

## Basics of Mechanical Engineering-2

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Week 11

Lecture 46

### Tutorial - 6 (Non-Conventional Machining)

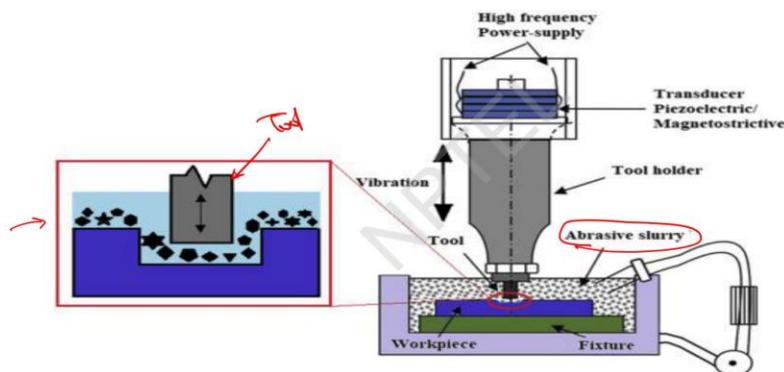
Welcome back to the course Basics of Mechanical Engineering 2. We have discussed non-conventional machining processes this week. And I will conduct a tutorial on the same. We have classified the non-conventional machining processes into three major categories. One is based on mechanical energy, then based on chemical energy.

Then based on electrical energy. In the combination of electrical and chemical, there is also electrochemical energy. Now, in this tutorial session, I will cover one of these processes. Each mechanical, electrical, and chemical, and try to solve problem statements on that. I am Dr. Naman Deep Singh Oberoi from IIT Kanpur.

## Non-Conventional Machining Problems



### Ultrasonic Machining process:



So, just to recall the ultrasonic machining process. Which is a mechanical energy-based process or mechanical-based process. In which abrasive particles flow through this vibrating tool here. This tool is given here, and this turns into a slurry. When we add some water or some liquid here, based upon the size of the abrasive particle.

Based on the parameters which we will discuss now, that is the volume of material removal impact. The number of particles and the frequency determine the material removal rate. And how do we calculate the material removal rate? Let us try to see this.

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## Non-Conventional Machining Problems

**Ultrasonic Machining process:**

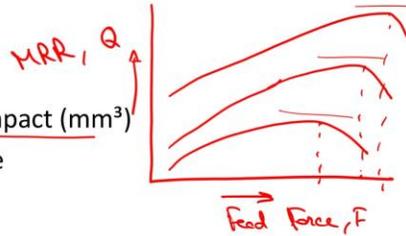
Volume of work material removal rate (Q)

$$Q \propto VZv$$

where,  $V$  = volume of the work material removal per impact ( $\text{mm}^3$ )  
 $Z$  = number of particles making impact per cycle  
 $v$  = frequency (Hz)

**Static loading (feed force) in Ultrasonic Machining:**  
*With an increase in static loading material, removal rate tends to increase initially, but after a critical value of force (MRR) starts to decrease because under high force grains start getting crushed.*





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Volume of work removal rate denoted by  $Q \propto VZv$ . Volume  $V$  is the material removal per impact, which is in millimeter cube.  $Z$  is the number of particles making impact per cycle, and  $v$  here is frequency. So, it is generally said that with an increase in static loading, material removal rate tends to increase initially.

But after a critical value of the force, MRR starts to decrease because under high forces, grains start getting crushed. So, in the beginning itself, the particles are completely sharp. The abrasive particles, as it was thought, are considered spherical here.

So, those are sharp. So, at a certain specific level, if I try to plot it here. After some specific critical value of MRR, the decrease comes. For example, if I have feed force here, feed force  $S$ , and I have MRR which is  $Q$  in this direction, it is something like this. It increases to a certain level and then the particles become blunt and get crushed. It starts

decreasing there. Something like this. So, from here it is decreasing. So, this is the maximum MRR.

## Non-Conventional Machining Problems



**Problem Statement:** A USM process operates at a frequency of 25 kHz, with 6000 abrasive particles making an impact per cycle. The volume of material removed per impact is  $1.8 \times 10^{-6} \text{ mm}^3$ .

