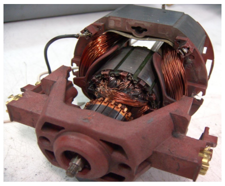


فصل سوم

بررسی ساختمان و اساس کار و مشخصات ماشینهای DC

جلسه اول

در این فصل مطالب مربوط به ماشینهای DC را شروع می کنیم:

مطالب این فصل به شرح زیر است:

- ۱- ماشینهای DC خطی
- ۲- ماشینهای DC خطی در عملکرد موتوری و ژنراتوری
- ۳- مروری بر مدارهای مغناطیسی و الکتریکی ماشینهای DC
- ٤- شروع فهم عملکرد یک ماشین DC با چرخش یک حلقه ساده بین قطبهای مغناطیسی
- ٥- بررسی اجزای تشکیل دهنده ماشینهای DC
- ٦- کموتاسیون و بررسی مسایل مربوط به آن در ماشینهای DC واقعی
- ۷- سیم بندی استاتور و روتور (آرمیچر) در ماشینهای DC
- ۸- روابط مربوط به ولتاژ و نیرو و گشتاور در ماشینهای DCواقعی
- ۹- دیاگرامهای مربوط به توانهای ورودی و خروجی و تلفات و راندمان در ماشینهای DC
- ۱۰-تمرینهای مختلف

- **Fundamentals of dc machines:**
  - – The linear dc machine,
  - – Linear dc machine as motor and generator,
  - – **Electric** circuit and magnetic circuit aspect of DC machines,
  - – Simple rotating loop between two curves pole faces,
  - – Commutation,
  - – problem with commutation in real dc machine,
  - – The internal generated voltage and induced torque equation of real dc machine,
  - – The construction of real dc machine,
  - – Power flow and losses in a real dc machine

تقسیم بندی ماشینهای DC به دو گروه موتور و ژنراتور

- **۱- ژنراتورهای DC**
  - **۱-۱ تقسیم بندی ژنراتورهای DC**
  - **۱-۲ مدار معادل الکتریکی معادل هر کدام**
  - **۱-۳ منحنی مغناطیسی و بی باری ژنراتورها**
- **۲- موتورهای DC**
  - **۲-۱ مدار معادل الکتریکی**
  - **۲-۲ انواع موتورهای الکتریکی**
  - **۲-۳ روابط گشتاور و سرعت و کنترل سرعت در موتورهای DC**

- **DC motors:**
  - – Equivalent circuit,
  - – Type of dc motors,
  - – DC motor efficiency.
  - – Mathematical model of dc motor
- **DC generators**:
  - – Equivalent circuit,
  - – Magnetization curve,
  - – Types of dc-generators
- **Special Machine:**
  - – Reluctance Motors
  - – Stepper Motors,
  - – Hysteresis Motors.
  - – Examples of Industrial Applications of DC Machines

(میدان مغناطیسی)

دیدیم که میدان مغناطیسی از مکانیزمهای اساسی هستند که انرژی از شکلی به شکل دیگر تبدیل می گردند. (در موتورها – ژنراتورها – ترانسفورماتورها)

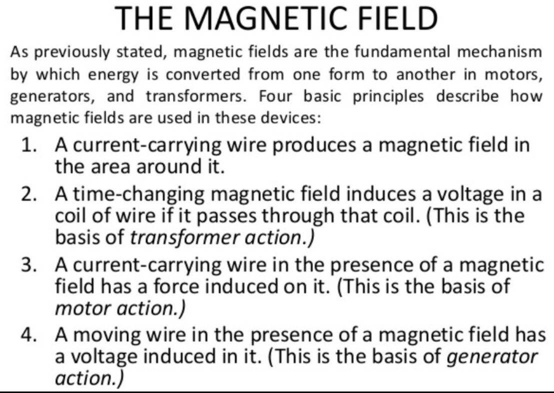
چهار اصل اساسی زیر چگونگی استفاده از میدان های مغناطیسی در این تجهیزات تبدیل انرژی را مشخص می نماید.

$$1\text{-}H = (I/2\pi R)\ \text{A/m} \rightarrow B=\mu H \rightarrow \Phi = B\times A\ \text{Wb}$$

$$2\text{-}e_{ind} = N(d\Phi/dt)\ \text{volt}$$

$$3\text{-}F = i(l\times B)\ \text{N}$$

$$4\text{-}e_{ind} = (V\times B).l\ \text{Volt}$$



THE MAGNETIC FIELD

As previously stated, magnetic fields are the fundamental mechanism by which energy is converted from one form to another in motors, generators, and transformers. Four basic principles describe how magnetic fields are used in these devices:

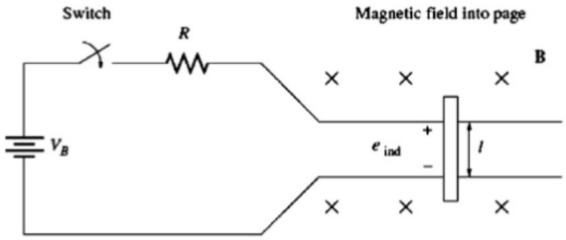
1. A current-carrying wire produces a magnetic field in the area around it.
2. A time-changing magnetic field induces a voltage in a coil of wire if it passes through that coil. (This is the basis of *transformer action.)*
3. A current-carrying wire in the presence of a magnetic field has a force induced on it. (This is the basis of *motor action.)*
4. A moving wire in the presence of a magnetic field has a voltage induced in it. (This is the basis of *generator action.)*

بررسی یک ماشین DC خطی برای فهم عملکرد ماشینهای DC :

شرح اجزای یک ماشین DC خطی

THE LINEAR DC MACHINE

A linear dc machine is shown in Figure. It consists of a battery and a resistance connected through a switch to a pair of smooth, frictionless rails. Along the bed of this "railroad track" is a constant, uni form-density magnetic field directed into the page. A bar of conducting metal is lying across the trac

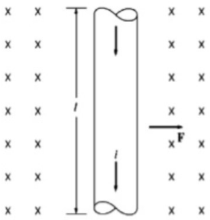


عملکرد یک ماشین DC خطی بر اساس چهار اصل اساسی زیر استوار است

اصل ۱ - تولید نیروی القایی در یک هادی حامل جریان در حضور یک میدان مغناطیسی

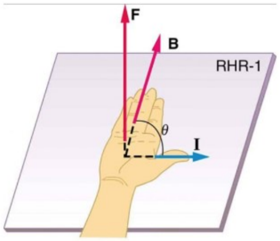
- A magnetic field on its surroundings induces a force on a current-carrying wire within the field.

$$\mathbf{F} = i(\mathbf{l} \times \mathbf{B})$$



در شکل بالا طول l به عنوان یک بردار عمود بر جهت بردار میدان B (که عمود بر صفحه می باشد) قرار گرفته لذا:

$$\mathbf{F} = \mathbf{ilB}\ \mathrm{N}$$



$F = I\ell B\sin\theta$

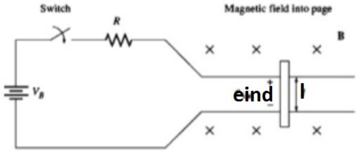
F ⊥ plane of I and B

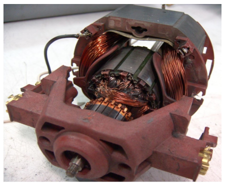
PRODUCTION OF INDUCED FORCE ON A WIRE

1. The equation for the force on a wire in the presence of a magnetic field:

$$\boxed{\mathbf{F} = i(\mathbf{l} \times \mathbf{B})} \qquad (1\text{–}43)$$

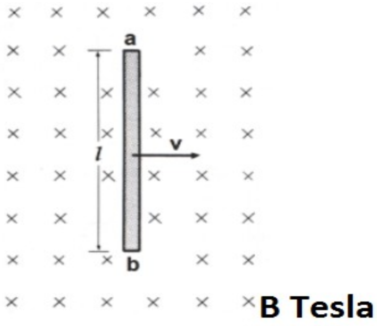
where **F** = force on wire
i = magnitude of current in wire
l = length of wire, with direction of **l** defined to be in the direction of current flow
B = magnetic flux density vector





اصل دوم :

