Basics of Mechanical Engineering-2

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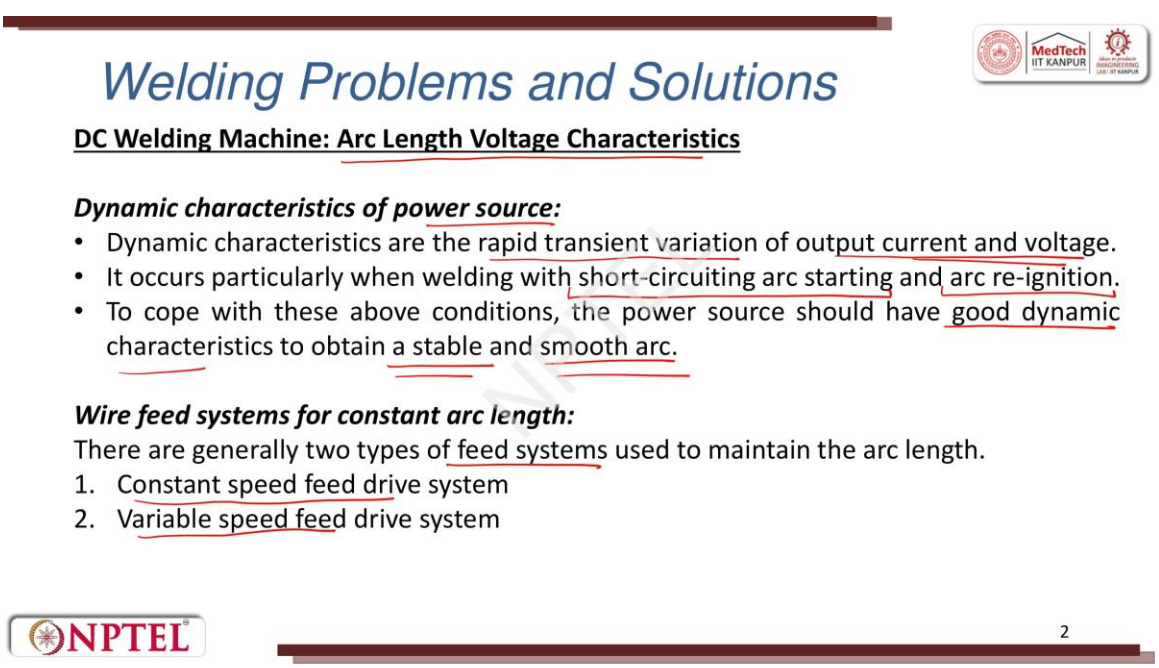
Week 08

Lecture 31

Tutorial-4 (Welding)

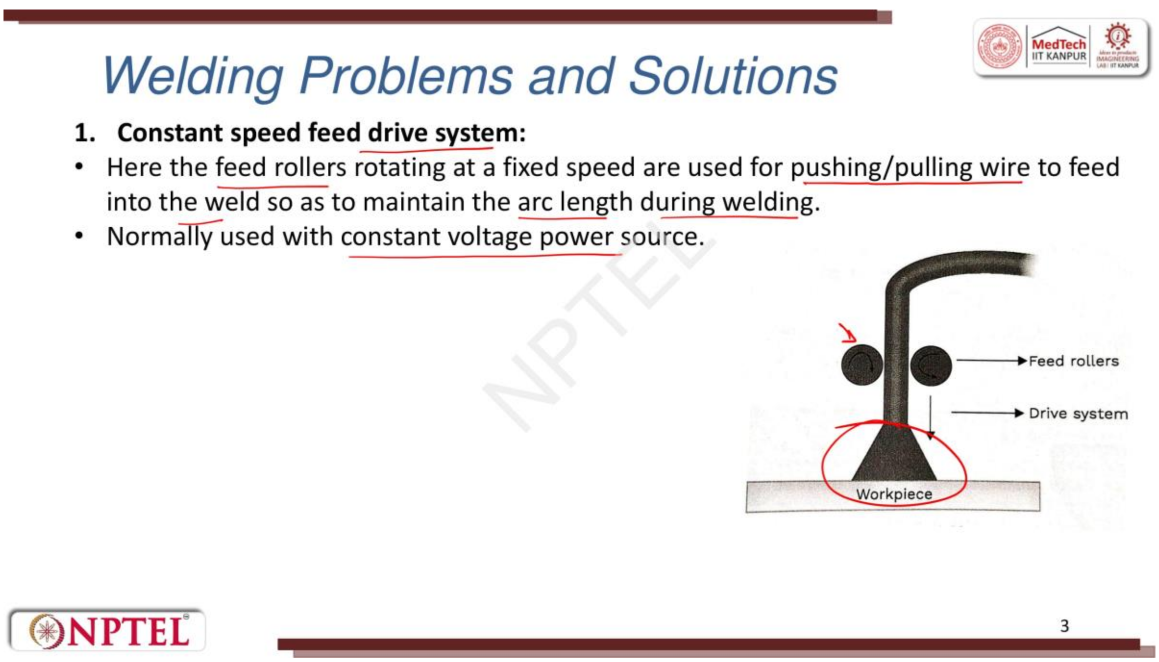
Welcome to the tutorial session on welding. We discussed the theory part of welding last week and earlier this week. Welding is of various kinds; it could be gas welding or arc welding, usually. When arc welding is discussed, we always require an electricity supply because an arc is generated due to the voltage difference between the workpiece and the electrode.

There are certain problem statements we will explore, such as what kind of welding to choose, the voltage and current settings, and the heat generated or dissipated during the welding process. We will walk through this during the lecture. Tutorial session on welding. I am Dr. Amandeep Singh Oberoi from the Indian Institute of Technology, Kanpur.