Find:

- The total number of impacts per second
- The Material Removal Rate (MRR) in  $\text{mm}^3/\text{s}$
- The MRR in  $\text{mm}^3/\text{min}$

$$\begin{aligned}
 \nu &= 25 \text{ kHz} = 25,000 \text{ cycles/sec} \\
 Z &= 6000 \\
 V &= 1.8 \times 10^{-6} \text{ mm}^3
 \end{aligned}$$

$$\begin{aligned}
 \text{a) No. of impacts per sec.} \\
 Z\nu &= 6000 \times 25000 \\
 &= 150,000,000 \\
 &= 150 \times 10^6 \text{ impacts/sec} \\
 \text{b) MRR: } Q &= VZ\nu \\
 &= (1.8 \times 10^{-6}) (150 \times 10^6) \text{ mm}^3/\text{sec} \\
 &= 270 \text{ mm}^3/\text{sec} \\
 \text{c) } Q &= 270 \text{ mm}^3/\text{sec} \\
 &= 270 \times 60 \text{ mm}^3/\text{min} \\
 &= 16,200 \text{ mm}^3/\text{min}
 \end{aligned}$$



Let me try to see the problem statement here. A USM process operates at a frequency of 25 kHz, with 6000 abrasive particles making an impact per cycle. The volume of material removed per impact is  $1.8 \times 10^{-6} \text{ mm}^3$ .

Find:

- The total number of impacts per second
- The Material Removal Rate (MRR) in  $\text{mm}^3/\text{s}$
- The MRR in  $\text{mm}^3/\text{min}$

Given:

$$\nu = 25 \text{ KHz}$$

$$Z = 6000$$

$$V = 1.8 \times 10^{-6} \text{ mm}^3$$

Solution:

a) No. of impacts per second

$$Zv = 6000 \times 25000 = 150000000$$

$$= 150 \times 10^6 \text{ impacts/sec}$$

b) MRR:  $Q = VZv$

$$= (1.8 \times 10^{-6}) (150 \times 10^6)$$

$$= 270 \text{ mm}^3/\text{sec}$$

c)  $Q = 270 \text{ mm}^3/\text{sec}$

$$= 270 \times 60 = 16,200 \text{ mm}^3/\text{min}$$

## Non-Conventional Machining Problems



**Problem Statement:** A USM process operates at a frequency of 25 kHz, with 6000 abrasive particles making an impact per cycle. The volume of material removed per impact is  $1.8 \times 10^{-6} \text{ mm}^3$ .

Find:

- a) The total number of impacts per second
- b) The Material Removal Rate (MRR) in  $\text{mm}^3/\text{s}$
- c) The MRR in  $\text{mm}^3/\text{min}$

$$V = 25 \text{ kHz} = 25,000 \text{ cycles/sec}$$

$$Z = 6000$$

$$V = 1.8 \times 10^{-6} \text{ mm}^3$$

a) No. of impacts per sec.

$$Zv = 6000 \times 25000$$

$$= 150000000$$

$$= 150 \times 10^6 \text{ impacts/sec}$$

b) MRR:  $Q = VZv$

$$= (1.8 \times 10^{-6}) (150 \times 10^6) \text{ mm}^3/\text{sec}$$

$$= 270 \text{ mm}^3/\text{sec}$$

c)  $Q = 270 \text{ mm}^3/\text{sec}$

$$= 270 \times 60 \text{ mm}^3/\text{min}$$

$$= 16,200 \text{ mm}^3/\text{min}$$

# Non-Conventional Machining Problems

Given  $MRR = 10,000 \text{ mm}^3/\text{min}$   
 $\nu = 22 \text{ kHz} = 22,000 \text{ cycles/sec}$   
 $Z = 5000$   
 $V = 2 \times 10^{-6} \text{ mm}^3$

a) Verify MRR

$$Q = VZ\nu = (2 \times 10^{-6}) \times (5000) \times (22000)$$

$$= 220 \text{ mm}^3/\text{sec}$$

Converting into  $\text{mm}^3/\text{min}$

$$Q_{\text{min}} = 220 \times 60 = 13,200 \text{ mm}^3/\text{min}$$

Experimental MRR is 132% of the given data (MRR given)

b)  $\nu' = 1.2\nu = 1.2 \times 22000 = 26,400 \text{ cycles/sec}$

$$Q' = VZ\nu'$$

$$= (2 \times 10^{-6}) (5000) (26400)$$

$$= 264 \text{ mm}^3/\text{sec}$$

$$Q' \text{ in } \text{mm}^3/\text{min} = 264 \times 60 \text{ mm}^3/\text{min}$$