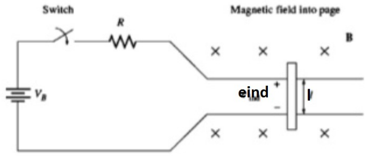
نیروی محرکه القایی در یک هادی به طول l مترکه با سرعت V متر بر ثانیه در یک میدان مغناطیسی به چگالی شار B تسلا حرکت می کند



2. The equation for the voltage induced on a wire moving in a magnetic field:

$$\boxed{e_{ind} = (\mathbf{v} \times \mathbf{B}) \cdot \mathbf{l}} \qquad (1\text{–}45)$$

where e_{ind} = voltage induced in wire
$\mathbf{v}$ = velocity of the wire
$\mathbf{B}$ = magnetic flux density vector
$\mathbf{l}$ = length of conductor in the magnetic field



اصل سوم: قانون ولتاژ کرشهوف در مدار الکتریکی این ماشین DC خطی:

مقدار جریان عبوری:

$$i = \frac{V_B - e_{ind}}{R}$$

اصل چهارم:

قانون نیوتون برای میله فلزی در حال حرکت روی ریل

$F_{net} = ma$

a شتاب حرکت بر حسب (m/s^2) و m جرم قطعه متحرک بر حسب کیلو گرم

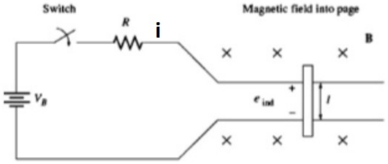
3. Kirchhoff's voltage law for this machine. From Figure 1–19 this law gives

$$V_B - iR - e_{ind} = 0$$

$$\boxed{V_B = e_{ind} + iR = 0} \qquad (1\text{–}46)$$

4. Newton's law for the bar across the tracks:

$$\boxed{F_{net} = ma} \qquad (1\text{–}7)$$



با توصیف ماشین DC خطی مورد بررسی در فوق و تشریح اصول چهار گانه حاکم بر این ماشین حالا اجازه راه اندازی به ماشین می دهیم.

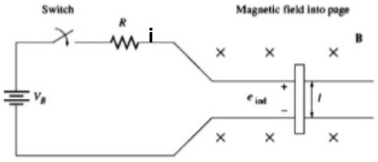
الف) حالت بی باری

اگر در این لحظه Switch را ببندیم اتفاقات مقابل می افتد.

$$Start \rightarrow i\uparrow \rightarrow F_{ind} = ma \rightarrow v\uparrow \rightarrow e_{ind}\uparrow \rightarrow i\downarrow$$

THE LINEAR DC MACHINE

Starting the Linear dc machine



To start this machine, simply close the switch. Now a current flows in the bar, which is given by Kirchhoff's voltage law:

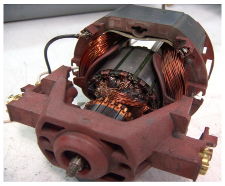
$$i = \frac{V_B - e_{ind}}{R}$$

Since the bar is initially at rest $e_{ind} = 0$

So
$i = V_B/R$
$\mathbf{F} = i(\mathbf{l} \times \mathbf{B})$
$F_{ind} = ilB$ to the right

Therefore, the bar will accelerate to the right (by Newton's law). However, When the velocity of the bar begins to increase, a voltage appears across the bar. The voltage is given by Equation

$e_{ind} = (\mathbf{v} \times \mathbf{B}) \cdot \mathbf{l}$
$e_{ind} = vBl$ positive upward



ادامه عملیات:

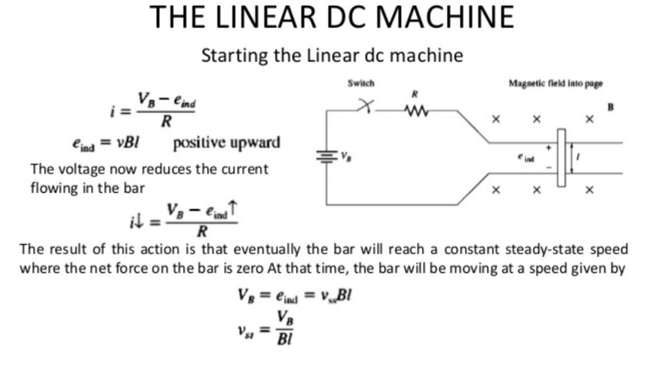
$$e_{ind}\uparrow \rightarrow V_B = e_{ind} \rightarrow i = 0 \rightarrow F_{ind} = 0$$

با گذراندن مراحل فوق به جایی می رسیم که ولتاژ باطری(منبع) و ولتاژ القایی برابر شده و جریان صفر و در نتیجه نیروی القایی صفر و می رسیم به قانون دیگر نیوتن:

اگر هیچ نیرویی به جسمی وارد نشود اگر ساکن است همواره ساکن و اگر در حال حرکت است با همان سرعت به کار خود ادامه می دهد.

پس در این حالت به سرعت ماندگار می رسیم:

$$V_{ss} = \frac{V_B}{Bl}$$



THE LINEAR DC MACHINE

Starting the Linear dc machine

$$i = \frac{V_B - e_{ind}}{R}$$

$e_{ind} = vBl$ positive upward

The voltage now reduces the current flowing in the bar

$$i\downarrow = \frac{V_B - e_{ind}\uparrow}{R}$$

The result of this action is that eventually the bar will reach a constant steady-state speed where the net force on the bar is zero At that time, the bar will be moving at a speed given by

$$V_B = e_{ind} = v_{ss}Bl$$

$$v_{ss} = \frac{V_B}{Bl}$$

ب) حالت موتوری

حال فرض می کنیم یک نیروی F_{load} (نیروی معرف بار مکانیکی) در جهت خلاف حرکت به میله ماشین DC خطی وارد شود.

در واقع با این کار یک حالت موتوری برای ماشین DC خطی ایجاد می کنیم. دو تا نیرو در دو جهت مختلف بر میله وارد می گردد. بر آیند این دو نیرو:

$$F_{net} = F_{ind} - F_{load}$$

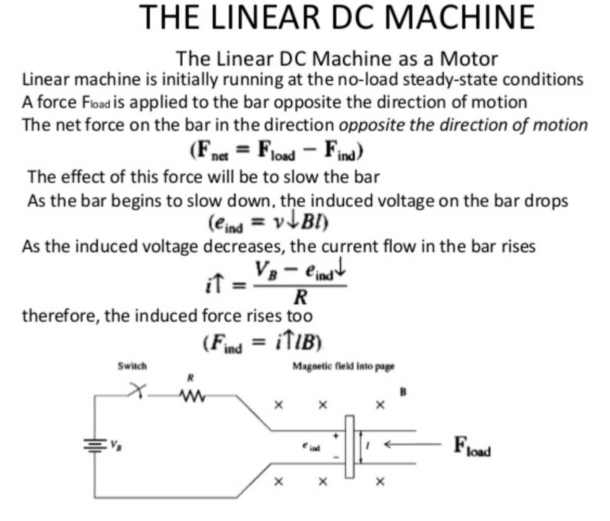
اتفاقاتی که می افتد عبارتست از:

$$F_{load} \rightarrow v\downarrow \rightarrow e_{ind}\downarrow \rightarrow i\uparrow \rightarrow F_{ind}\uparrow \rightarrow$$

در نهایت نیروی القایی و نیروی بار با هم مساوی می گردند. در این حالت جمع نیروهای دارد بر میله صفر گردیده و سرعت ثابت می شود.

محاسبه سرعت ثابت : $F_{ind} = F_{load} = ilB$

$$\rightarrow i = \frac{F_{load}}{lB} \rightarrow e_{ind} = V_B - iR = V_{ss}Bl \rightarrow V_{ss} = (V_B - iR)/Bl$$



THE LINEAR DC MACHINE

The Linear DC Machine as a Motor

Linear machine is initially running at the no-load steady-state conditions

A force F_{load} is applied to the bar opposite the direction of motion

The net force on the bar in the direction *opposite the direction of motion*

$$(F_{net} = F_{load} - F_{ind})$$

The effect of this force will be to slow the bar

As the bar begins to slow down, the induced voltage on the bar drops

$$(e_{ind} = v\downarrow Bl)$$

As the induced voltage decreases, the current flow in the bar rises

$$i\uparrow = \frac{V_B - e_{ind}\downarrow}{R}$$

therefore, the induced force rises too

$$(F_{ind} = i\uparrow lB)$$

پس از این آنالیز به این نتیجه رسیدیم که در نهایت بعد از یک سلسله عملیاتی که به طور خودکار انجام می شود نهایتا به یک سرعت ثابت می رسیم.

