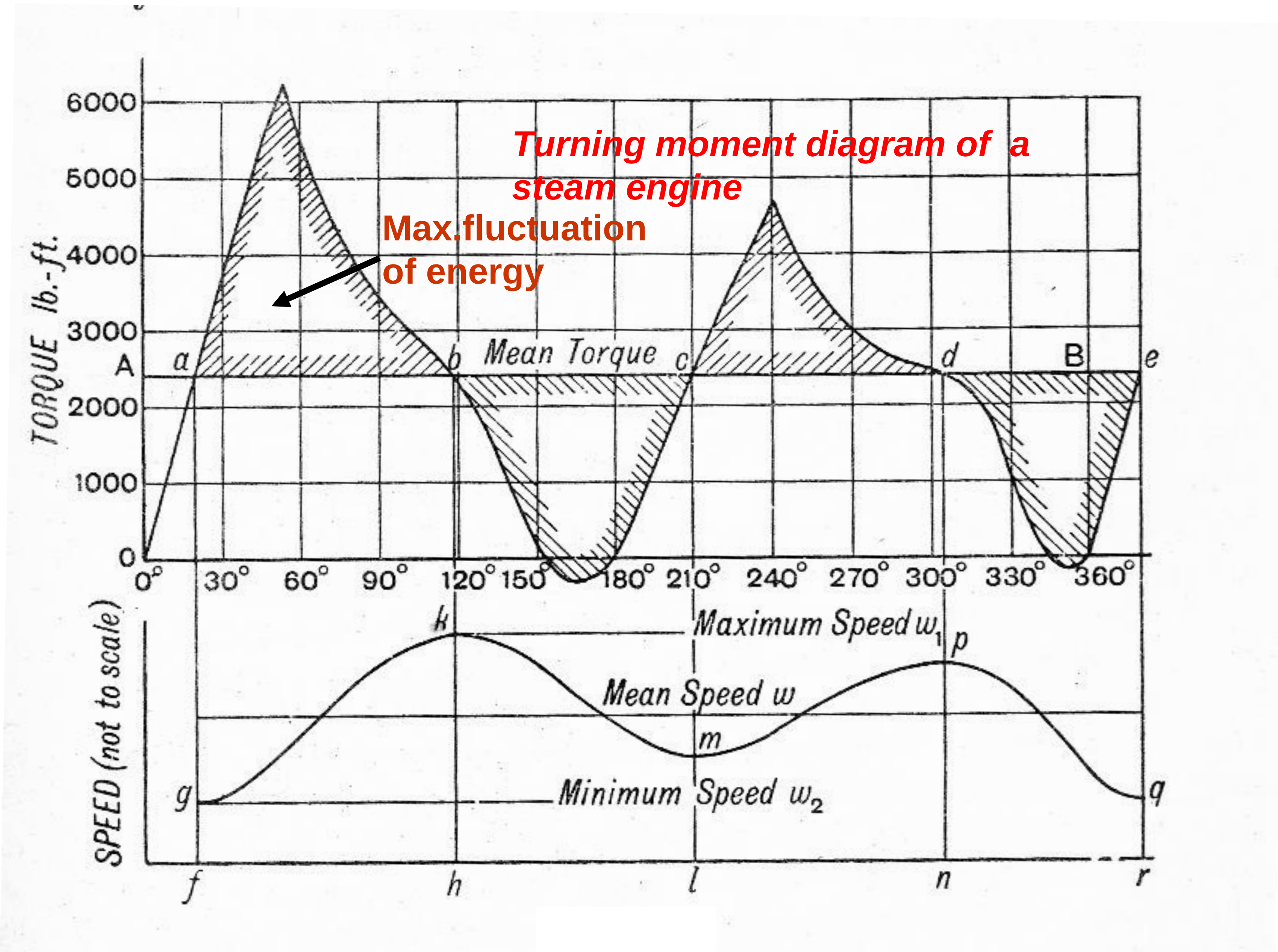
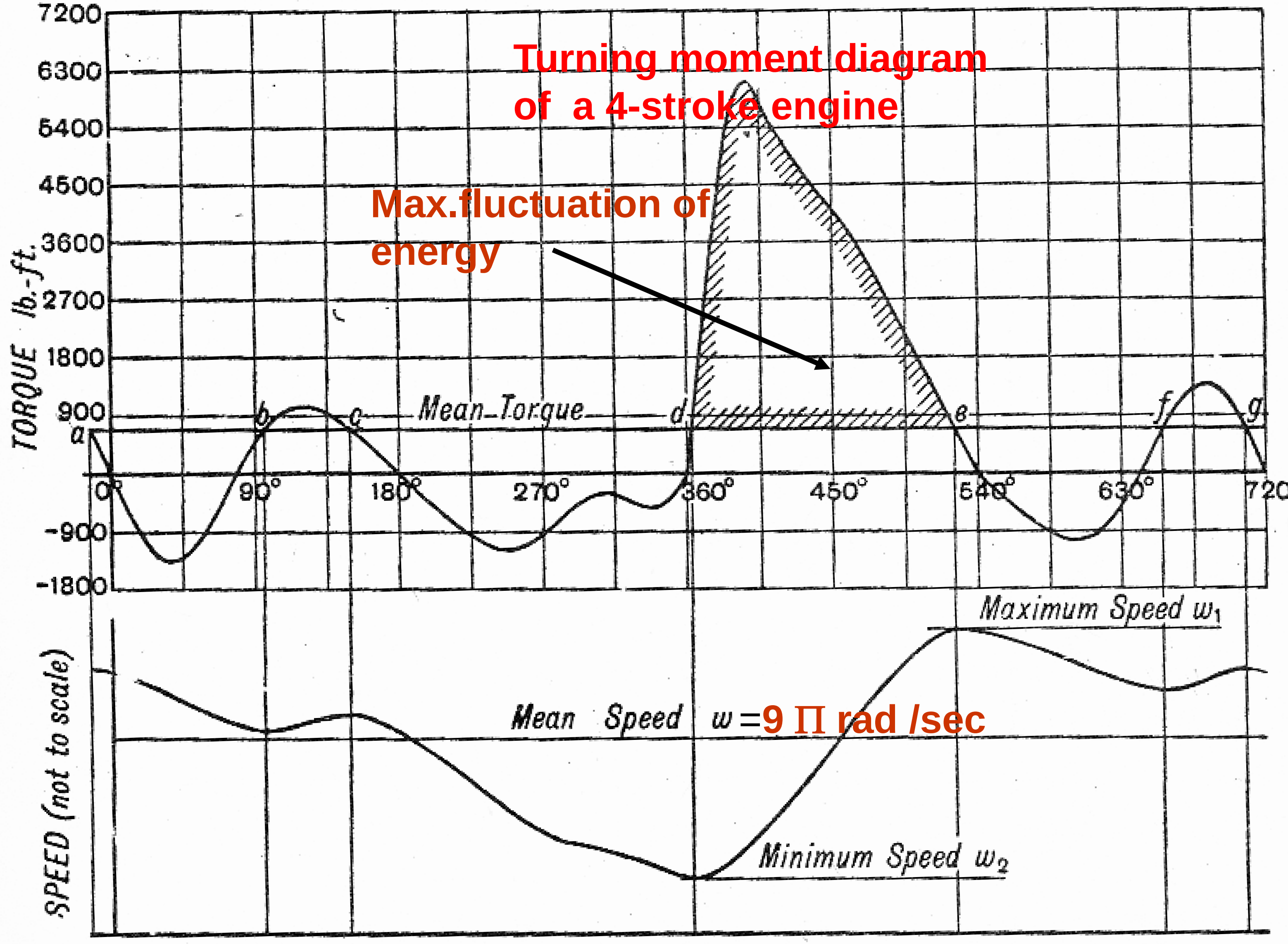