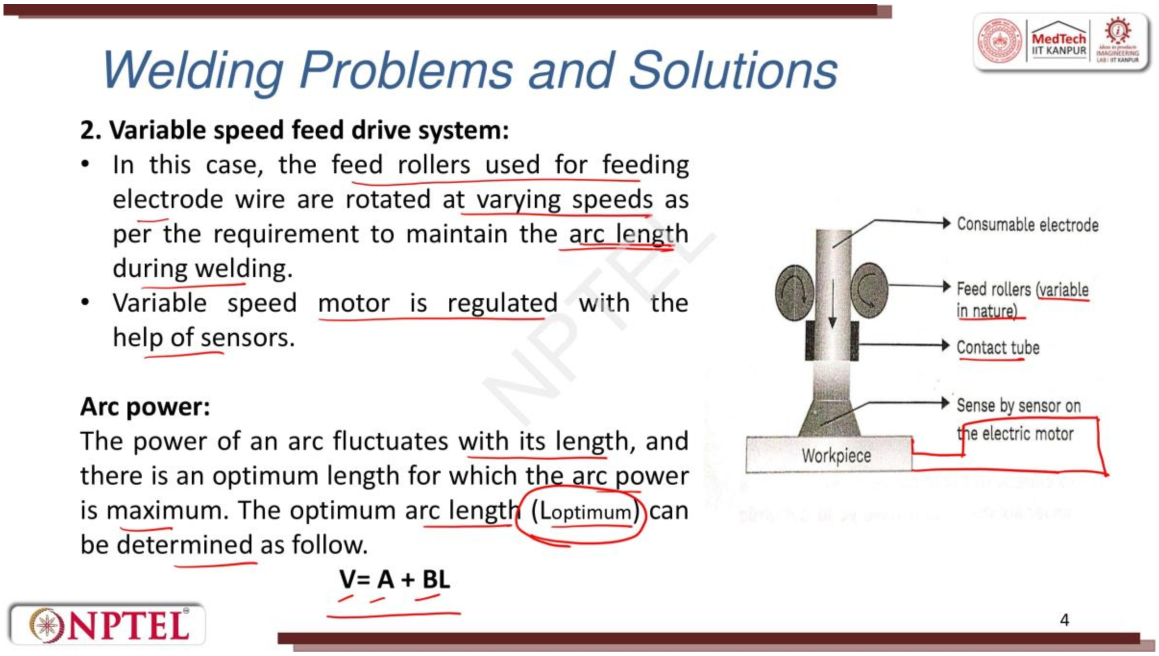


Let me go through the concept of the DC welding machine, which is arc length voltage characteristics. Dynamic characteristics of the power source refer to the rapid transient variations of output current and voltage.

These occur particularly when welding with a short-circuiting arc, starting an arc recognition. To cope with these conditions, the power source should have good dynamic characteristics to ensure a stable and smooth arc for optimal welding. Wire feed systems for constant arc length. There are generally two types of feed systems. To maintain the arc length, there are constant-speed feed drive systems and variable-speed feed drive systems.

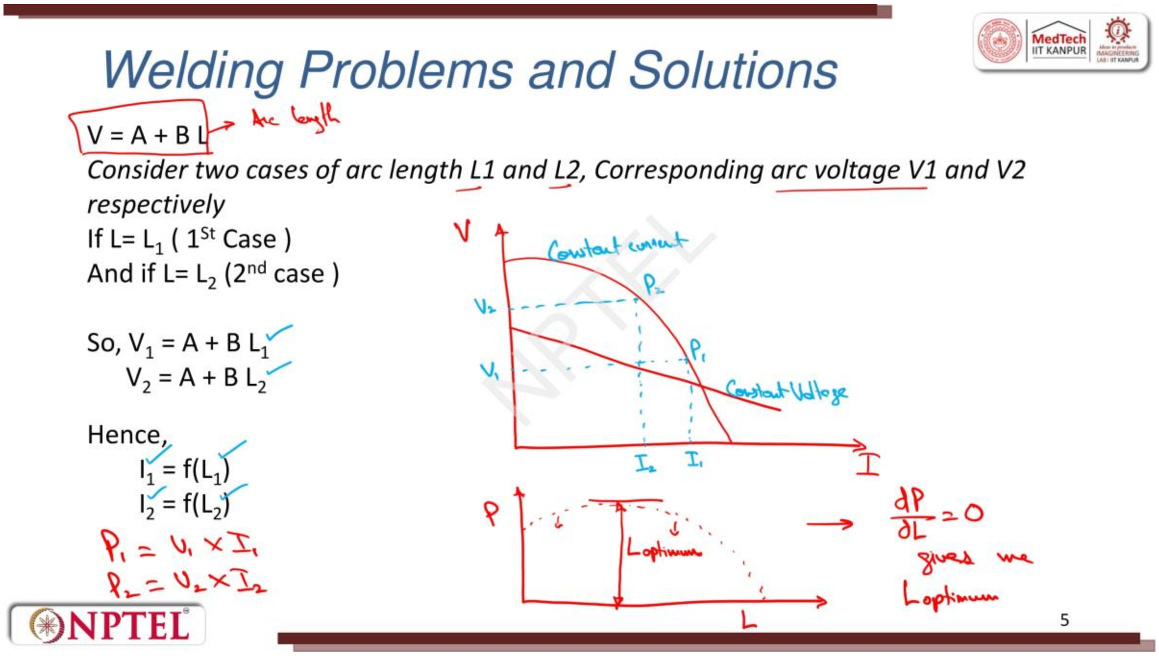


What are these two? Constant speed feed drive systems are having feed rollers that rotate at a fixed speed and are used for pushing or pulling the wire to feed into the weld so as to maintain the arc length during welding. So this is feed roller that is running at a constant speed and these are drive systems. This is my arc that is there. Normally used with constant voltage power source.



On the other hand, we have variable speed drive system. In this case, feed roller used for feeding electrode wire are rotating at varying speeds as per the requirements to maintain the arc length during welding. So, it is rotated at varying speed. There is a contact tube. So, depending upon the arc length required, whether the thickness of the work piece is varying, it is becoming smaller at some point, it is becoming further larger at certain points.

So, depending upon the arc requirements, the speed of the rollers monitors the arc length. Variable speed motor is regulated with the help of sensors. Now arc power is calculated here. Arc power of an arc fluctuates with its length and there is an optimum length for which the arc power is maximum. The optimum arc length and optimum can be determined as follows. We have here V = A + BL. It is known as the characteristic curve.



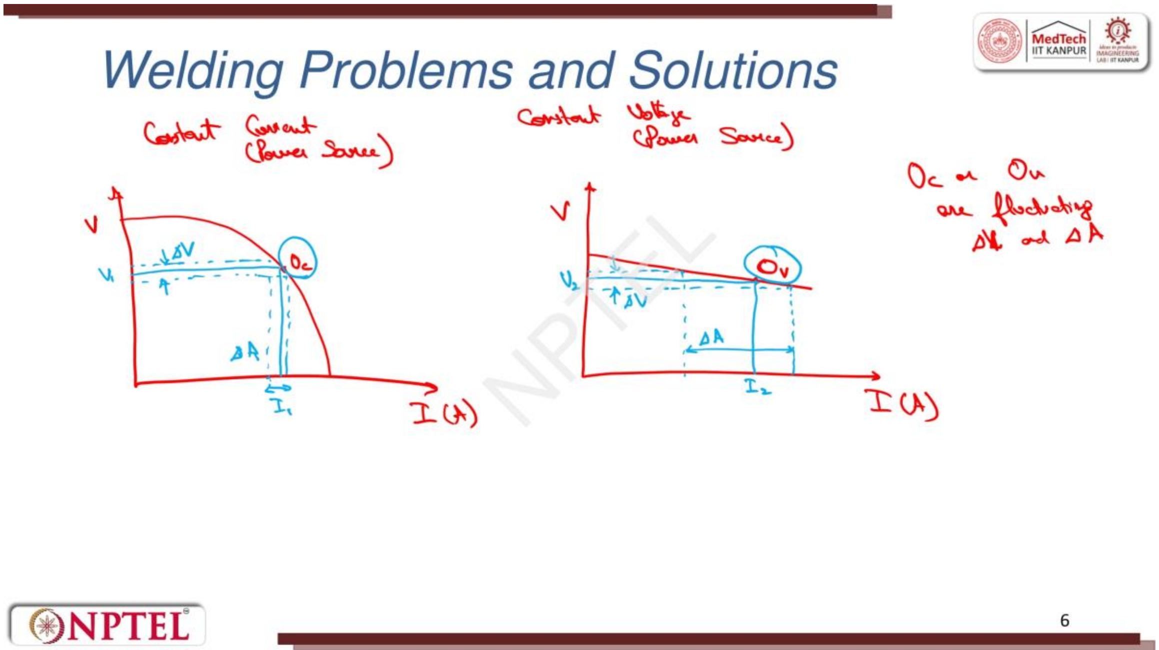
To explain it further, L is my arc length. Consider two cases of arc length L1 and L2, corresponding to arc voltages V1 and V2, respectively. This is something like this.