محاسبه توان مصرفی:

در اینجا توان مورد نیاز است که از منبع الکتریکی به سیستم مکانیکی منتقل شود این توان در سیستم الکترومکانیکی به شرح زیر است :

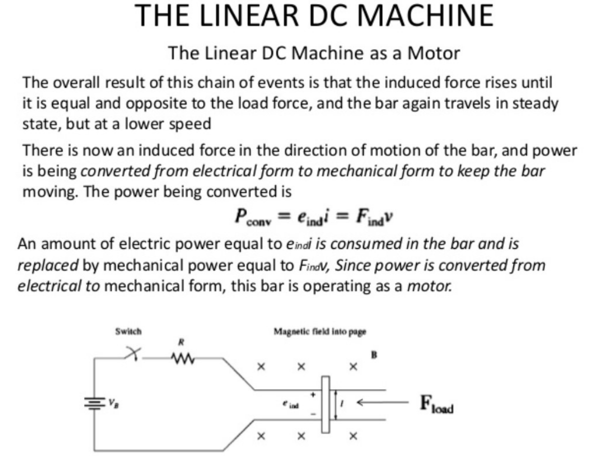
$$P_{in} = V_B i = (Ri + e_{ind})i = Ri^2 + e_{ind}i$$

جمله اول تلفات در مقاومت است

جمله دوم توان تبدیل شده از الکتریکی به مکانیکی است:

$$P_{converted} = e_{ind}i = F_{ind}\,v = P_m$$

این شد یک سیستم الکترومکانیمی (مبدل انرژی)



THE LINEAR DC MACHINE

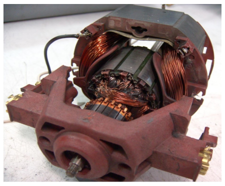
The Linear DC Machine as a Motor

The overall result of this chain of events is that the induced force rises until it is equal and opposite to the load force, and the bar again travels in steady state, but at a lower speed

There is now an induced force in the direction of motion of the bar, and power is being *converted from electrical form to mechanical form to keep the bar* moving. The power being converted is

$$P_{conv} = e_{ind}i = F_{ind}v$$

An amount of electric power equal to $e_{ind}i$ *is consumed in the bar and is replaced* by mechanical power equal to $F_{ind}v$*, Since power is converted from electrical to* mechanical form, *this bar is operating as a motor.*



ج) حالت ژنراتوری

اگر ماشین را در بی باری راه اندازی کنیم و یک نیرو هم در جهت حرکت با میله اعمال نماییم. **(چه اتفاقی می افتد)**

۱- نیروی مکانیکی اعمالی با نیرو ی القایی جمع شده و باعث حرکت سریعتر میله می گردد.

$\text{Statr}\rightarrow i=(V_B)/R\rightarrow F_{net} = F_{ind} + F_{app}$

$\rightarrow v\uparrow\rightarrow e_{ind}\uparrow\rightarrow (V_B - e_{ind})\downarrow\rightarrow(V_B - e_{ind}) = 0$

$\rightarrow i=0\rightarrow F_{ind}=0\rightarrow F_{net}=F_{app}\rightarrow v\uparrow \rightarrow e_{ind}>V_B$

$$i = \frac{e_{ind} - V_B}{R}$$

$$F_{ind} = ilB \qquad \text{to the left}$$

در اینجا جهت جریان معکوس گردیده **(درواقع باطری شارژ می گردد)** و جهت F_{ind} معکوس گردیده و تا جایی این موضوع ادامه پیدا می کند تا در نهایت F_{ind} با F_{app} برابر شده و سرعت ماندگار فرا می رسد.

ج-۱محاسبه سرعت ماندگار:

$E_{ind}= (V_B + Ri) =v_{ss}\, lB\rightarrow v_{ss} = (V_B+Ri)/lB$

ج-۲ محاسبه توان مکانیکی ورودی و توان الکتریکی خروجی و تلفات و راندمان:

Mechanical $P_{in} = v_{ss}F_{app}$ W

Produced Electrical Power $P_{ind} = E_{ind}i$

$P_{loss} = Ri^2$ $\quad P_{load} = V_Bi$

Efficiency = $(P_{load}/P_{in})\times 100\%$

THE LINEAR DC MACHINE

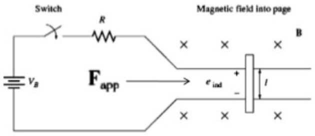
The Linear DC Machine as a Generator

The linear machine is again operating under no-load steady-state conditions.
Apply a force *in the direction of motion*
Now the applied force will cause the bar to accelerate in the direction of motion, and the velocity *v of the bar will increase. As the velocity* increases, e_{ind} *will increase and will be larger than the battery voltage* V_B*. Now* the current flown in reverses direction

$$i = \frac{e_{ind} - V_B}{R}$$

$$F_{ind} = ilB \qquad \text{to the left}$$

Notice that now *the battery is charging. The linear machine is now serving as a generator, converting mechanical* power $F_{ind}v$ *into electric power* $e_{ind}i$.



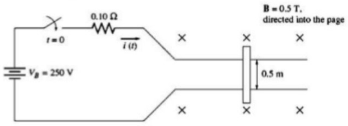
مشکل راه اندازی در ماشینهای DC خطی

جریان راه اندازی بالا است

$\text{Start} \rightarrow v=0\rightarrow e_{ind}=0\rightarrow i=(V_B/R)\rightarrow\gg$

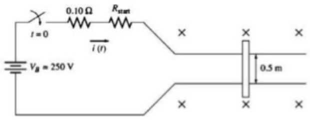
THE LINEAR DC MACHINE

Starting Problems with the Linear Machine

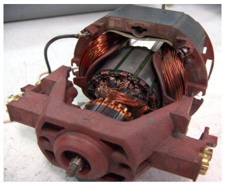


$$e_{ind} = 0$$

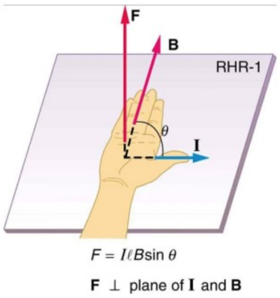
$$i_{start} = \frac{V_B}{R} = \frac{250\ V}{0.1\ \Omega} = 2500\ \text{A}$$

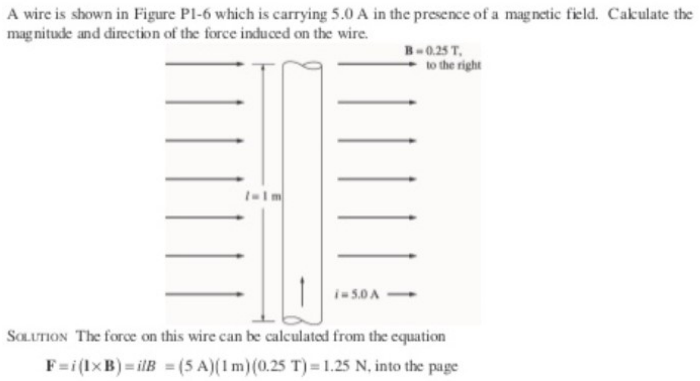


تمرینات متعدد



تمرین ۱:





A wire is shown in Figure P1-6 which is carrying 5.0 A in the presence of a magnetic field. Calculate the magnitude and direction of the force induced on the wire.