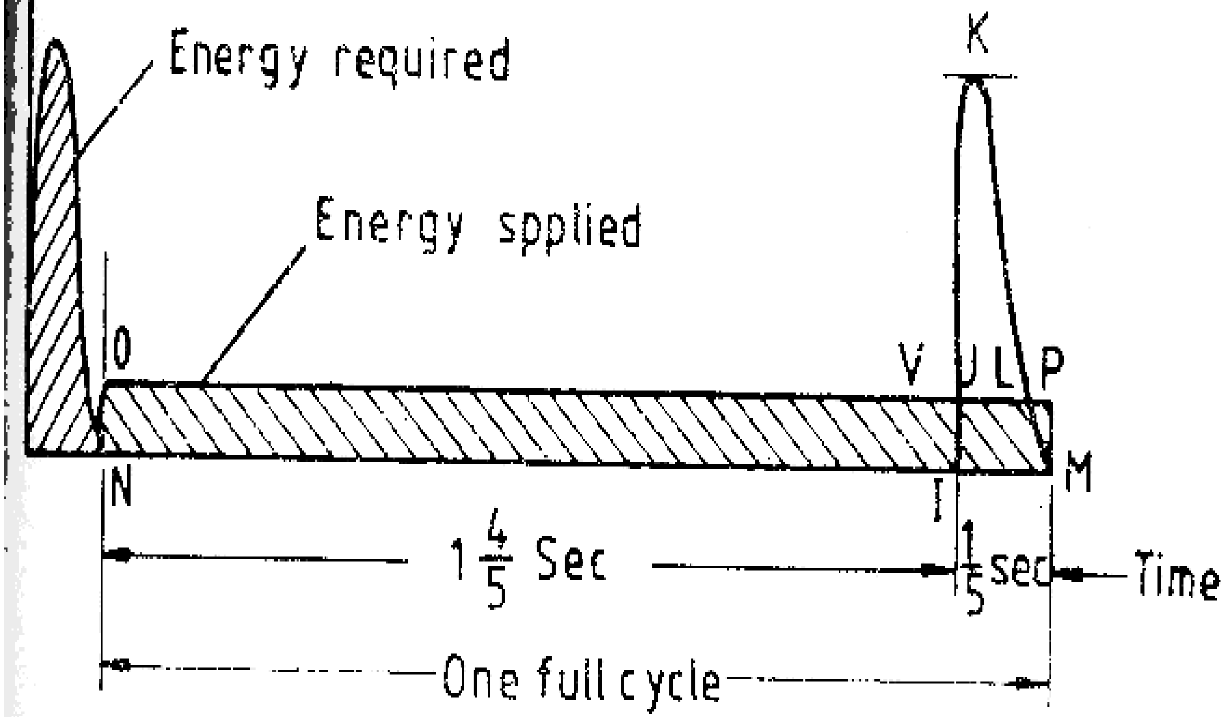