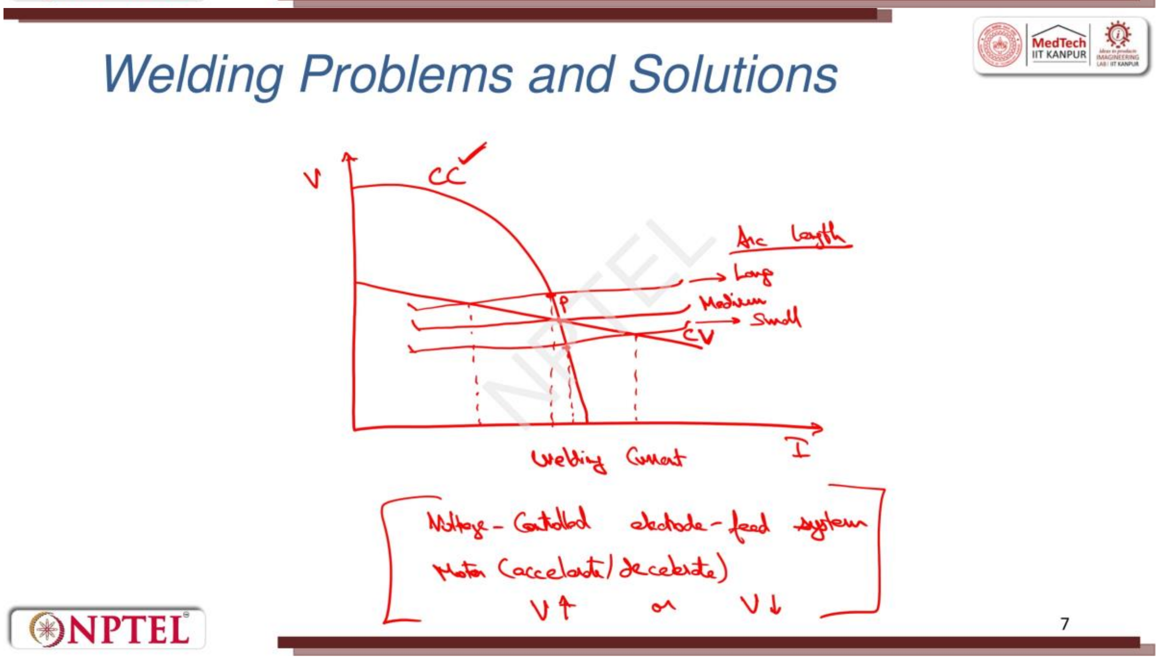
We have the voltage versus current plot (V and I), and this is a curve. It is a kind of quadratic equation curve where I can put two instances. This is the first instance, and this is the second instance. I will name this as I1, and here I have V1 correspondingly, and this point I will say is P1. Another point P2 has a corresponding voltage V2 and a corresponding current I2. So, if L = L1 in the first case and L = L2 in the second case, this is the arc length that is there.

This is a constant current power supply. I will write it here: constant current power supply. Here, V1 = A + BL1, V2 = A + B L2, and current is a function of the arc length, that is, I1 is a function of L1 and I2 is a function of L2. That is there, and if we need to calculate the power, which I showed you as the L optimum. This optimum power, if I need to calculate or find it, is something like this here.

If I plot my power with respect to length L, this is how the power curve would look. The optimal power would be here when it is highest at this point. That means this length is L optimum. Now, if I put here, P1 = V1I1 and P2 = V2I2. Then at this point, if I take the derivative of power with respect to L, it should be 0 because the slope on both directions is coming down. So, that means from this case, I could write equating the derivative of power with respect to L, this is 0, I can find L optimum. So, about the characteristic curve, there is a very interesting finding. There could be a constant current curve. There could also be a constant voltage curve. It is something like this. I will put it here. This is the constant voltage curve.

In the constant voltage curve, with a very small variation in voltage, the current variation is very high. And in the constant current curve, a small variation in current does not lead to a very high variation in voltage. I will show you how. I will just redraw this figure, the constant current and constant voltage curves, and show you how it varies.





It is something like this. So, it could be two cases. Constant current. I am talking about the power source or it could be constant voltage power source. So this is something like this. If I plot voltage and current here, constant current curve as you saw in the previous slide, it is something like this. So, if this is suppose the constant voltage curve, it is something like this. Now, suppose if this is the point where we are operating, one point here, one point here, I am naming this point as operating point for constant current and this is operating point for constant voltage.

So, I have current this side and voltage this side units of current are amperes. Here if I try to plot see this is a constant current curve. And we suppose there is a variation in voltage. This is voltage where I am suppose working on voltage V1 and this is a variation in the voltage. Corresponding variation in current would be this much only.

That is if this is dV and dA, change in amperes, this is small. However, in the case of the constant voltage at point Ov, if suppose there is small change in voltage, let me first locate the points, this is voltage V2 and current I2, I will name this as current I1. Here the small variation in voltage you see, corresponding current variation is very high. That means this is my dA and this is my dV. The arc voltage is directly proportional to length of arc that we have seen here.

Consequently, the arc voltage is regulated by altering the arc length. The arc striking voltage has a minimal threshold and open circuit voltage of the power source is evidently greater than this threshold. That is why, that is how and that is when the welding happens, when the voltage is greater than the minimum threshold so that the melting and welding does happen. To comprehend the mechanics of arc maintenance, we can have a constant voltage curve or constant current conditions I have mentioned here. The point at which arc voltage intersects with voltage source curve is referred as, so this is the operating point, that is the point where the voltage source, intersects with the voltage curve.

So, this is fluctuating point always I am just I am putting here is Oc or Ov are fluctuating that means, dV and dA are the change in the current. In that case of the constant voltage power source with a fixed V wire feed speed. Let me draw another curve here. For example, it is something like this. Just to show you how the variation is happening.

We have a constant current here and in this curve itself I draw the constant voltage. Now you know this. This is constant current Cc. I am naming this as constant voltage. I am naming this as Cv.