SOLUTION The force on this wire can be calculated from the equation

$$\mathbf{F} = i(\mathbf{l} \times \mathbf{B}) = ilB = (5 \text{ A})(1 \text{ m})(0.25 \text{ T}) = 1.25 \text{ N, into the page}$$

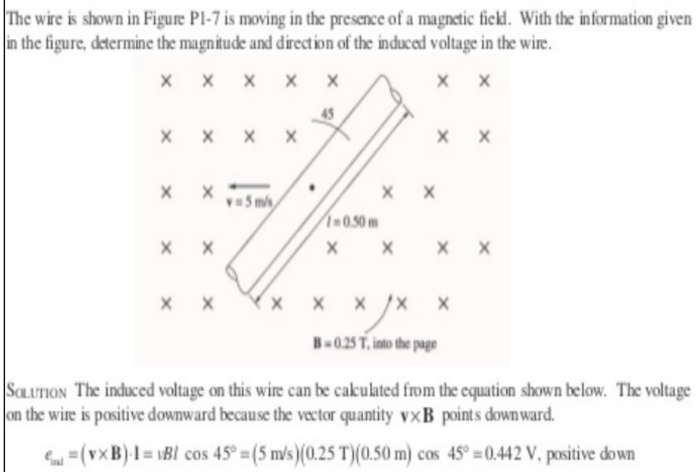
تمرین ۲:

l= 0.50 m
v= 5 m/sec
B= 0.25 T
$\Theta = 45^0$

داریم:

$E_{ind}=(v\times B).l$

$v \perp B$



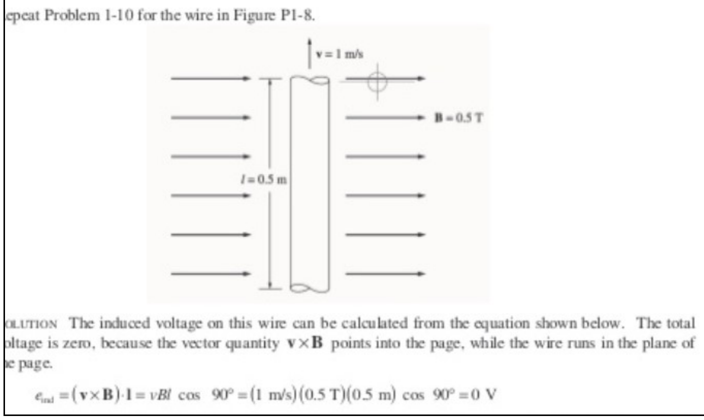
The wire is shown in Figure P1-7 is moving in the presence of a magnetic field. With the information given in the figure, determine the magnitude and direction of the induced voltage in the wire.

SOLUTION The induced voltage on this wire can be calculated from the equation shown below. The voltage on the wire is positive downward because the vector quantity $\mathbf{v} \times \mathbf{B}$ points downward.

$$e_{ind} = (\mathbf{v} \times \mathbf{B}) \cdot \mathbf{l} = vBl \cos 45° = (5 \text{ m/s})(0.25 \text{ T})(0.50 \text{ m}) \cos 45° = 0.442 \text{ V, positive down}$$

تمرین ۳ :

نشان دهید ولتاژ القایی صفر است

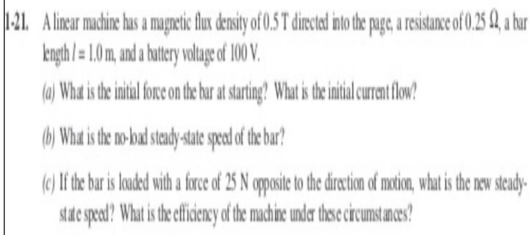


epeat Problem 1-10 for the wire in Figure P1-8.

OLUTION The induced voltage on this wire can be calculated from the equation shown below. The total oltage is zero, because the vector quantity $\mathbf{v} \times \mathbf{B}$ points into the page, while the wire runs in the plane of e page.

$$e_{ind} = (\mathbf{v} \times \mathbf{B}) \cdot \mathbf{l} = vBl \cos 90° = (1 \text{ m/s})(0.5 \text{ T})(0.5 \text{ m}) \cos 90° = 0 \text{ V}$$

تمرین ٤:

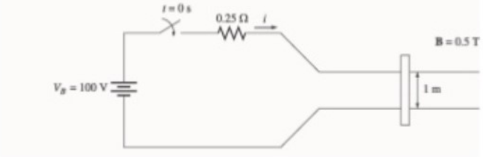


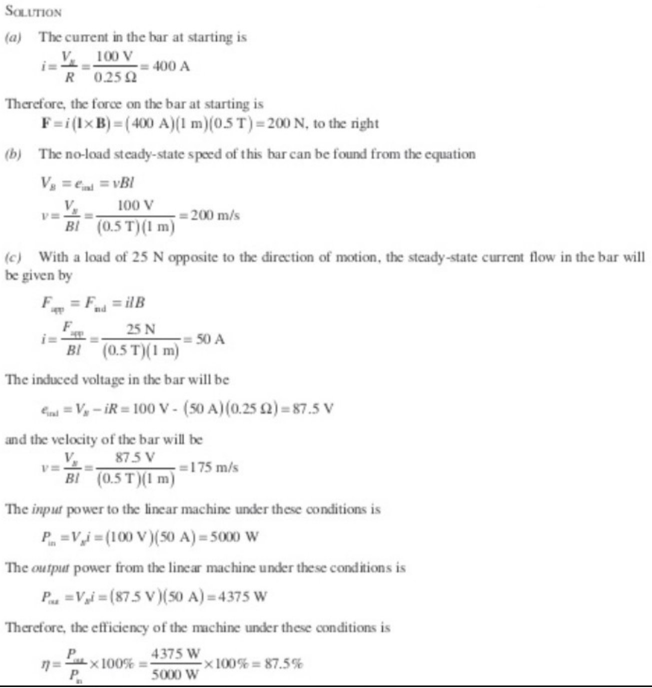
1-21. A linear machine has a magnetic flux density of 0.5 T directed into the page, a resistance of 0.25 Ω, a bar length $l = 1.0$ m, and a battery voltage of 100 V.

(a) What is the initial force on the bar at starting? What is the initial current flow?

(b) What is the no-load steady-state speed of the bar?

(c) If the bar is loaded with a force of 25 N opposite to the direction of motion, what is the new steady-state speed? What is the efficiency of the machine under these circumstances?





SOLUTION

(a) The current in the bar at starting is

$$i = \frac{V_B}{R} = \frac{100\text{ V}}{0.25\ \Omega} = 400\text{ A}$$

Therefore, the force on the bar at starting is

$$\mathbf{F} = i(\mathbf{l} \times \mathbf{B}) = (400\text{ A})(1\text{ m})(0.5\text{ T}) = 200\text{ N, to the right}$$

(b) The no-load steady-state speed of this bar can be found from the equation

$$V_B = e_{\text{ind}} = vBl$$

$$v = \frac{V_B}{Bl} = \frac{100\text{ V}}{(0.5\text{ T})(1\text{ m})} = 200\text{ m/s}$$

(c) With a load of 25 N opposite to the direction of motion, the steady-state current flow in the bar will be given by

$$F_{\text{app}} = F_{\text{ind}} = ilB$$

$$i = \frac{F_{\text{app}}}{Bl} = \frac{25\text{ N}}{(0.5\text{ T})(1\text{ m})} = 50\text{ A}$$

The induced voltage in the bar will be

$$e_{\text{ind}} = V_B - iR = 100\text{ V} - (50\text{ A})(0.25\ \Omega) = 87.5\text{ V}$$

and the velocity of the bar will be

$$v = \frac{V_B}{Bl} = \frac{87.5\text{ V}}{(0.5\text{ T})(1\text{ m})} = 175\text{ m/s}$$

The *input* power to the linear machine under these conditions is

$$P_{\text{in}} = V_B i = (100\text{ V})(50\text{ A}) = 5000\text{ W}$$

The *output* power from the linear machine under these conditions is

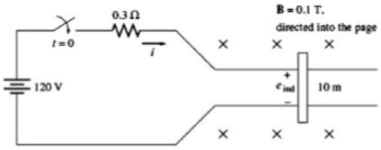
$$P_{\text{out}} = V_B i = (87.5\text{ V})(50\text{ A}) = 4375\text{ W}$$

Therefore, the efficiency of the machine under these conditions is

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100\% = \frac{4375\text{ W}}{5000\text{ W}} \times 100\% = 87.5\%$$

تمرین ٥:

Example 1-10. The linear dc machine shown in Figure 1-27a has a battery voltage of 120 V, an internal resistance of 0.3 ohm, and a magnetic flux density of 0.1 T.