$$= 15,840 \text{ mm}^3/\text{min}$$

(20% increase)

$$Q' = 1.2 Q$$

c)  $Z' = 0.9Z$

$$Q'' = VZ'\nu$$

$$Q'' = V(0.9Z)\nu$$

$$Q'' = 0.9(VZ\nu)$$

$$Q'' = 0.9 Q$$

$$= 11880 \text{ mm}^3/\text{min}$$

This is another problem statement in a similar way. A USM machine is removing material at a reported MRR of 10,000 mm<sup>3</sup>/min. The process parameters are as follows:

Frequency = 22 kHz

Number of particles impacting per cycle = 5000

Volume removed per impact =  $2 \times 10^{-6} \text{ mm}^3$

Find:

- Verify if the reported MRR is correct.
- If the frequency increases by 20%, what is the new MRR?
- If the number of abrasive particles per cycle is reduced by 10%, what happens to MRR?

Given:

MRR = 10,000 mm<sup>3</sup>/min

$\nu = 22 \text{ kHz} = 22,000 \text{ cycles/sec}$

$Z = 5000$

$$V = 2 \times 10^{-6}$$

Solution:

a) Verify MRR

$$\begin{aligned} Q &= VZv = (2 \times 10^{-6}) \times (5000) \times (22000) \\ &= 220 \text{ mm}^3/\text{sec} \end{aligned}$$

Converting to  $\text{mm}^3/\text{min}$

$$Q_{\text{min}} = 220 \times 60 = 13,200 \text{ mm}^3/\text{min}$$

Experimental MRR is 132% of the given data.

b)  $v' = 1.2 v = 1.2 \times 22000 = 26,400 \text{ cycles/sec}$

$$\begin{aligned} Q' &= VZv' \\ &= (2 \times 10^{-6}) \times (5000) \times (26400) \\ &= 264 \text{ mm}^3/\text{sec} \end{aligned}$$

Converting to  $\text{mm}^3/\text{min}$

$$= 264 \times 60 = 15,840 \text{ mm}^3/\text{min} \quad (20\% \text{ increase})$$

$$Q' = 12 Q$$

c)  $Z' = 0.9 Z$

$$Q'' = VZ'v$$

$$Q'' = V (0.9Z) v$$

$$Q'' = 0.9 (VZv)$$

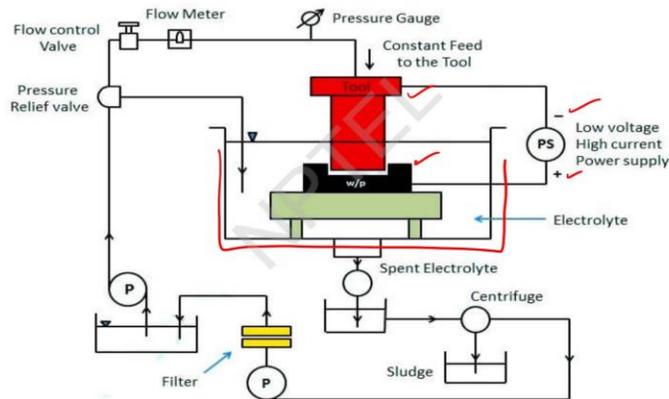
$$Q'' = 0.9 Q$$

$$= 11880 \text{ mm}^3/\text{min}$$

# Non-Conventional Machining Problems



## Electro Chemical Machining process:



<https://www.technielectro-chemical.com/non-traditional-machining/>

So, this is just a recalling of the process. Electrochemical machining, we have this setup where workpiece is machined using a tool and constant feed to the tool is given. There is also electrical connection. The workpiece is anode and tool is cathode here.

We have electrolyte filled in the tank. This is a tank where electrolyte is filled. Both electrical and chemical energy work together. MRR here remains unaffected by workpiece hardness. So, making ECM very ideal for low-machinability materials and complex materials because hardness is not a concern here.

There is virtually no tool wear. However, due to rusting, some deterioration of the overall system components does occur. So, electrochemical machining is an advanced non-contact machining process, similar to EDM, which we have discussed.