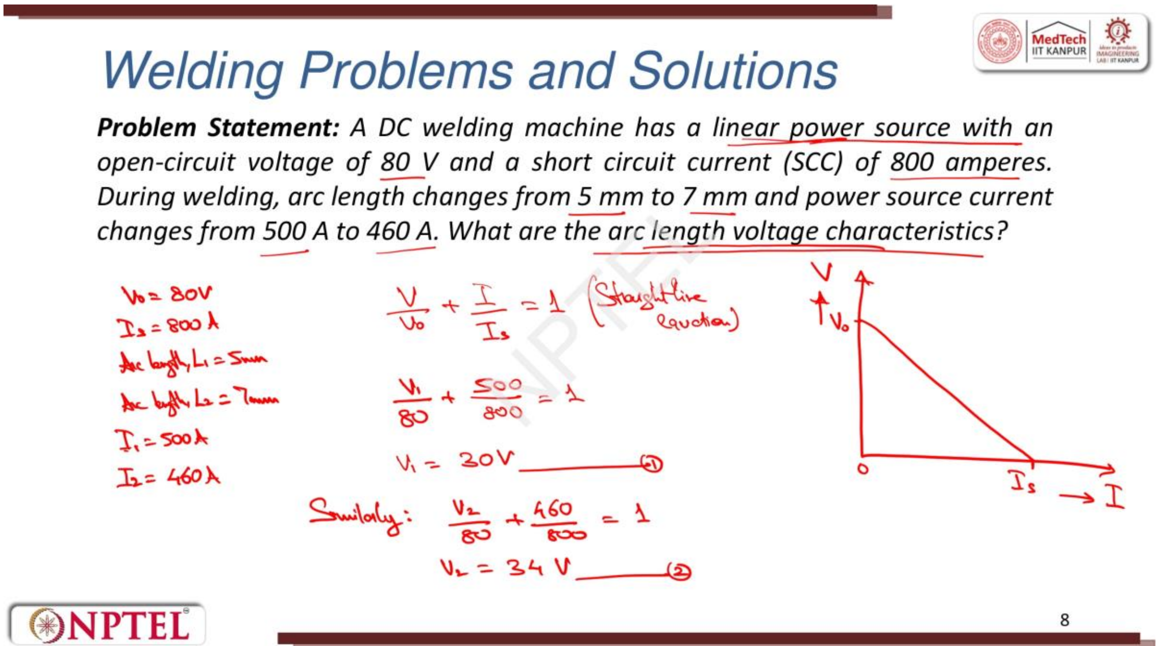
Now, suppose there is a point P. I am plotting V and I once again. This point could be represented here. If I say this is my medium arc length, there are fluctuations from here in the current or in the voltage. So, these are the corresponding arc lengths. This is a small arc length; this is a long arc length. I am talking about arc length.

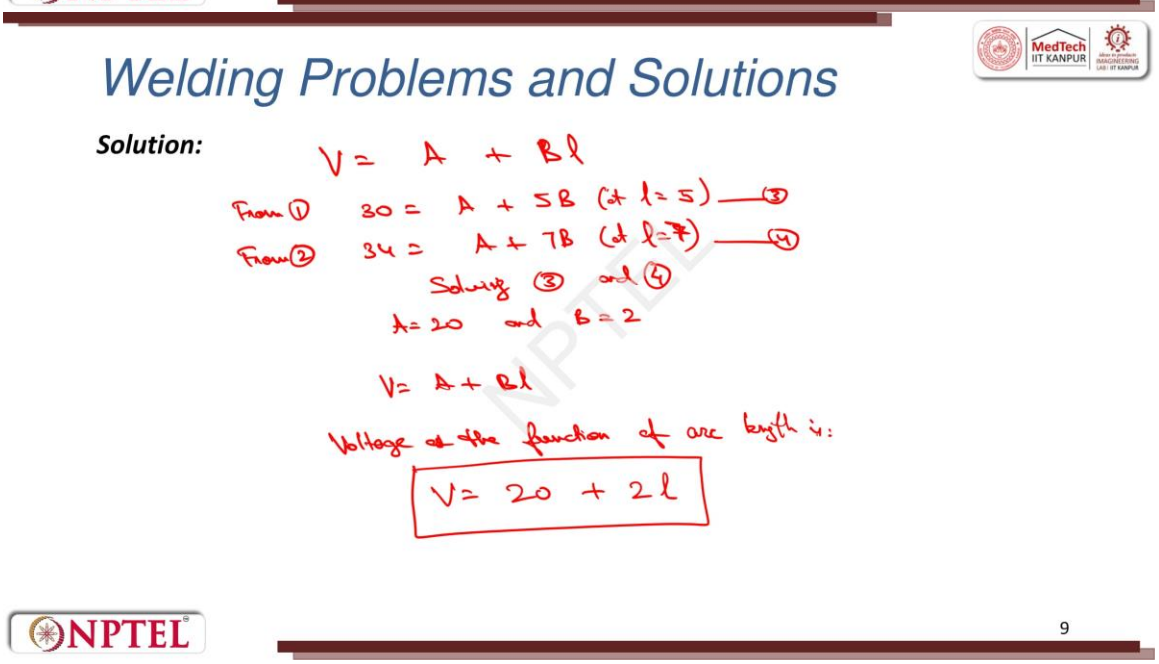
Now, with respect to this length, this is the change in the current from here. And also, with respect to the smaller length, this is the change in the current. So, this is the welding current. So, in the case of this concept, we have a voltage power source with a fixed wire feed speed. At point P, a minor reduction in arc length causes a slight fall in the arc voltage, which leads to a comparatively significant rise in the welding current, as I have shown here.

A substantial rise in the current accelerates the melt-off rate, extending the arc length and thereby restoring the arc voltage to its normal operating level. So, this is in the case of the constant voltage power source. In the case of the constant current power source with a steady wire feed speed, a comparable sequence of events occurs, meaning the variation in current is significantly reduced, resulting in a prolonged duration for the system to achieve self-regulation.

The self-regulating system that we are talking about still has fluctuations, but the system is trying to self-regulate so that the arc length is maintained. In the constant current system, the variation in the current is significantly diminished. This indicates the welder has minimal or no control over the current by adjusting the arc length. So, that is why the voltage is more varied whenever we try to control it. So, this can be corrected by a voltage-controlled electrode feed control system.

That is, if there is a change in voltage, whether rise or fall, the motor accelerates or decelerates to maintain a consistent arc length. So, we apply here a voltage-controlled electrode feed system. Where the motor accelerates or decelerates depending upon the voltage rise or voltage fall. Now, to explain this, let me come to a problem statement. And the problem statement would also help you to understand how we calculate or how we find the characteristic of the curve.





A DC welding machine has a linear power source with an open-circuit voltage of 80 volts and a short-circuit current of 800 amperes. During welding, the arc length changes from 5 millimeters to 7 millimeters, and the power source current changes from 500 amperes to 460 amperes. What are the arc length voltage characteristics?