Turning moment diagram of a steam engine
Max.fluctuation of energy
6000
5000
4000
3000
2000
1000
0
TORQUE lb.-ft.
A
a
b
Mean Torque
c
d
B
e
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
360°
SPEED (not to scale)
k
Maximum Speed ω_1
p
Mean Speed ω
m
g
Minimum Speed ω_2
q
f
h
l
n
r



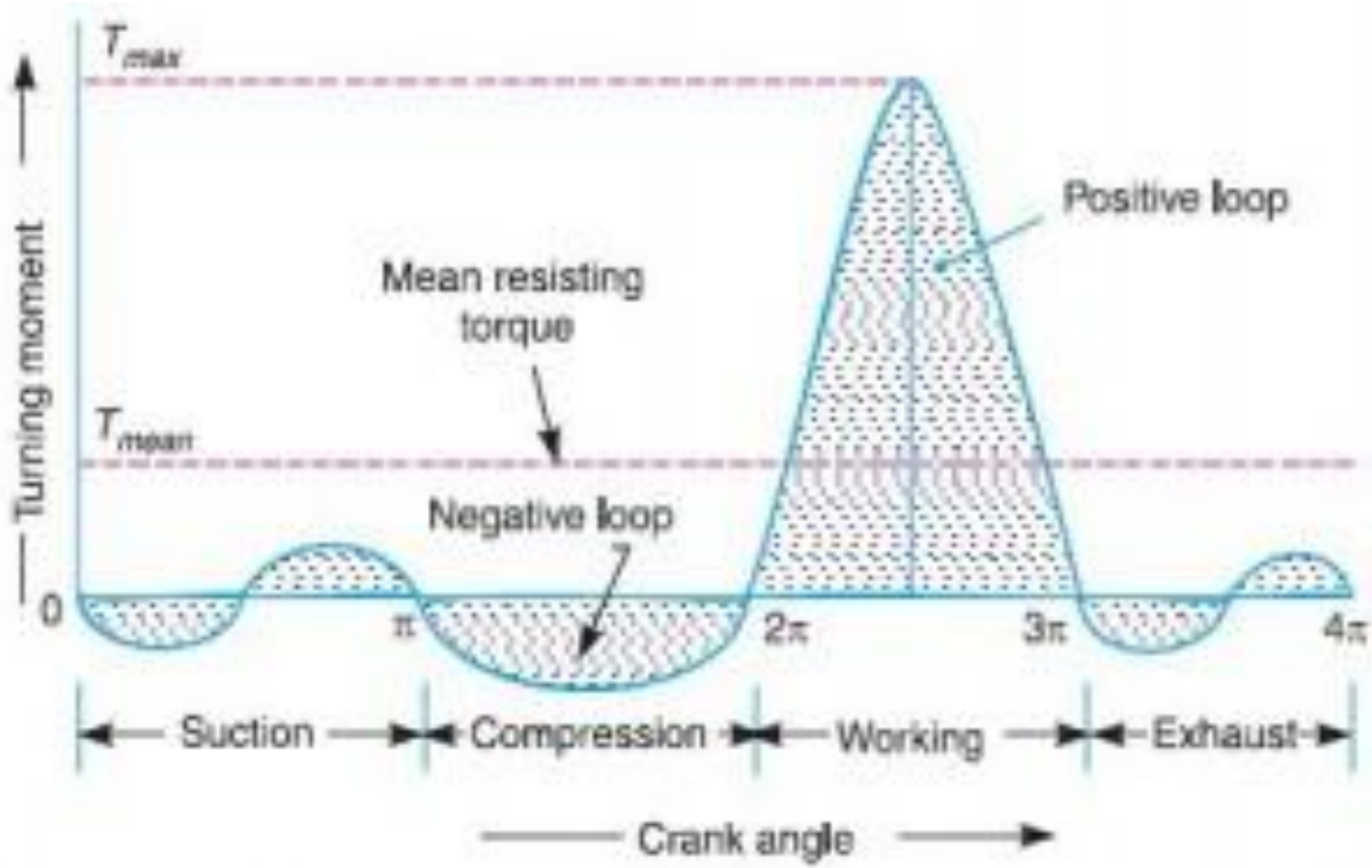
Turning moment diagram
of a 4-stroke engine
Max.fluctuation of
energy
TORQUE lb.-ft.
7200
6300
5400
4500
3600
2700
1800
900
-900
-1800
a
b
c
Mean-Torque
d
e
f
g
0°
90°
180°
270°
360°
450°
540°
630°
720°
SPEED (not to scale)
Maximum Speed ω_1
Mean Speed ω =9 Π rad /sec
Minimum Speed ω_2