## Non-Conventional Machining Problems

### Electro Chemical Machining process:

Electrolysis process is governed by Faraday's Laws:

1. Amount of material dissolved from the anode is proportional to the amount of current passed.
2. Amount of different substances dissolved by the same amount of current is proportional to gram equivalent weight of the material.

$$m \propto It \epsilon$$

$$m = \frac{It\epsilon}{F}$$

Where  $m$  = weight of material dissolved (g)

✓  $I$  = current (A)

✓  $t$  = Time (s)

✓  $\epsilon$  = Gram equivalent weight of the material

✓  $F$  = Faraday's constant (= 96500 Coulombs)

✓  $\rho$  = density of work material (g/cm<sup>3</sup>)

## Non-Conventional Machining Problems

High current, high atomic weight and low valency leads to higher MRR in ECM.

$$\text{Gram equivalent weight } (\epsilon) = \frac{\text{Atomic weight } (A)}{\text{Valency of work Material } (Z)}$$

$$\epsilon = \frac{A}{Z}$$

$$m = \frac{AIt}{ZF} \quad (\text{g})$$

$$\text{MRR} = Q = \frac{AI}{ZF\rho} = \frac{\epsilon I}{F\rho} \quad (\text{cm}^3/\text{Sec})$$

$$\dot{m} = \frac{AI}{ZF} \quad (\text{g/sec})$$

↑  
MRR Flow Rate

In this process, the electrolysis process is governed by Faraday's law. The amount of material dissolved from the anode is proportional to the amount of current passed. The amount of different substances dissolved by the same amount of current is proportional to the gram equivalent weight of the material.

So, this is gram equivalent weight  $m = \frac{It\epsilon}{F}$ . Here,  $I$  is the current in amperes,  $t$  is time in seconds, and  $\epsilon$  is the gram equivalent weight of the material.  $F$  is Faraday's constant, and  $\rho$  is the density of the work material in grams per centimeter cubed.

So here in ECM, both the tool and workpiece experience significant forces due to high-pressure fluid in the gap. So that is Faraday's law here governing the process, stating the material removal rate is directly proportional to the electric charge being passed here. The different substances dissolved or deposited are in proportion to the chemical equivalent weights, a certain advantage. A surface finish of up to 25 microns can be achieved in the ECM process. And the gram equivalent weight here is  $\epsilon = \frac{A}{Z}$ . So, we can put here that  $m = \frac{AI t}{ZF}$  (g). And  $m = \frac{AI}{ZF}$  (g/sec). So  $MRR = Q = \frac{AI}{ZF\rho} = \frac{\epsilon I}{F\rho}$  (cm<sup>3</sup>/Sec)

And all the notations have been given in the previous slide here.  $\rho$  is the density of the work material in g/cm<sup>3</sup>. So, that is why the solution is given in cm<sup>3</sup>/sec.

## Non-Conventional Machining Problems



**Problem Statement:** A hole of square shape having dimension 5mm x 5mm is to be drilled in a copper block through ECM. Further, it is given that atomic weight and valency of copper are 63 and 1, respectively. If 5000 A current is passed for machining the block, then find the Material Removal Rate (MRR) in g/s.

$$\begin{aligned} A &= 63 \\ I &= 5000 \text{ A} \\ Z &= 1 \\ F &= 96500 \text{ Coulombs} \end{aligned}$$

$$\begin{aligned} MRR &= \frac{A I}{Z F} \\ &= \frac{63 \times 5000}{1 \times 96500} \\ &= 3.26 \text{ g/sec} \end{aligned}$$

A hole of square shape having dimension 5mm x 5mm is to be drilled in a copper block through ECM. Further, it is given that atomic weight and valency of copper are 63 and 1, respectively. If 5000 A current is passed for machining the block, then find the Material Removal Rate (MRR) in g/s.

Given:

$$A = 63$$

$$I = 5000 \text{ A}$$

$$Z = 1$$

$$F = 96500$$

Solution:

$$\text{MRR} = \frac{AI}{ZF}$$

$$= \frac{63 \times 5000}{1 \times 96500} = 3.26 \text{ g/sec}$$

## Non-Conventional Machining Problems



**Problem Statement:** In the ECM process, MRR of  $2 \text{ cm}^3/\text{min}$  is required to be obtained using iron as workpiece whose properties are given in the below table. What is the amount of current (in A) required for achieving this?