Given:

$V_o = 80$ V

$I_o = 800$ A

$L_1 = 5$ mm

$L_2 = 7$ mm

$I_1 = 500$ A

$I_2 = 460$ A

Solution:

$V/V_o + I/I_o = 1$ (Straight Line Equation)

$V_1/80 + 500/800 = 1$

$V_1 = 30$ V (1)

$V_2/80 + 460/800 = 1$

$V_2 = 34$ V (2)

$V = A + Bl$

From (1) $30 = A + 5B$ (at $l = 5$) (3)

From (2) $34 = A + 7B$ (at $l = 7$) (4)

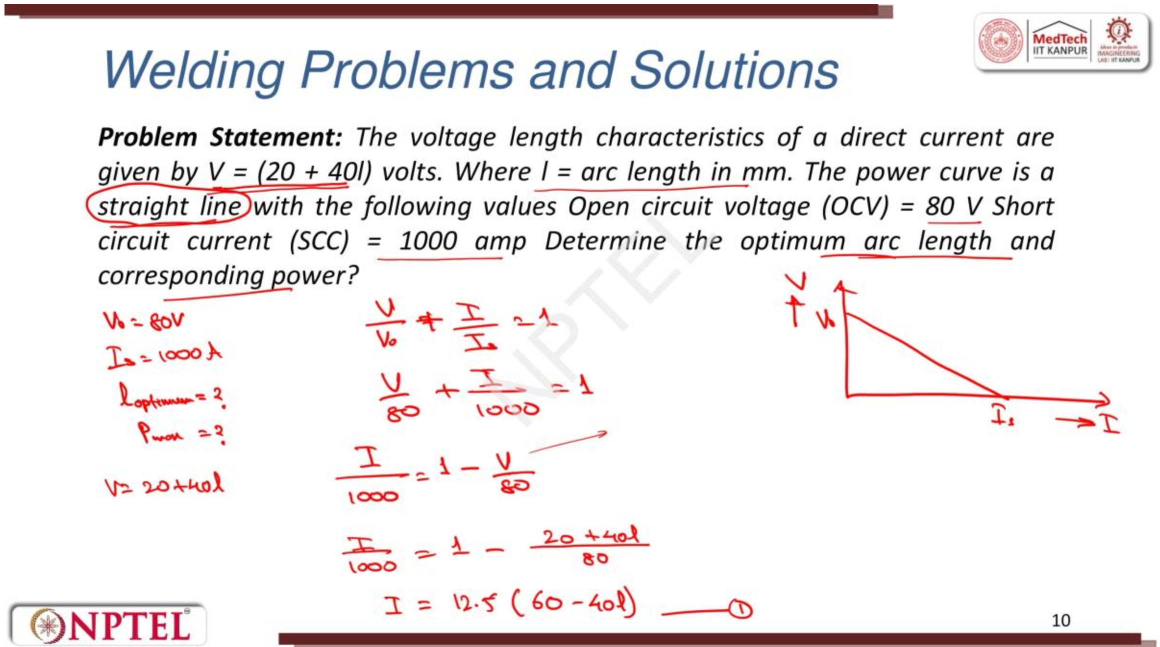
Solving (3) and (4)

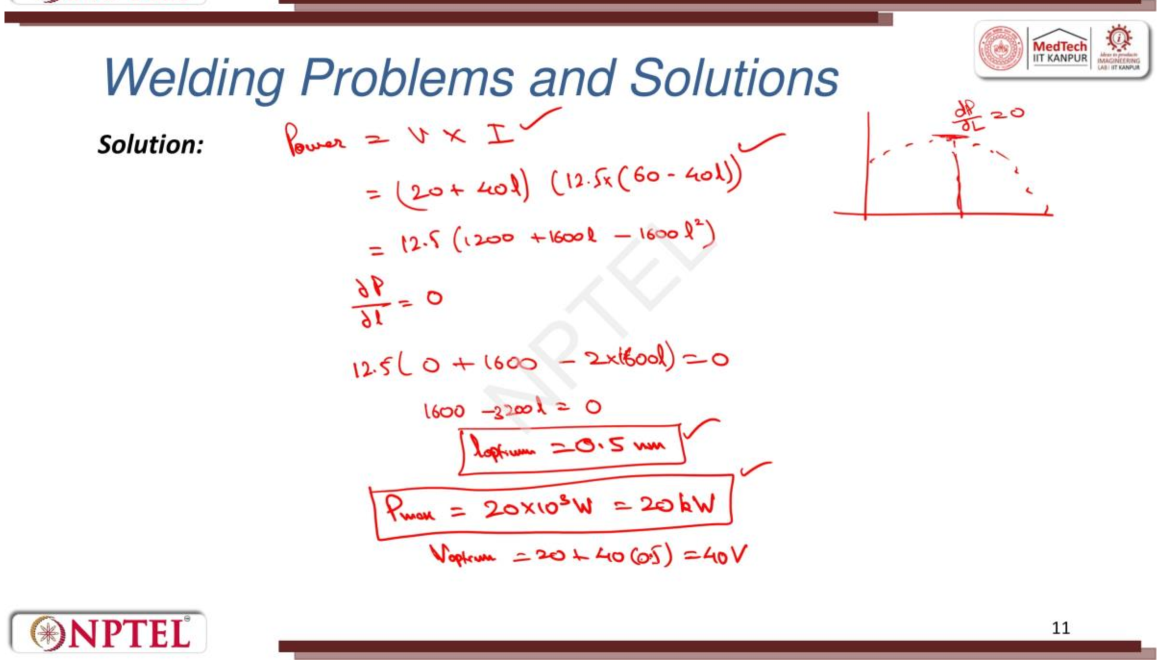
$A = 20$ and $B = 2$

$V = A + Bl$

Voltage and function of arc length is:

$V = 20 + 2l$ (Ans.)





Similarly, this is a problem statement The voltage length characteristics of a direct current are given by V = (20 + 40l) volts. Where l = arc length in mm. The power curve is a straight line with the following values Open circuit voltage (OCV) = 80 V Short circuit current (SCC) = 1000 amp. Determine the optimum arc length and corresponding power?

Given:

V = 80 V

Is = 1000 A

L optimum = ?

P = ?

