -0.0313 -0.24

3 35.0 5.7600 5.6996 0.0573 0.0604 0.47

4 45.0 6.0800 6.0346 0.0573 0.0454 0.35

5 35.0 4.7600 4.6329 0.0573 0.1271 0.99

6 45.0 4.9000 4.9679 0.0573 -0.0679 -0.53

7 35.0 5.6000 5.5363 0.0573 0.0637 0.50

8 45.0 5.9000 5.8713 0.0573 0.0287 0.22

9 40.0 5.1400 5.3338 0.0287 -0.1938 -1.41

10 40.0 5.1400 5.3338 0.0287 -0.1938 -1.41

11 40.0 5.1600 5.3338 0.0287 -0.1738 -1.26

12 40.0 5.1400 5.3338 0.0287 -0.1938 -1.41

13 30.0 5.1100 4.9988 0.0641 0.1112 0.89

14 50.0 5.7800 5.6688 0.0641 0.1112 0.89

15 40.0 4.4000 4.4304 0.0641 -0.0304 -0.24

16 40.0 6.1000 6.2371 0.0641 -0.1371 -1.10

17 40.0 5.7000 5.4971 0.0641 0.2029 1.62

18 40.0 5.3000 5.1704 0.0641 0.1296 1.04

19 30.0 4.9000 4.9988 0.0641 -0.0988 -0.79

20 50.0 5.6600 5.6688 0.0641 -0.0088 -0.07

21 40.0 4.4000 4.4304 0.0641 -0.0304 -0.24

22 40.0 6.1800 6.2371 0.0641 -0.0571 -0.46

23 40.0 5.7200 5.4971 0.0641 0.2229 1.78

24 40.0 5.3800 5.1704 0.0641 0.2096 1.68

Table 5.6 Regression Analysis Table

Durbin-Watson statistic = 1.29756

Lack of fit test

Possible curvature in variable Gap Volt (P-Value = 0.013)

Overall lack of fit test is significant at P = 0.013



**Fig 5.1** 3D Scatter Plot of Surface Roughness (µm) Vs Feed (mm/min) Vs Gap Voltage (V)

This 3D Scatter plot graph is between Surface roughness v/s Feed v/s Gap Voltage. Surface roughness is taken at y-axis, gap voltage at x-axis and feed at z-axis. Y axis is varying from 0 - 8.0 micron having interval of 0.5 micron, X axis varying from 0 – 30 having interval of 6 volts while Z axis is varying from 0 - 50 having interval of 10 mm/min. This shown graph shows surface roughness value at corresponding feed and gap voltage.



**Fig 5.2** 3D Scatter Plot of Surface Roughness (µm) Vs Feed (mm/min) Vs Ton (µsec)

This 3D Scatter plot graph is between Surface roughness v/s Feed v/s Ton. Surface roughness is taken at y-axis, Ton at x-axis and feed at z-axis. Y axis is varying from 0 - 8.0 micron having interval of 0.5 micron, X axis varying from 0 – 30 having interval of 10 µsec while Z axis is varying from 0 - 50 having interval of 10 mm/min. This shown graph shows surface roughness value at corresponding feed and Ton.



**Fig 5.3** 3D Scatter Plot of Surface Roughness (µm) Vs Ton (µsec) Vs Gap Voltage (V)

This 3D Scatter plot graph is between Surface roughness v/s Ton v/s Gap Voltage. Surface roughness is taken at y-axis, gap voltage at x-axis and Ton at z-axis. Y axis is varying from 0 - 8.0 micron having interval of 0.5 micron, X axis varying from 0 – 30 having interval of 6 volts while Z axis is varying from 0 - 30 having interval of 10 µsec. This shown graph shows surface roughness value at corresponding gap voltage and Ton.



**Fig 5.6** Surface Plot of Surface Roughness (µm) Vs Feed (mm/min) Vs Ton (µsec)

**Fig 5.4** Surface Plot of Surface Roughness (µm) Vs Feed (mm/min) Vs Ton (µsec)

This 3D Scatter plot graph is between Surface roughness v/s Feed v/s Ton. Surface roughness is taken at y-axis, Ton at x-axis and feed at z-axis. Y axis is varying from 0 - 8.0 micron having interval of 0.5 micron, X axis varying from 0 – 30 having interval of 10 µsec while Z axis is varying from 0 - 50 having interval of 10 mm/min. A surface is obtained surface roughness value at corresponding feed and Ton, this surface is having various peak and valley and from this surface plot roughness values can be obtained at various feed and Ton.