| Atomic Weight | Valency | Density ( $\text{g}/\text{cm}^3$ ) |
|---------------|---------|------------------------------------|
| 56            | 2       | 7.8                                |

$$\text{MRR} = 2 \text{ cm}^3/\text{min} = 2/60 = 1/30 \text{ cm}^3/\text{sec}$$

$$A = 56$$

$$Z = 2$$

$$\rho = 7.8 \text{ g/cm}^3$$

$$\text{MRR} = \frac{AI}{ZF\rho} \text{ cm}^3/\text{sec}$$

$$\frac{1}{30} = \frac{56 \times I}{2 \times 96500 \times 7.8}$$

$$I = 896.07 \text{ Amp.}$$



In the next problem statement, we have also been given the density. In the ECM process, MRR of  $2 \text{ cm}^3/\text{min}$  is required to be obtained using iron as workpiece whose properties are given in the below table. What is the amount of current (in A) required for achieving this?

Given:

$$\text{MRR} = 2 \text{ cm}^3/\text{min} = 2/60 = 1/30 \text{ cm}^3/\text{sec}$$

$$A = 56 \text{ g}$$

$$Z = 2$$

$$\rho = 7.8 \text{ g/cm}^3$$

Solution:

$$\text{MRR} = \frac{AI}{ZF\rho}$$

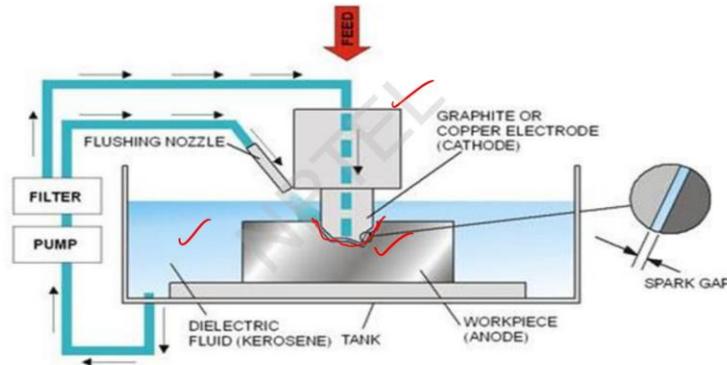
$$\frac{1}{30} = \frac{56 \times I}{2 \times 96500 \times 7.8}$$

$$I = 896.07 \text{ Amp.}$$

## Non-Conventional Machining Problems



### Electric Discharge Machining (EDM):



<https://www.techniwaterjet.com/non-traditional-machining/>

## Non-Conventional Machining Problems



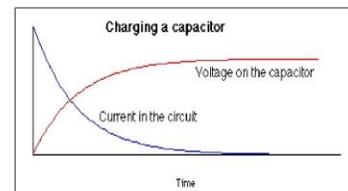
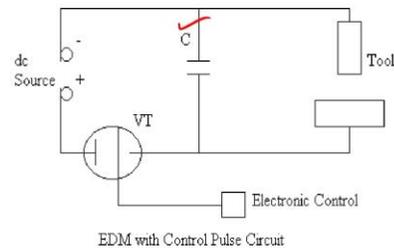
### Resistance Capacitance Relaxation Circuit:

- As can be seen from the figure, capacitor C is charged by a variable resistance R by the DC source of  $V_0$ .
- Voltage across tool work gap is the same as the voltage across the capacitor which varies with time as,

$$V = (1 - e^{-\frac{t}{RC}}) V_0$$

- When voltage reaches discharge voltage ( $V_d$ ) a spark takes place across the tool workpiece gap, and thus, discharging the capacitor.

$$\text{Energy released per spark} = E = \frac{1}{2} C V_d^2$$



Next comes the last topic of this session, that is electric discharge machining, EDM. Some authors do say that EDM is now no longer a non-conventional process. Because it is so widely used in industry. But because the material removal rate is very low. That is why it is still talked about in the non-conventional processes only. It uses electrical energy.

The conventional processes use the shearing force; here, we use the mechanical. The chemical, the electrical forces. But it was designed way back, a few decades ago. And it is now widely used in different formats for different applications. Wherever it is required, so just to recall.

So there is a tool and workpiece; depending upon the shape of the tool, we get the shape of the workpiece. There is always a spark gap that determines the MRR and the surface quality. So there is a DC pulse generator with certain components. If I say that, it generates the pulse. And the electrode tool is there; servo motor mechanism, spark generator, fluid.