V = 20 + 40l

Solution:

V/Vo + I/Is = 1

V/80 + I/1000 = 1

I/1000 = 1 – V/80

I/1000 = 1 - $\frac{20+40l}{80}$

I = 12.5 (60 – 40l)   (1)

P = V x I

= (20 + 40l) (12.5 (60 – 40l))

= 12.5 (1200 + 1600l – 1600l^2)

dP/dl = 0

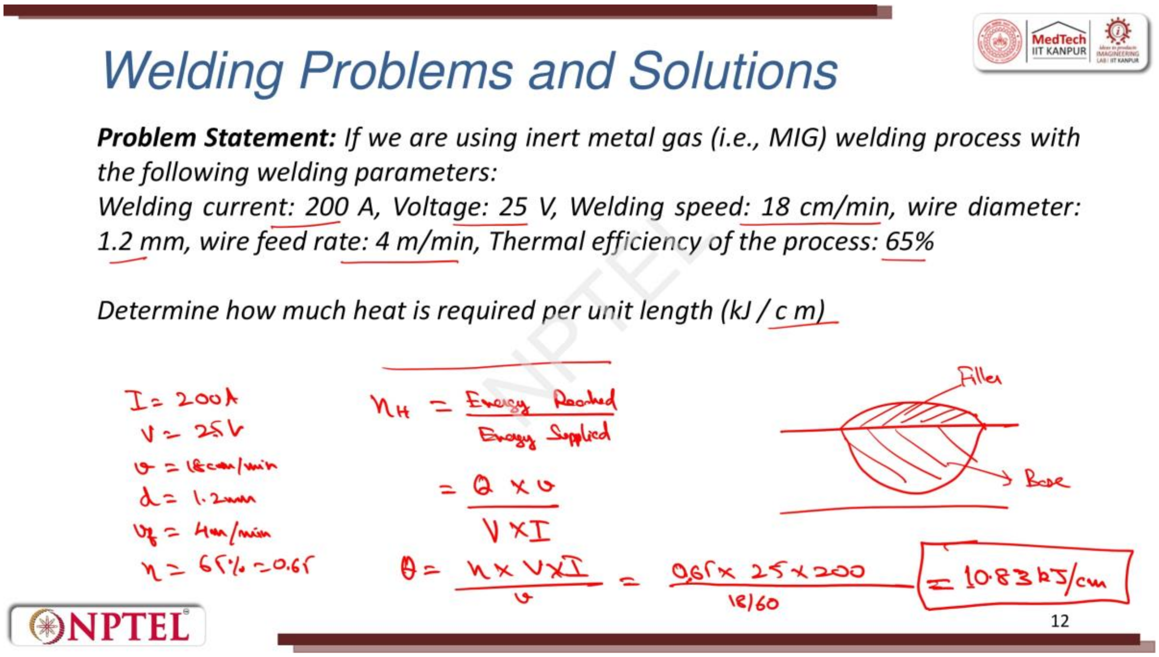
= 12.5 (0 + 1600 – 2 x 1600l) = 0

1600 – 3200l = 0

l optimum = 0.5 mm (Ans.)

P = 20 x 10^3 W = 20 kW (Ans.)

V optimum = 20 + 40 (0.5) = 40 V



Here, we are using an inert metal gas welding process with the following parameters:

Given:

I = 200 A

V = 25 V

v = 18 cm/min

d = 1.2 mm

vf = 4 m/min

η = 65% = 0.65

$\eta H = \frac{Energy\ Reached}{Energy\ Supplied}$

$= \frac{Q \times v}{V \times I}$

$$\theta = \frac{\eta \times V \times I}{v} = \frac{0.65 \times 25 \times 200}{\frac{18}{60}} = 10.83\ kJ/cm$$

Welding Problems and Solutions

Heat Terms involved and Melting Efficiency of Weld Nugget

Area of Weld Nugget (A) = $\frac{\pi}{4} \times (d_o^2 - d_i^2)$

Volume of the weld nugget(vol.) = A × b

Heat supplied by power source (H) = $I^2Rt = (\frac{V}{R})^2 t$

Power Supplied by source (P) = VI = $I^2R = \frac{H}{t}$

Heat Required for welding (H_r) = Sensible heat required + Latent Heat required

Sensible heat required (Qs) = m ×C × (Δ T)

Latent heat required of Melting (QL) = m × (LH)

Heat Required to melt the nugget per unit volume (H_m) = Q

The total heat required to melt the entire volume of the nugget = Q×vol.

Melting Efficiency = η_m = $\frac{\text{Heat required to melt total volume of Nugget = Q×vol.}}{\text{Heat supplied by power source (H) = } I^2Rt = (\frac{V}{R})^2 t}$

Welding Problems and Solutions

If in a question Melting efficiency not given assume that 100%

⇒ Melting Efficiency = η_m = 100%

$$\Rightarrow \frac{\text{Heat required to melt total volume of Nugget = Q×vol.}}{\text{Heat supplied by power source (H) = } I^2Rt = (\frac{V}{R})^2 t} = 1$$

⇒Heat supplied by power source (H) = Heat required to melt total volume of Nugget

Where

I = Welding Current or Supplied current to weld interface

V= Welding Voltage or Voltage current to weld interface

R= Resistance

t= time period of heating the weld interface

b = width of Nugget or depth of the Nugget(= h)

d_o = Outer diameter of Hollow tube/ pipe

d_i = Inner diameter of Hollow tube/ pipe

Welding Problems and Solutions

A = Area of Weld Nugget

vol.= Volume of the weld nugget = A × b

m= Mass of weld nugget = Density of weld nugget (ρ) × Volume of Nugget (vol.)

C= Specific heat of the nugget

ΔT = difference between Melting Temperature(T_m) and Ambient Temperature(T_o)

LH = latent heat of melting per unit mass of weld nugget

Q = Heat Required to melt per unit volume (H_m)

H = Heat supplied by power source

η_m = Melting Efficiency

So, here heat terms involved in welding efficiency of weld nugget as we might have discussed in the previous lectures.

Area of Weld Nugget (A) = $\frac{\pi}{4} \times (d_o^2 - di^2)$

Volume of the weld nugget(vol.) = A × b

Heat supplied by power source (H) = $I^2Rt = (\frac{V}{R})^2 t$

Power Supplied by source (P) = $VI = I^2R = \frac{H}{t}$

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The total heat required to melt the entire volume of the nugget = Q×vol.

Melting Efficiency = ηm = $\frac{\text{Heat required to melt total volume of Nugget} = Q \times vol.}{\text{Heat supplied by power source (H)} = I^2Rt = (\frac{V}{R})^2 t}$

If in a question Melting efficiency not given assume that 100%

- ⇒ Melting Efficiency = η_m = 100%
- ⇒ $\frac{\text{Heat required to melt total volume of Nugget} = Q \times vol.}{\text{Heat supplied by power source (H)} = I^2Rt = (\frac{V}{R})^2 t} = 1$
- ⇒ Heat supplied by power source (H) =
  Heat required to melt total volume of Nugget

Where

I = Welding Current or Supplied current to weld interface

V= Welding Voltage or Voltage current to weld interface

R= Resistance

t= time period of heating the weld interface

b = width of Nugget or depth of the Nugget(= h)

d_o = Outer diameter of Hollow tube/ pipe

d_i = Inner diameter of Hollow tube/ pipe

A = Area of Weld Nugget

vol.= Volume of the weld nugget = A × b

m= Mass of weld nugget = Density of weld nugget (ρ) × Volume of Nugget (vol.)