(a) What is this machine's maximum starting current? What is its steady-state velocity at no load?

$$i = \frac{V_B - e_{ind}}{R} = \frac{120V - 0}{0.3\Omega} = 400A$$

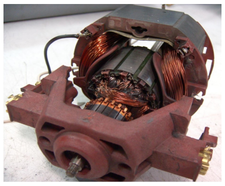
When the machine reaches steady state, $\mathbf{F}_{\text{ind}} = 0$ and $i = 0$. Therefore,

$$e_{ind} = VBl$$

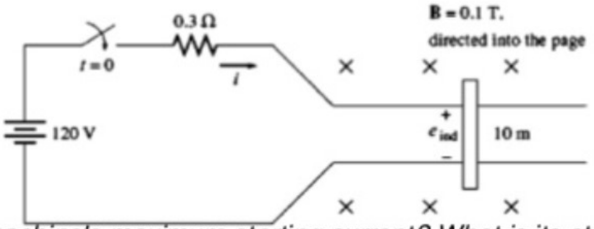
$$e_{ind} = v_{ss}Bl$$

$$v_{ss} = \frac{e_{ind}}{Bl}$$

$$v_{ss} = \frac{120V}{(0.1T)(10m)} = 120\ {}^{m}/_{s}$$



Example 1-10. The linear dc machine shown in Figure 1-27a has a battery voltage of 120 V. an internal resistance of 0.3 ohm. and a magnetic flux density of 0.1 T.



(a) What is this machine's maximum starting current? What is its steady-state velocity at no load?

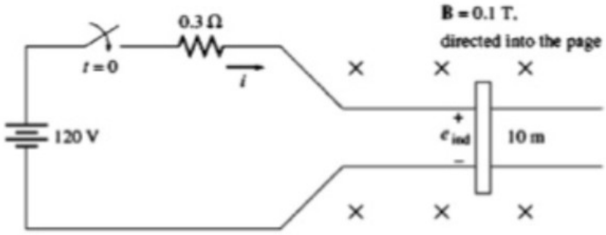
(b) Suppose that a 30-N force pointing to the right were applied to the bar. What would the steady-state speed be? How much power would the bar be producing or consuming? How much power would the battery be producing or consuming? Explain the difference between these two figures. Is this machine acting as a motor or as a generator

(c) Now suppose a 30-N force pointing to the left were applied to the bar. What would the new steady-state speed be? Is this machine a motor or a generator now?

(d) Assume that a force pointing to the left is applied to the bar. Calculate speed of the bar as a function of the force for values from 0 N to 50 N in IO-N steps. Plot the velocity of the bar versus the applied force.

(e) Assume that the bar is unloaded and that it suddenly runs into a region where the magnetic field is weakened to 0.08 T. How fast will the bar go now?

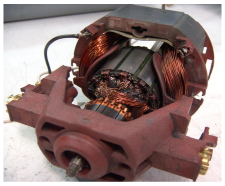
Example 1-10. The linear dc machine shown in Figure 1-27a has a battery voltage of 120 V. an internal resistance of 0.3 ohm. and a magnetic flux density of 0.1 T.

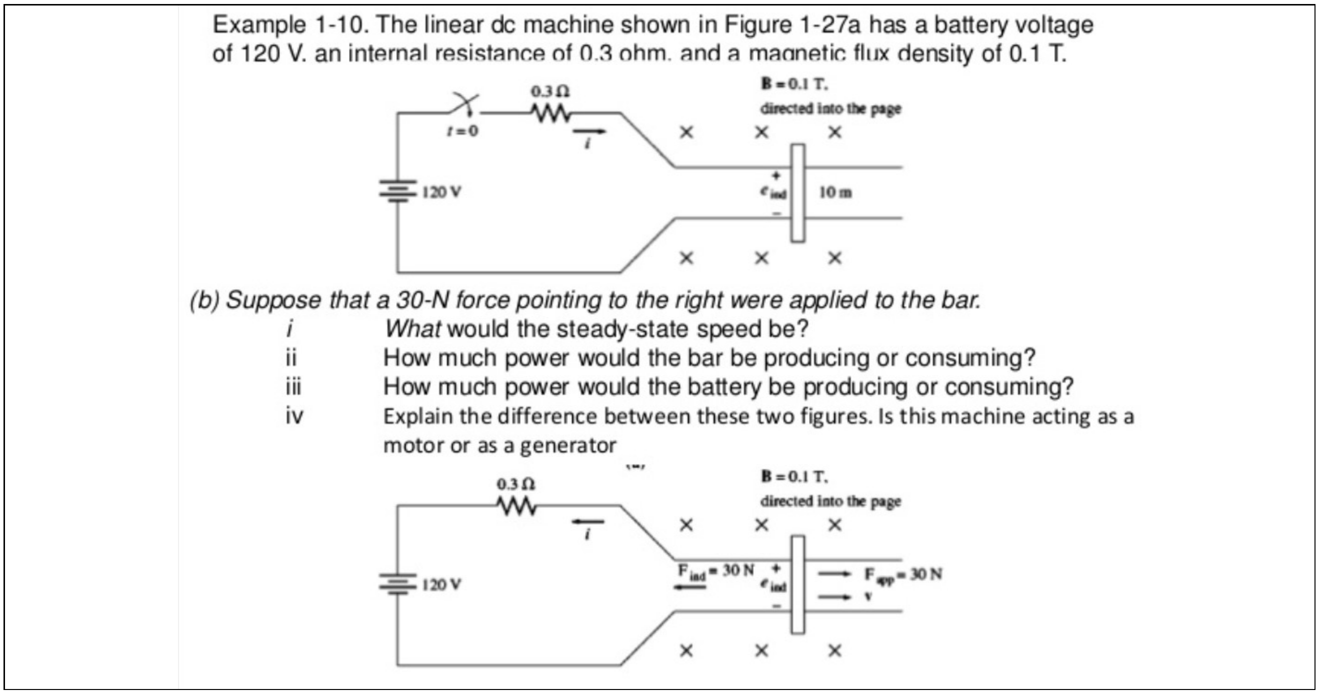


(b) Suppose that a 30-N force pointing to the right were applied to the bar. What would the steady-state speed be? How much power would the bar be producing or consuming? How much power would the battery be producing or consuming? Explain the difference between these two figures. Is this machine acting as a motor or as a generator

(b) Suppose that a 30-N force pointing to the right were applied to the bar.

i *What* would the steady-state speed be?
ii How much power would the bar be producing or consuming?
iii How much power would the battery be producing or consuming?
iv Explain the difference between these two figures. Is this machine acting as a motor or as a generator

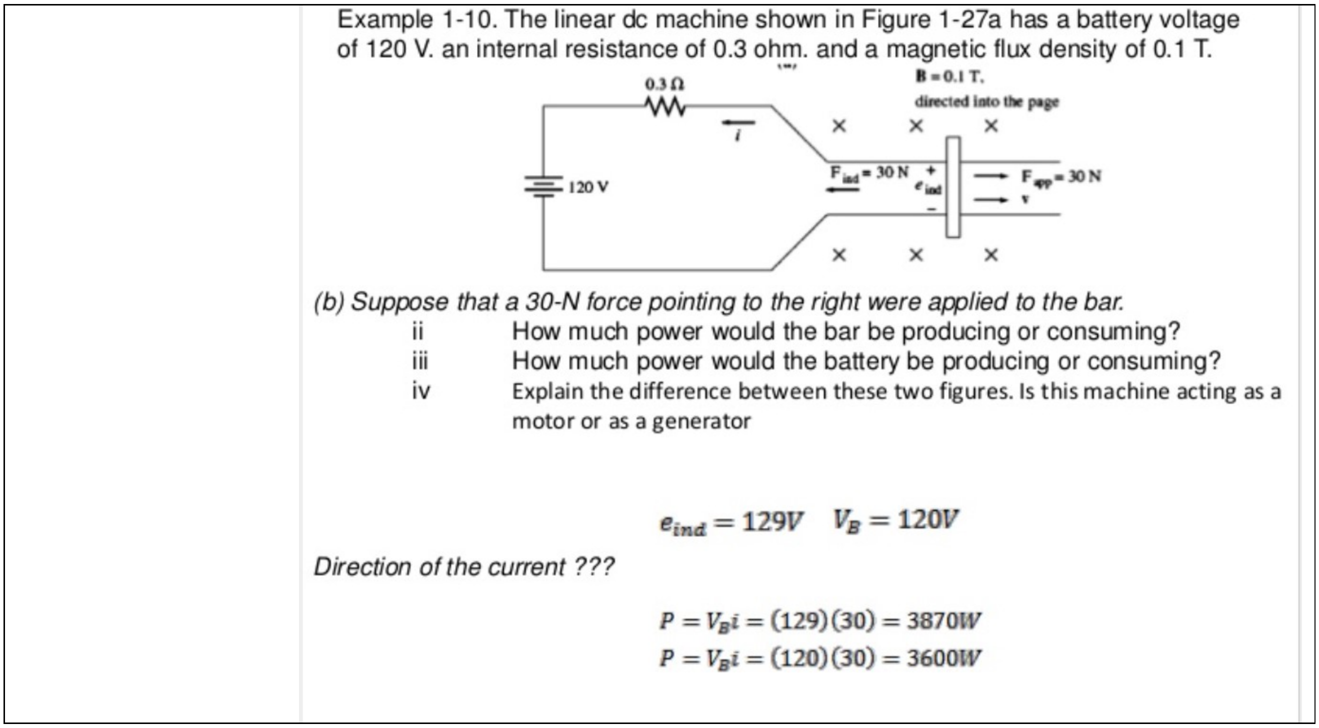




Example 1-10. The linear dc machine shown in Figure 1-27a has a battery voltage of 120 V. an internal resistance of 0.3 ohm. and a magnetic flux density of 0.1 T.