**Fig 5.5** Surface Plot of Surface Roughness (µm) Vs Feed (mm/min) Vs Gap Voltage (V)

This Surface plot is between Surface roughness v/s Feed v/s Gap Voltage. Surface roughness is taken at y-axis, gap voltage at x-axis and feed at z-axis. Y axis is varying from 0 - 8.0 micron having interval of 0.5 micron, X axis varying from 0 – 30 having interval of 6 volts while Z axis is varying from 0 - 50 having interval of 10 mm/min. A surface is obtained surface roughness value at corresponding feed and gap voltage, this surface is having various peak and valley and from this surface plot roughness values can be obtained at various feed and gap voltage.



**Fig 5.6** Surface Plot of Surface Roughness (µm) Vs Ton (µsec) Vs Gap Voltage (V)

This 3D Scatter plot graph is between Surface roughness v/s Ton v/s Gap Voltage. Surface roughness is taken at y-axis, gap voltage at x-axis and Ton at z-axis. Y axis is varying from 0 - 8.0 micron having interval of 0.5 micron, X axis varying from 0 – 30 having interval of 6 volts while Z axis is varying from 0 - 30 having interval of 10 µsec. A surface is obtained surface roughness value at corresponding ton and gap voltage, this surface is having various peak and valley and from this surface plot roughness values can be obtained at various ton and gap voltage.



**Fig 5.7** Contour Plot of Surface Roughness (µm) Vs Feed (mm/min) Vs Gap Voltage (V)

This is Contour Plot of Surface Roughness (µm) Vs Feed (mm/min) Vs Gap Voltage (V). From this contour plot, it is observed that from 9 to 25 volts surface roughness is remaining same, only with the increase in feed surface roughness is changing, therefore it can said that gap voltage has less significant factor, that can affect surface roughness, while feed is more prominent factor than gap voltage that can cause variation in surface roughness.



**Fig 5.8** Contour Plot of Surface Roughness (µm) Vs Ton (µsec) Vs Gap Voltage (V)

In this contour plot Surface Roughness (µm) Vs Ton (µsec) Vs Gap Voltage (V), high variation in surface roughness can be seen. Variation in both parameters i: e gap voltage and ton causing variation in surface roughness. At gap voltage 15volts and ton 10µsec very less surface roughness less than 4.50 micron is obtained but with increase in ton i:e 30µsec at same gap voltage i:e 15 volts high surface roughness more than 6.00 micron is obtained that shows ton is highly significant parameter that can affect roughness of workpiece.



**Fig 5.9** Contour Plot of Surface Roughness (µm) Vs Feed (mm/min) Vs Ton (µsec)

In this contour plot of surface roughness (µm) Vs Feed (mm/min) Vs Ton (µsec), high variation of surface roughness can be seen with the increase in ton surface roughness is also increasing. But in case of feed at 40 mm/min high surface finish is obtained and both with the increase and decrease in feed from 40 mm/min keeping Ton constant 10 µsec surface roughness start to increase. But feed is less significant parameter in comparison to Ton which is affect surface roughness to a great deal.

**Chapter 6**

**CONCLUSION**

In this work, surface roughness is investigated by varying the machining parameters on EN-31 steel with wire electric discharge machine. The machining parameters included pulse on time (Ton), wire feed rate (Feed) and gap voltage. Experiments were conducted according to Central Composite Design. The optimum parameter level combination was found which would yield the least surface roughness. The following conclusions have been made out:

1. Regression analysis has been successfully used to develop the surface roughness model.
2. The dominant factor affecting surface roughness is pulse-on time (*T*on), because the surface roughness depends on the size of spark crater. A shallow crater together with a larger diameter leads to a better workpiece surface roughness. To obtain a flat crater, it is important to control the electrical discharging energy at a smaller level by setting a small pulse-on time (*T*on) since most Wire-EDM machines were designed to discharge with the electrical discharging current proportional to the pulse-on time. A large discharging energy will cause violent sparks and results in a deeper erosion crater on the surface. Accompanying the cooling process after the spilling of molten metal, residues will remain at the periphery of the crater to form a rough surface.
3. The wire feed rate is second most dominating factor affecting; with too high or low a value producing undesirable results in surface finish. As in general machining case, higher feed results in enhanced rate of the operation, thereby lesser fineness in surface finish.
4. Gap voltage is expected to be low to obtain good surface finish. With lesser value of voltage, lesser sparking energy is available at the gap, yielding low values of surface roughness.
5. The surface roughness equation shows that the pulse on time (Ton) is the main influencing factor, followed by feed and gap voltage in the operation model.

**Chapter 6**

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