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ΔT = difference between Melting Temperature (T_m) and Ambient Temperature (T_o)

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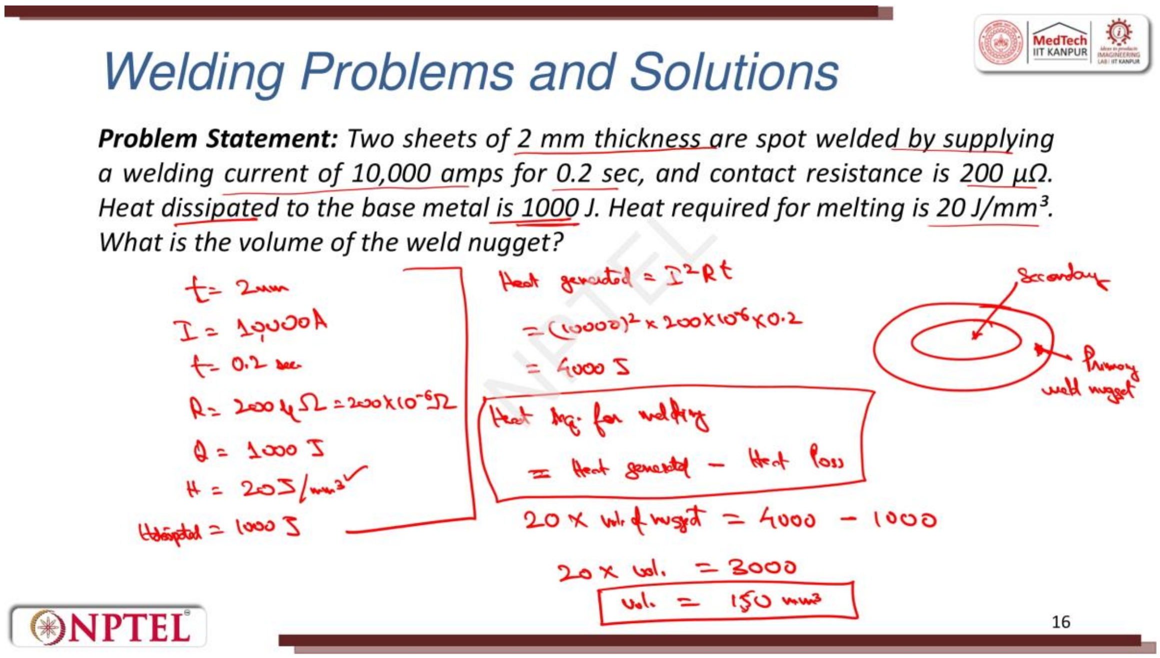


Let me come to the problem statement. Two sheets of 2 mm thickness are spot welded by supplying a welding current of 10,000 amps for 0.2 sec, and contact resistance is 200 μΩ. Heat dissipated to the base metal is 1000 J. Heat required for melting is 20 J/mm³. What is the volume of the weld nugget?

Given:

t = 2 mm

I = 10,000 A

T = 0.2 sec

R = 200 μΩ

Q = 1000 J

H = 20 J/m^2

H dissipated = 100 J

Solution:

Heat generated = I^2Rt

= $(10000)^2 \times 200 \times 10^{-6} \times 0.2$

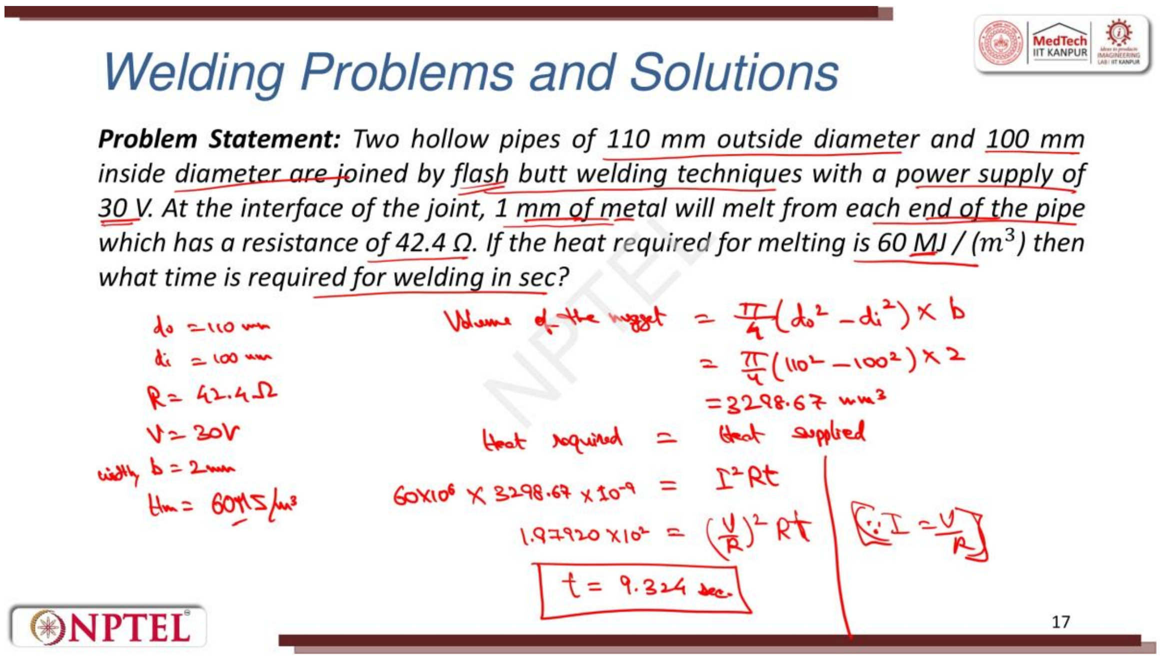
= 4000 J

Heat required for melting = Heat generated – Heat possessed

= 20 x vol. of weld nugget = 4000 – 1000

= 20 x vol. = 3000

Vol. = 150 mm^3 (Ans.)



The next problem is: Two hollow pipes of 110 mm outside diameter and 100 mm inside diameter are joined by flash butt welding techniques with a power supply of 30 V. At the interface of the joint, 1 mm of metal will melt from each end of the pipe which has a resistance of 42.4 Ω. If the heat required for melting is 60 MJ / (m^3) then what time is required for welding in sec?