(b) Suppose that a 30-N force pointing to the right were applied to the bar.

- *i* *What* would the steady-state speed be?
- ii How much power would the bar be producing or consuming?
- iii How much power would the battery be producing or consuming?
- iv Explain the difference between these two figures. Is this machine acting as a motor or as a generator



Example 1-10. The linear dc machine shown in Figure 1-27a has a battery voltage of 120 V. an internal resistance of 0.3 ohm. and a magnetic flux density of 0.1 T.

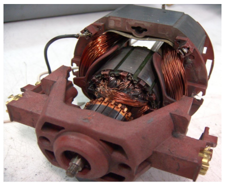
(b) Suppose that a 30-N force pointing to the right were applied to the bar.

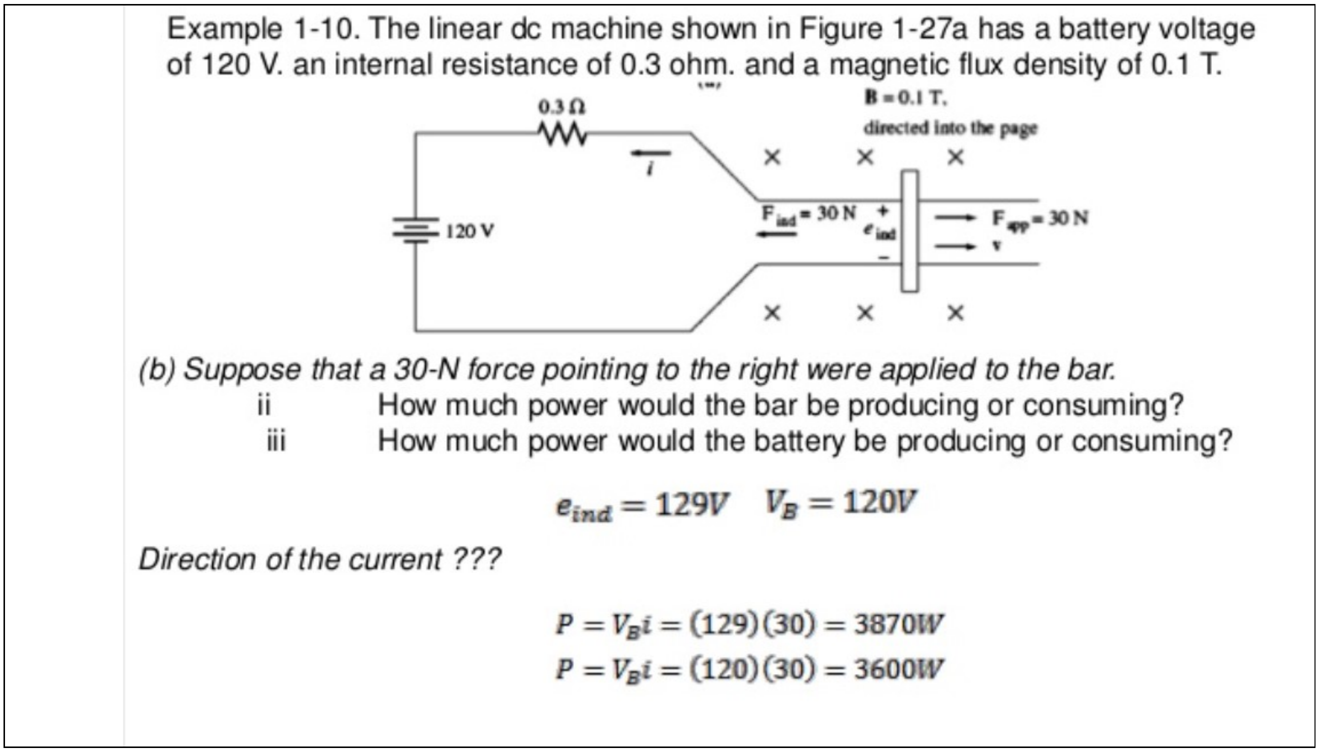
- ii How much power would the bar be producing or consuming?
- iii How much power would the battery be producing or consuming?
- iv Explain the difference between these two figures. Is this machine acting as a motor or as a generator

$$e_{ind} = 129V \quad V_B = 120V$$

Direction of the current ???

$$P = V_B i = (129)(30) = 3870W$$
$$P = V_B i = (120)(30) = 3600W$$





Example 1-10. The linear dc machine shown in Figure 1-27a has a battery voltage of 120 V. an internal resistance of 0.3 ohm. and a magnetic flux density of 0.1 T.

(b) Suppose that a 30-N force pointing to the right were applied to the bar.

ii How much power would the bar be producing or consuming?

iii How much power would the battery be producing or consuming?

$$e_{ind} = 129V \quad V_B = 120V$$

Direction of the current ???

$$P = V_B i = (129)(30) = 3870W$$
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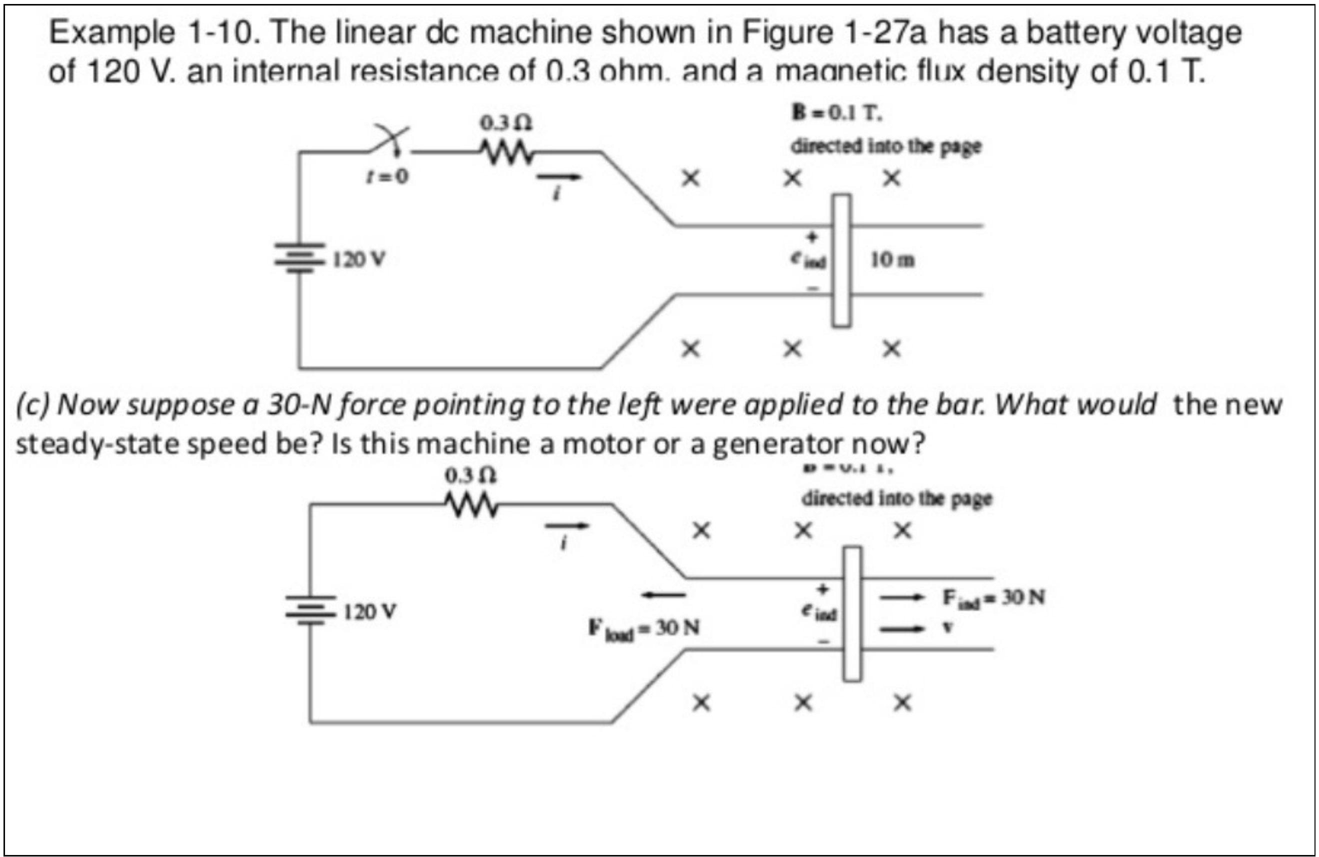
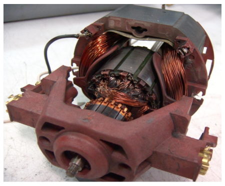