Turning moment diagram of a mechanical press



Force-time Relationship for One Full Cycle with a Flywheel

Turning moment diagram



Flywheel

In internal combustion engines,

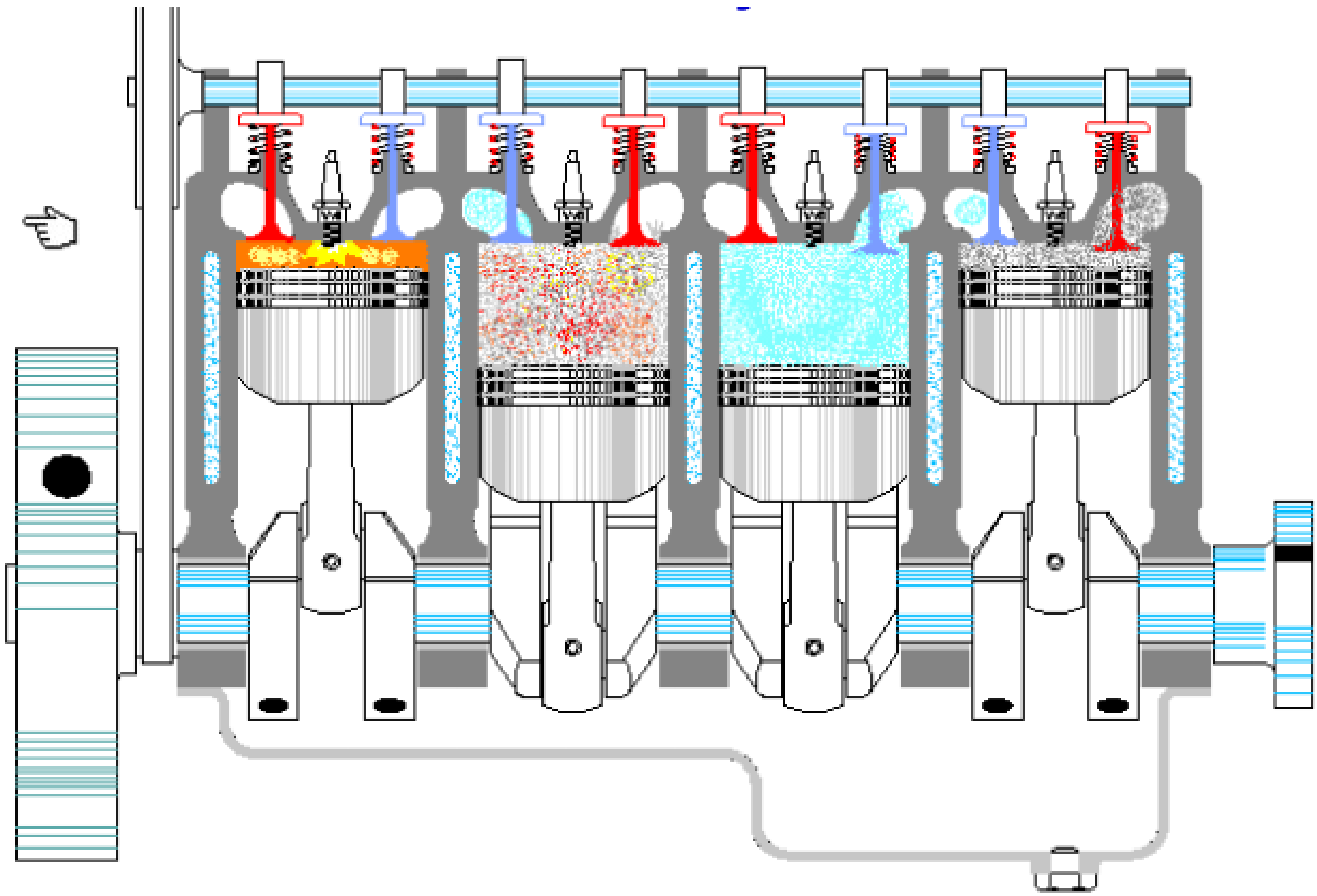
- the energy is developed **during one stroke** and the engine is to run for the whole cycle on the energy produced during this one stroke.
- the energy is developed, **only during power stroke** which is much more than the engine load; and no energy is being developed during *suction*, *compression* and *exhaust strokes* in case of 4 stroke engines & during *compression* in case of 2 stroke engines.