Given:

do = 100 mm

di = 100 mm

R = 42.4 Ω

V = 30 V

With, b = 2 mm

Heat req. for melting = 60 MJ / (m^3)

Solution:

Volume of the nugget = $\frac{\pi}{4} \times (d_o{}^2 - di^2)$ x b

= $\frac{\pi}{4} \times (100^2 - 100^2)$ x 2

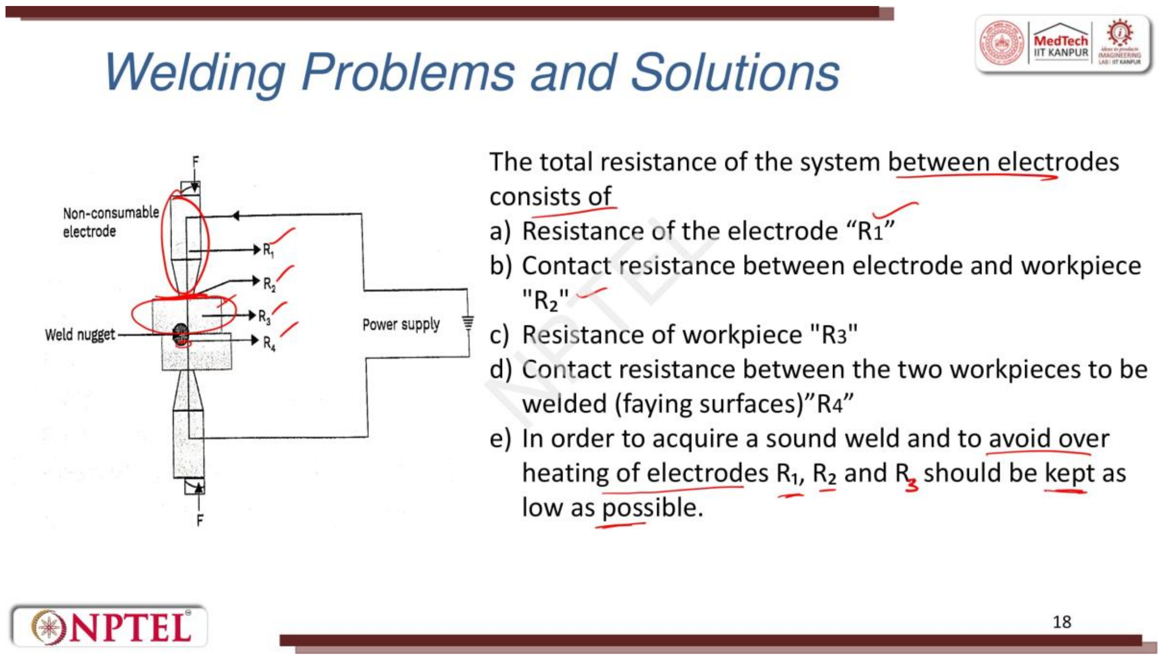
= 3298.67 mm^2

Heat required = Heat supplied

60 x 10^6 x 3298.67 x 10^{-9} = I^2Rt

1.97920 x 10^2 = $\left(\frac{V}{R}\right)^2 Rt$ (Since I = V/R)

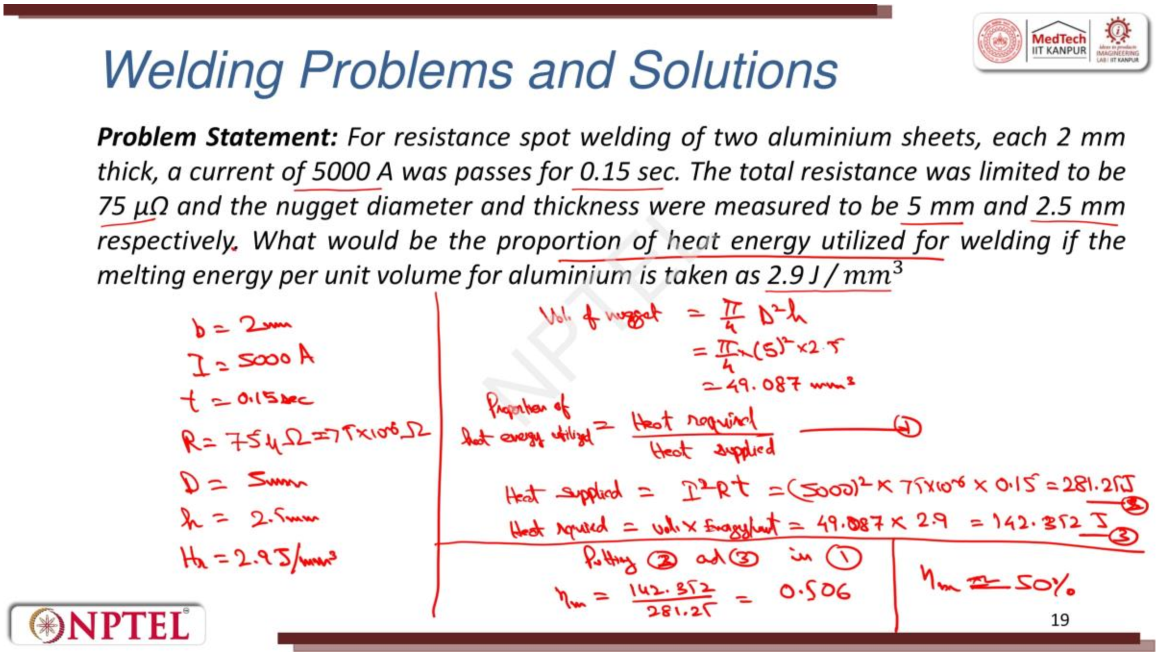
t = 9.324 sec (Ans.)



Another analogy that I will have to touch here is in the resistance welding. No more numerical problem I will take. Here we have been given a spot welding setup, in which the total resistance of the system between electrodes consists of the following parts: R1, R2, R3, and R4. R1 is from the non-zero electrode, and R4 comes down to the weld nugget.

So, R1 is the resistance of the electrode. The contact resistance between the electrode and the workpiece is R2. It is at the contact here. R2 is here. The resistance of the workpiece is R3.

See, this is electrode. This is our workpiece. Contact resistance between the two workpieces to be welded at its faying surfaces is R4. This is R4 here. In order to acquire a sound weld and to avoid overheating electrodes, R1, R2, and R3 should be kept as low as possible.



So, this last problem statement. For resistance spot welding of two aluminium sheets, each 2 mm thick, a current of 5000 A was passes for 0.15 sec. The total resistance was limited to be 75 μΩ and the nugget diameter and thickness were measured to be 5 mm and 2.5 mm respectively. What would be the proportion of heat energy utilized for welding if the melting energy per unit volume for aluminium is taken as 2.9 J / mm^3.

Given:

B = 2 mm

I = 5000 A

t = 0.15 sec

R = 75 μΩ = 5 x 10^{-6}

D = 5 mm

H = 2.5 mm

Hr = 2.9 J / mm^3

Vol. of nugget = $\frac{\pi}{4} D^2h$

$= \frac{\pi}{4} \times 5^2 \times 2.5 = 49.087\ mm^3$

Proportion of heat energy utilized = Heat required / Heat supplied (1)

Heat supplied = $I^2Rt = (5000)^2 \times 75 \times 10^{-6} \times 0.15 = 281.25$ J (2)

Heat required = Vol. x Energy heat = 49.087 x 2.9 = 142.352 J (3)

Putting (2) and (3) in (1):

$\eta_m = \frac{142.352}{281.25} = 0.506$

$\eta_m = 50\%$

And I will now take the virtual laboratory demonstration in the next lecture on welding.

Thank you.