Example 1-10. The linear dc machine shown in Figure 1-27a has a battery voltage of 120 V. an internal resistance of 0.3 ohm. and a magnetic flux density of 0.1 T.

(c) Now suppose a 30-N force pointing to the left were applied to the bar. What would the new steady-state speed be? Is this machine a motor or a generator now?



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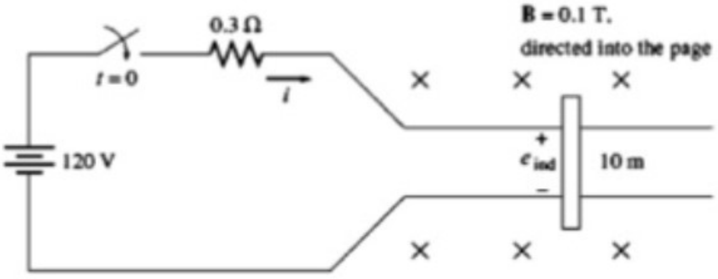


(e) Assume that the bar is unloaded and that it suddenly runs into a region where the magnetic field is weakened to 0.08 T. How fast will the bar go now?

$$V_B = e_{ind} = v_{ss}Bl$$

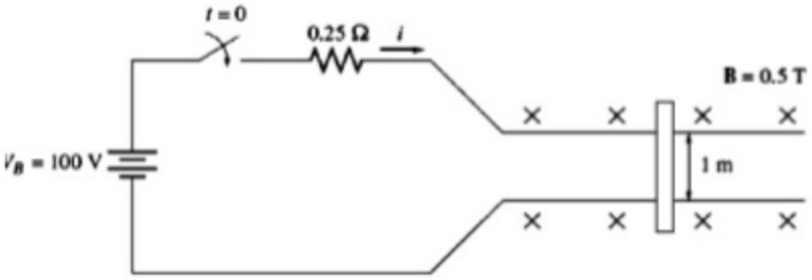
$$v_{ss} = \frac{V_B}{Bl}$$

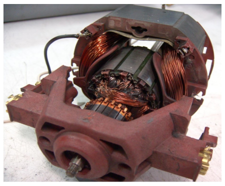
1-2 1. The linear machine shown in Figure PI - IS has a magnetic flux density of 0.5 T directed into the page, a resistance of 0.25Ω, a bar length *l = 1.0 m, and a battery* voltage of 100 V.

(a) What is the initial force on the bar at starting? What is the initial current flow?

(b) What is the no-load steady-state speed of the bar?

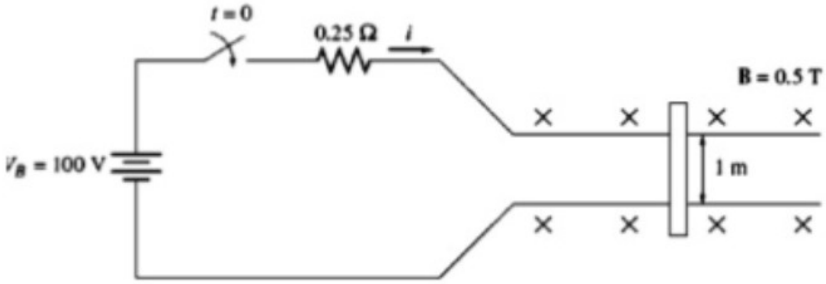
(c) If the bar is loaded with a force of 25 N opposite to the direction of motion, what is the new steady-state speed? What is the efficiency of the machine under these circumstances?





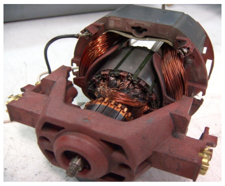
1-2 1. The linear machine shown in Figure PI - IS has a magnetic flux density of 0.5 T directed into the page, a resistance of 0.25Ω, a bar length *l = 1.0 m, and a battery* voltage of 100 V.

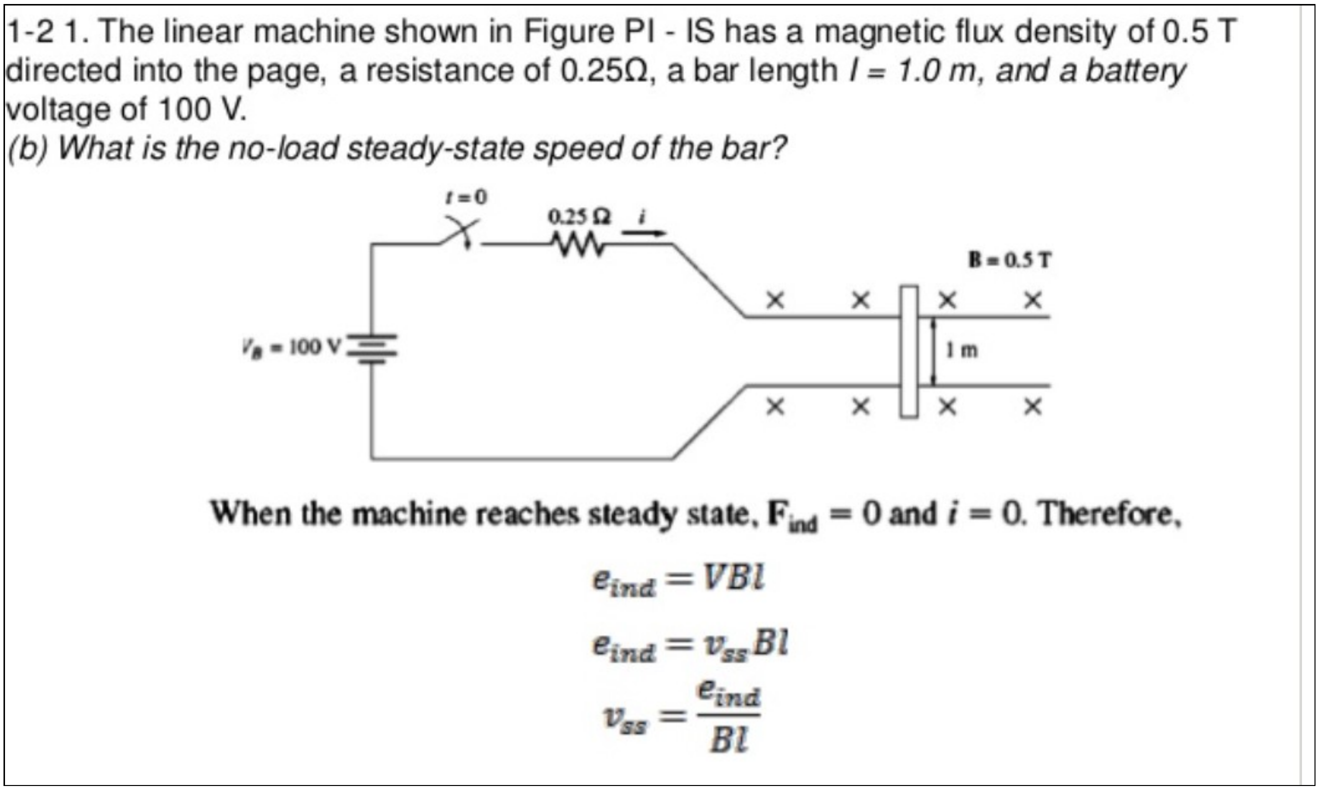
(a) What is the initial force on the bar at starting? What is the initial current flow?



$$i = \frac{V_B - e_{ind}}{R}$$

$$F = ilB$$





1-2 1. The linear machine shown in Figure PI - IS has a magnetic flux density of 0.5 T directed into the page, a resistance of 0.25Ω, a bar length *l = 1.0 m, and a battery* voltage of 100 V.