- In a **single cylinder engine(4 Stroke)**, in which there is only one power stroke in two revolutions of the crankshaft, a considerable fraction of energy generated per cycle is stored in the flywheel, & the proportion thus stored decreases with an increase in the No. of cylinders
- In a **4 cylinder engine** about 40% of the energy of the cycle is temporarily stored.

However,

not all of this energy goes into flywheel

During the 1st half of the power stroke, wher energy is being supplied in excess by the burning gases, all of the reciprocating parts of the engine are being accelerated & absorb energy; besides, the rotating parts other than the flywheel also have some flywheel capacity, & this reduces the proportion of the energy of the cycle which must be stored in the flywheel.



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- the energy is developed **during one stroke** and the engine is to run for the whole cycle on the energy produced during this one stroke.

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- The excess energy developed during power stroke is absorbed by the flywheel and releases it to the crankshaft during other strokes in which no energy is developed, thus rotating the crankshaft at a uniform speed.
- When the flywheel absorbs energy, its speed increases and when it releases, the speed decreases. Hence a flywheel does not maintain a constant speed, **it simply reduces the fluctuation of speed**.

- The flywheel does not maintain constant speed
- It simply reduces the fluctuation of speed.
- **A flywheel controls the speed variations caused by the fluctuation of the engine turning moment during each cycle of operation.**

  It does not control the speed variations caused by the varying load.

Maximum Fluctuation of Speed

&

Coefficient of Fluctuation of Speed

•The **Maximum Fluctuation of Speed** the difference between the maximum & minimum speeds during a cycle. *i.e.,* $=(N_1-N_2)$

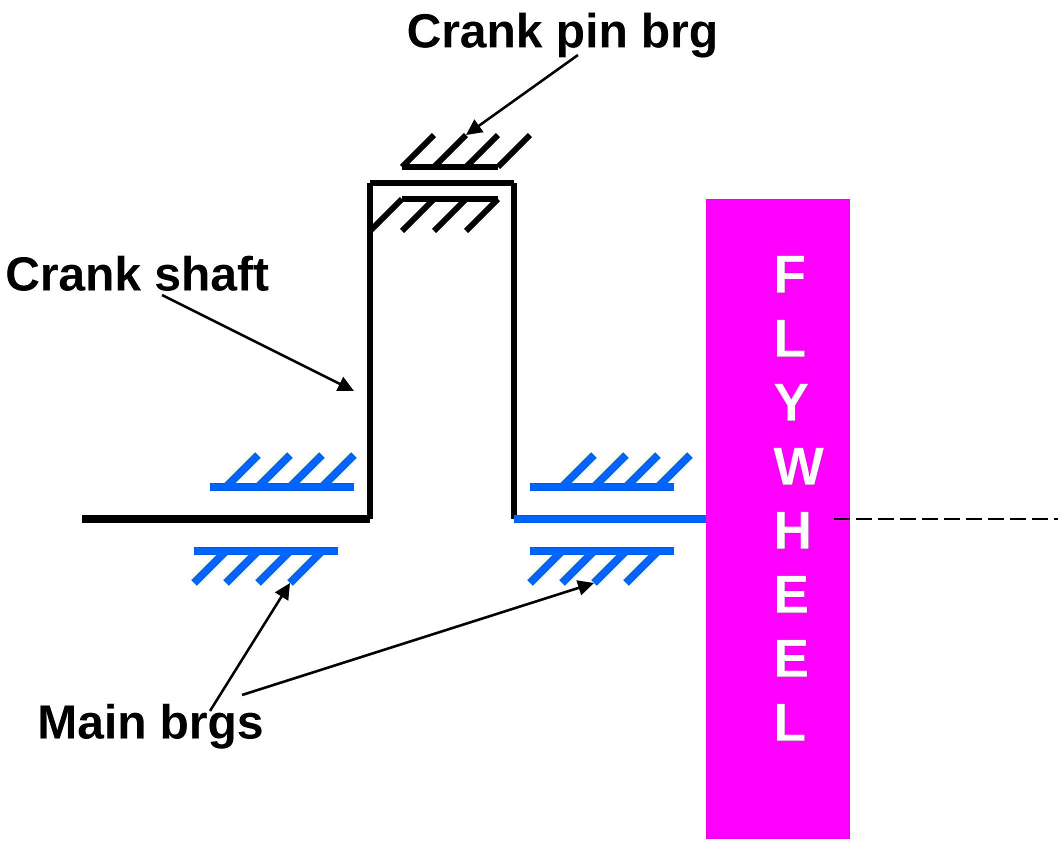
Where, N_1=Maximum speed in r.p.m. during the cycle,
N_2=Minimum speed in r.p.m. during the cycle

•The **Coefficient of Fluctuation of Speed** is the ratio of the maximum fluctuation of speed to the mean speed.