That is dielectric fluid. This kind of EDM that you have studied: wire EDM, sinker EDM. This is sink EDM, hole drilling EDM. Then certain advantages that we have seen: it gives high accuracy. That highly tight tolerances or minimal stress or vibrations are there. When we try to use EDM, it creates intricate pockets, deep holes, thin walls, geometries. That are very irregular, or so hard material could be cut because minimum force is required.

So, the material only has to be conductive that is the basic requirement. So, these things we have discussed let me come to the resistance capacitance reductions in circuit. That I will use in the problem statements. As can be seen from the figure that the capacitor. C here is charged by a variable resistance R by the DC source.

V naught voltage across the work gap is same as the voltage across the capacitor which varies with time. So,  $V = (1 - e^{-\frac{t}{RC}})V_0$ . When voltage reaches discharge voltage  $V_D$ , a spark takes place across a tool workpiece gap.

And thus discharging capacitor I am not going to deep details here just to give you very brief introduction of the EDM. That is already discussed because this is basics of mechanical engineering course. We will only take very simple problems here. And these problems are only to give you introduction or a little details. About how does EDM mechanism help.

## Non-Conventional Machining Problems



**Problem Statement:** In RC circuit of EDM, if the capacitance and maximum charging voltage are  $80 \mu\text{F}$  and  $80 \text{ V}$ , respectively, then calculate the spark energy in Joule.

$$\begin{aligned} C &= 80 \mu\text{F} \\ &= 80 \times 10^{-6} \text{ F} \\ V_d &= 80 \text{ V} \\ E &= \frac{1}{2} C V_d^2 \\ &= \frac{1}{2} \times 80 \times 10^{-6} \times (80)^2 \\ &= 0.256 \text{ J} \end{aligned}$$



Let me directly come to the problem statement. In RC circuit of EDM, if the capacitance and maximum charging voltage are  $80 \mu\text{F}$  and  $80 \text{ V}$ , respectively, then calculate the spark energy in Joule.

Given:

$$C = 80 \mu\text{F} = 80 \times 10^{-6}$$

$$V = 80 \text{ V}$$

Solution:

$$E = \frac{1}{2} C V_d^2$$

$$= \frac{1}{2} 80 \times 10^{-6} (80)^2$$

$$= 0.256 \text{ J}$$

## Non-Conventional Machining Problems

**Problem Statement:** Consider the following data regarding RC circuit in the EDM:

Open circuit voltage = 100 V ✓

Maximum discharging voltage = 70 V ✓

Capacitance = 100  $\mu$ F ✓

Calculate the charging resistance for the idle time of 500  $\mu$ s.

$$R =$$

$$V_0 = 100V$$

$$V_d = 70V$$

$$C = 100\mu F$$

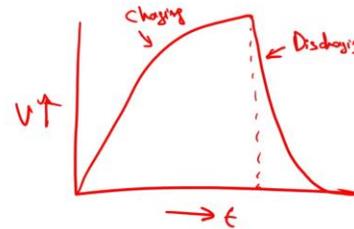
$$t_c = 500\mu s$$

$$V_d = V_0 \left(1 - e^{-\frac{t_c}{RC}}\right)$$

$$70 = 100 \left(1 - e^{-\frac{500 \times 10^{-6}}{R \times 100 \times 10^{-6}}}\right)$$

$$R = 4.15 \Omega$$

↑  
Charging resistance



There is another problem. Consider the following data regarding RC circuit in the EDM:

Open circuit voltage = 100 V

Maximum discharging voltage = 70 V

Capacitance = 100  $\mu$ F

Calculate the charging resistance for the idle time of 500  $\mu$ s.

Solution:

$$V_d = \left(1 - e^{-\frac{t}{RC}}\right)$$

$$70 = 100 \left(1 - e^{-\frac{500 \times 10^{-6}}{R \times 100 \times 10^{-6}}}\right)$$

$$R = 4.15 \Omega$$

So, I have taken very basic problems and examples using the very basic formulas or relationships. Which are there in these three processes that I have used or taken in this lecture. There are details; each of the processes itself has its own complete book written.

So, that is the details of mechanical engineering or details of non-conventional processes. Or maybe you can read a book on electrochemical machining itself or maybe a research paper booklet.

That is available handbook on these as well, which are available. So, this was about the non-conventional machining processes. I will now take the demonstration of the non-conventional machining or virtual laboratory demonstration in the next lecture. And we will close this week. Thank you.