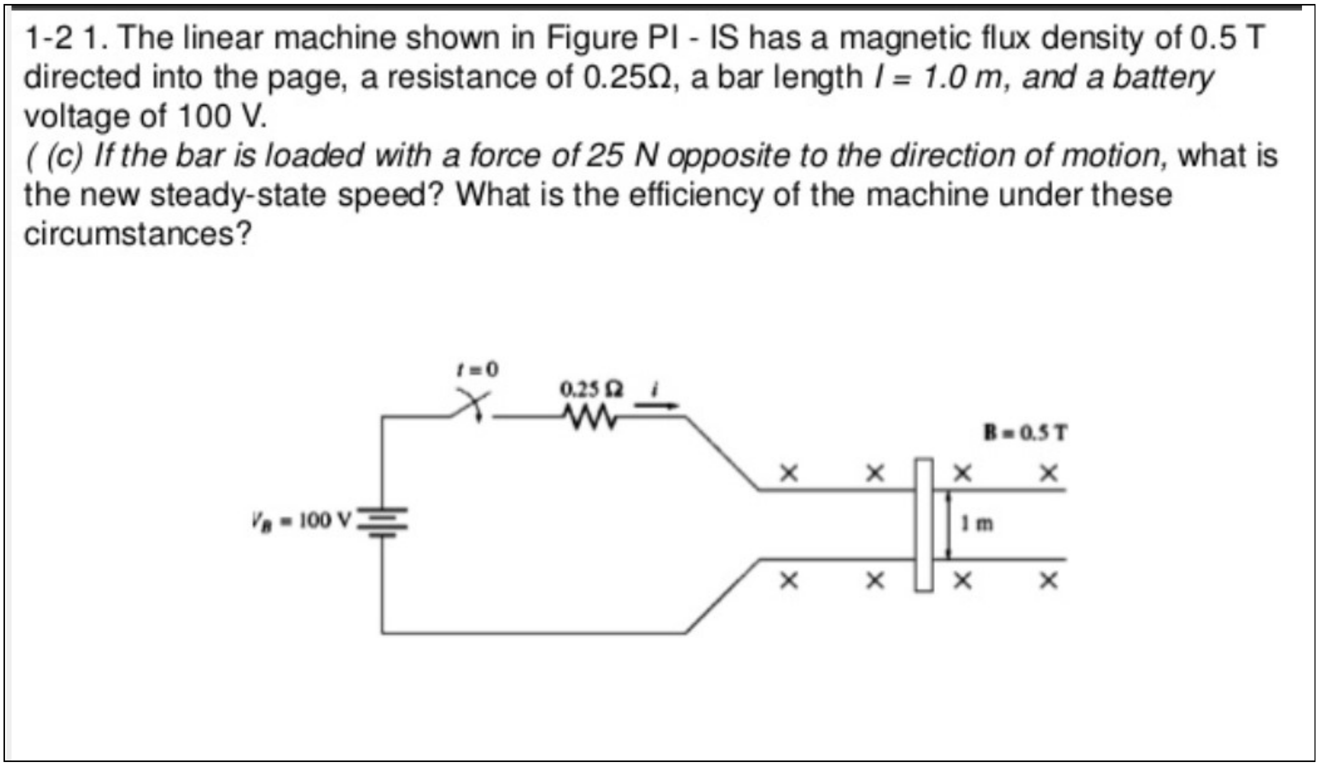
(b) What is the no-load steady-state speed of the bar?

When the machine reaches steady state, $\mathbf{F}_{\text{ind}} = 0$ and $i = 0$. Therefore,

$$e_{ind} = VBl$$

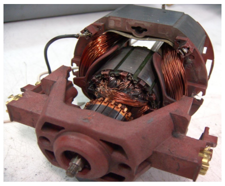
$$e_{ind} = v_{ss}Bl$$

$$v_{ss} = \frac{e_{ind}}{Bl}$$



1-2 1. The linear machine shown in Figure PI - IS has a magnetic flux density of 0.5 T directed into the page, a resistance of 0.25Ω, a bar length *l = 1.0 m, and a battery* voltage of 100 V.

((c) If the bar is loaded with a force of 25 N opposite to the direction of motion, what is the new steady-state speed? What is the efficiency of the machine under these circumstances?



1-22. A linear machine has the following characteristics:

$B = 0.33$ T into page $R = 0.50\ \Omega$

20

$l = 0.5$ m $V_B = 120$ V

(a) If this bar has a load of 10 N attached to it opposite to the direction of motion, what is the steady-state speed of the bar?

(b) If the bar runs off into a region where the flux density falls to 0.30 T, what happens to the bar? What is its final steady-state speed?

(c) Suppose V_B is now decreased to 80 V with everything else remaining as in part *(b)*. What is the new steady-state speed of the bar?

(d) From the results for parts *(b)* and *(c)*, what are two methods of controlling the speed of a linear machine (or a real dc motor)?

SOLUTION

(a) With a load of 20 N opposite to the direction of motion, the steady-state current flow in the bar will be given by

$$F_{\text{app}} = F_{\text{ind}} = ilB$$

$$i = \frac{F_{\text{app}}}{Bl} = \frac{10\ \text{N}}{(0.33\ \text{T})(0.5\ \text{m})} = 60.5\ \text{A}$$

The induced voltage in the bar will be

$$e_{\text{ind}} = V_B - iR = 120\ \text{V} - (60.5\ \text{A})(0.50\ \Omega) = 89.75\ \text{V}$$

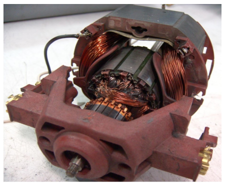
and the velocity of the bar will be

$$v = \frac{e_{\text{ind}}}{Bl} = \frac{89.75\ \text{V}}{(0.33\ \text{T})(0.5\ \text{m})} = 544\ \text{m/s}$$

(b) If the flux density drops to 0.30 T while the load on the bar remains the same, there will be a speed transient until $F_{\text{app}} = F_{\text{ind}} = 10\ \text{N}$ again. The new steady state current will be

$$F_{\text{app}} = F_{\text{ind}} = ilB$$

$$i = \frac{F_{\text{app}}}{Bl} = \frac{10\ \text{N}}{(0.30\ \text{T})(0.5\ \text{m})} = 66.7\ \text{A}$$



The induced voltage in the bar will be

$$e_{\text{ind}} = V_B - iR = 120\text{ V} - (66.7\text{ A})(0.50\ \Omega) = 86.65\text{ V}$$

and the velocity of the bar will be

$$v = \frac{e_{\text{ind}}}{Bl} = \frac{86.65\text{ V}}{(0.30\text{ T})(0.5\text{ m})} = 577\text{ m/s}$$

(c) If the battery voltage is decreased to 80 V while the load on the bar remains the same, there will be a speed transient until $F_{\text{app}} = F_{\text{ind}} = 10\text{ N}$ again. The new steady state current will be

$$F_{\text{app}} = F_{\text{ind}} = ilB$$

$$i = \frac{F_{\text{app}}}{Bl} = \frac{10\text{ N}}{(0.30\text{ T})(0.5\text{ m})} = 66.7\text{ A}$$

The induced voltage in the bar will be

$$e_{\text{ind}} = V_B - iR = 80\text{ V} - (66.7\text{ A})(0.50\ \Omega) = 46.65\text{ V}$$

and the velocity of the bar will be

$$v = \frac{e_{\text{ind}}}{Bl} = \frac{46.65\text{ V}}{(0.30\text{ T})(0.5\text{ m})} = 311\text{ m/s}$$

(d) From the results of the two previous parts, we can see that there are two ways to control the speed of a linear dc machine. *Reducing* the flux density B of the machine *increases* the steady-state speed, and *reducing* the battery voltage V_B *decreases* the stead-state speed of the machine. Both of these speed control methods work for real dc machines as well as for linear machines.