Q- The vertical scale of the turning – moment diagram for a multi-cylinder engine is 1 cm = 7000 Nm of torque and the horizontal scale is 1 cm = 30 ^{o} of crank rotation. The areas (in cm ^{2}) of the turning moment diagram above and below the mean torque line taken in order are -0.5, +1.2, -0.95, + 1.55, -0.85, +0.61, -1.06.

The engine speed is 700 rpm and it is desired that the fluctuation from minimum to maximum speed should not to be more than 2 % of the average speed. Determine the moment of inertia of the flywheel. .(2007) **(Ans. 60 kg. m2**)

Flywheels as energy reservoir :



Example : (flywheel calculation)

The torque exerted on the crank of a **two stroke** engine Is given as

$T(\theta)$

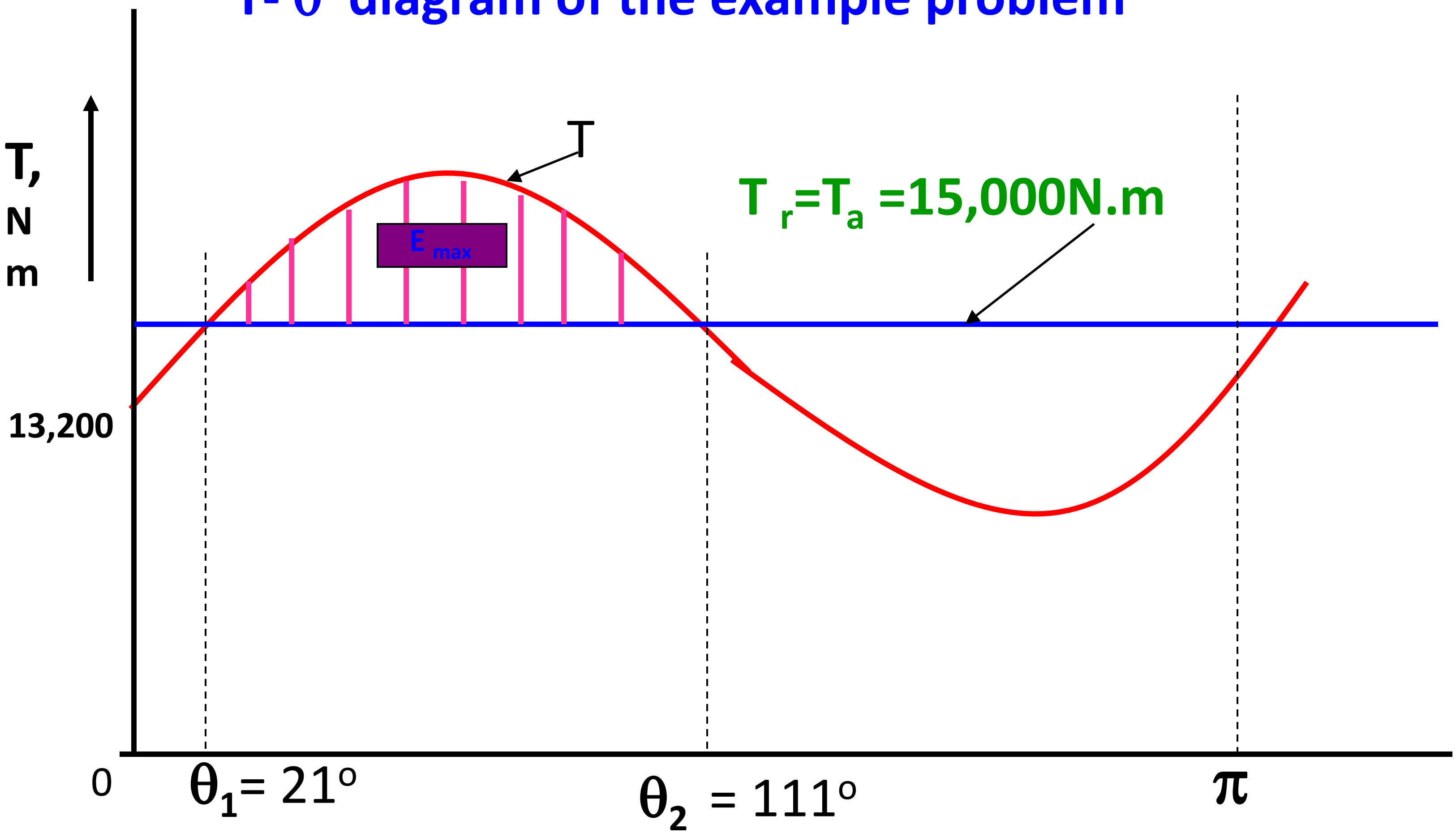
$$= [15{,}000+2{,}000\sin 2(\theta) - 1{,}800\cos 2(\theta)] \ \text{N.m}$$

If the **load torque** on the engine is **constant**,

Determine the following :

1. Power of the engine if the mean speed is 150 rpm.
2. M.I of the flywheel if K_s =0.01
3. Angular acceleration of the flywheel for $\theta = 30^{o}$

T- θ diagram of the example problem



Solution :

$$T_{av} = 1/2\pi \int_0^{2\pi} M \, d\theta$$

$$= 1/2\pi \int_0^{2\pi} (15000 + 2000\sin 2(\theta) - 1800\cos 2(\theta)) \, d\theta$$

= **15,000 N.m = T_r (resisting torque)**

Work output /cycle = (15,000 X 2π) N.m

Work output /second = 15,000 X 2π (150 /60) W

Power of the engine = **235.5 k W**

The value of θ at which T-θ diagram intersect with T_r are given by

$$[15000+2000\sin 2(\theta) - 1800\cos 2(\theta)] = 15{,}000 \text{ N.m}$$

or

$$[2000\sin 2(\theta) - 1800\cos 2(\theta)] = 0,$$

$$\therefore \tan 2\theta = 0.9$$

$$\mathbf{2(\theta)_1 = 42^o \quad \& \quad 2(\theta)_2 = (180+42)^o}$$

$$\mathbf{(\theta)_1 = 21^o \quad \& \quad (\theta)_2 = 111^o}$$

$$\mathbf{E}_{\mathbf{max}} = \int_{(\theta)1}^{(\theta)\,2} (2000\sin 2(\theta) - 1800\cos 2(\theta))\, d\theta$$

= **2690.2 N.m**

Contd....

We have $K_s = 0.01$ & $\omega = (150 \times 2\pi)/ 60$

$= 15.7 \text{ rad /s}$

Using the relation , $\boxed{E_{max} = I\,\omega^2\,K_s}$

M.I of the flywheel , $I = 2690.2 / (15.7^2 \times 0.01)$

$= \underline{\mathbf{1090\ kg.m^2}}$

when $\theta = 30^o$, $T = 15{,}000 + 1732 - 900 = \underline{\mathbf{15{,}832\ N.m}}$

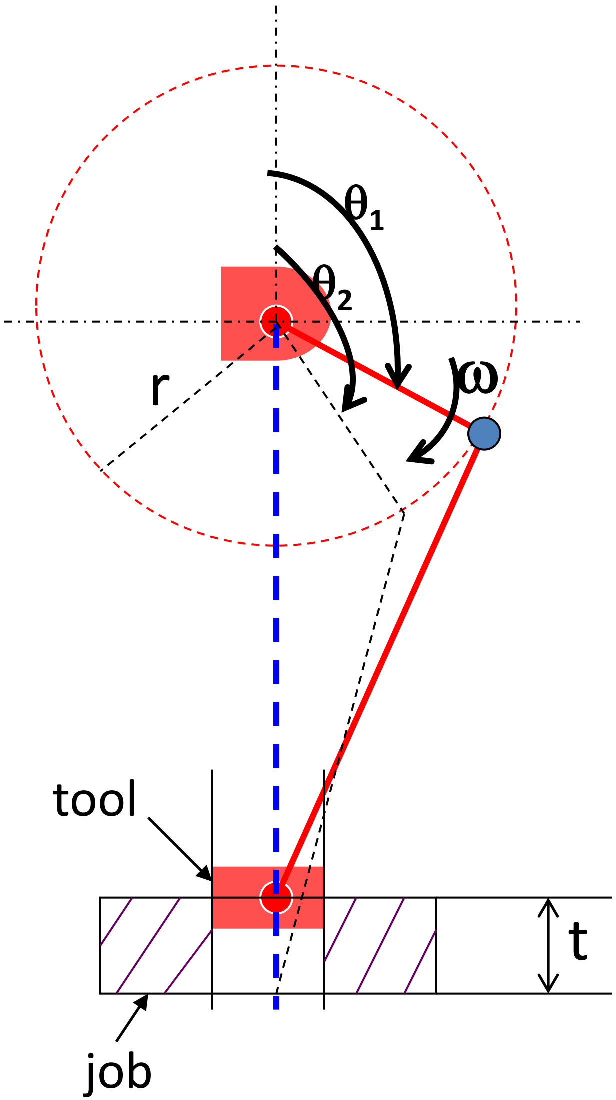
Hence ang. acceleration of the flywheel at $\theta = 30^o$

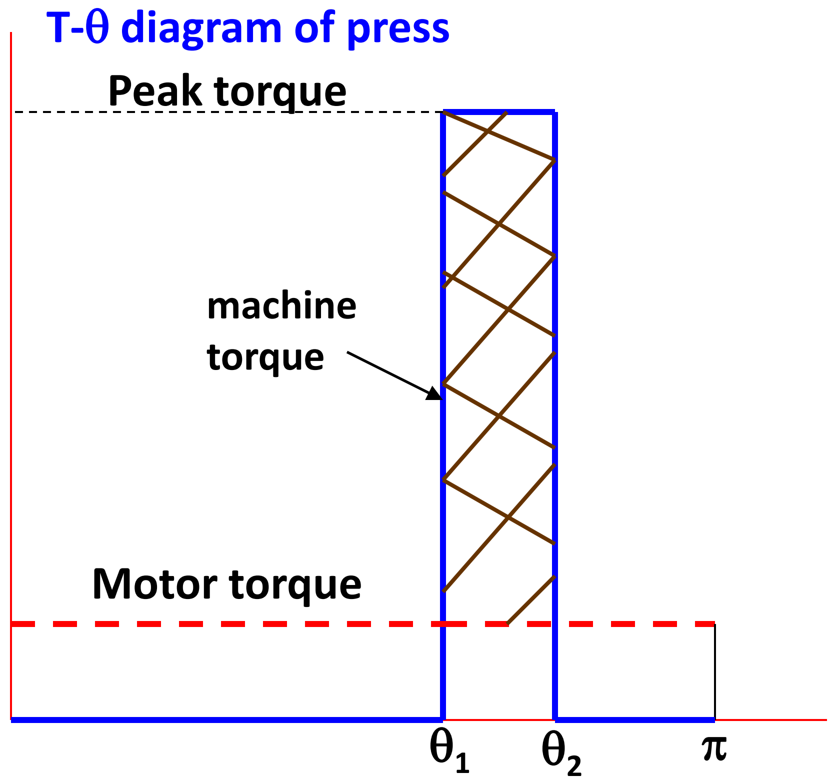
$$\alpha_{30} = (15{,}832 - 15{,}000) / 1090$$

$$= \underline{\mathbf{0.764\ rad /s^2}}$$

Flywheels of punching presses:

Prime mover	shaft torque	Load torque
Reciprocating Engine	varying torque	constant
Electrical Motors for Press operation	constant	varying torque





Assuming uniform velocity of the tool,

$$(\theta_2 - \theta_1) / 2\pi = t / 2s = t / 4r$$

Example :

Operation :3.8 cm dia hole in 3.2 cm plate

Work done in punching : 600 N.m / cm^2
of sheared area

Stroke of the punch : 10.2 cm

No. of holes punched : 6 holes /min

Max speed of the flywheel at its $\mathbf{r_g}$ = 27.5 m /s

Min speed of the flywheel at its $\mathbf{r_g}$ = 24.5 m /s

To find :

Power of the motor of the machine ?

Mass of the required flywheel ?

Solution :

Sheared area /hole $= \pi\, d\, t = \pi \times 3.8 \times 3.2 = 38.2\ cm^2$

$\therefore$ work done in shearing /hole = 38.2 X 600

= 22,920 N.m

$\therefore$ work done / minute = (22,920 X 6) N.m

Power of the motor = (22,920 X 6) / 60

= **2.292 k W**

We have, $t/2s = 3.2 / (2 \times 10.2)$

$= 3.2 / 20.4 = \mathbf{(\theta_2 - \theta_1) / 2\pi}$

Energy required by the machine / cycle = **22,920 N.m**

Energy delivered by the motor during actual Punching

i.e (when crank rotates from θ_1 to θ_2)

= 22,920 X (t /2s)

= 22,920 X (3.2 /20.4)

= **3,595 N.m**

Contd ...

$\therefore$ **Max .fluctuation of energy,**

$$E_{max} = 22{,}920 - 3595 = \underline{19{,}325 \text{ N.m}}$$

$$= I \, (\omega_1^2 - \omega_2^2) / 2$$

$$= m \, r_g^2 \, (\omega_1^2 - \omega_2^2) / 2$$

But $r_g^2 \ \omega_1^2 = 27.5$ **m/s** & $r_g^2 \ \omega_2^2 = 24.5$ **m/s**

$$\therefore \quad m \, (27.5^2 - 24.5^2) / 2 = 19{,}325$$

$$m = \underline{244 \text{ kg}}$$