Thermodynamics
Professor Anand T N C
Department of Mechanical Engineering
Indian Institute of Technology, Madras
Tutorial Problem on 'Work' - Part 1

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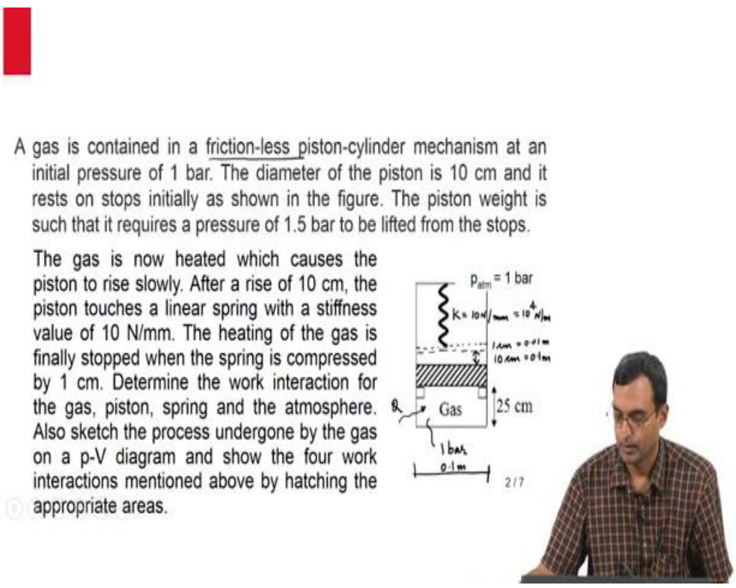


Solution:

We have a frictionless piston-cylinder mechanism containing gas.

Initial volume of the gas, $V_1 = \frac{\pi}{4} d_{cyl}^2 h = 1.96 \times 10^{-3} m^3$

$p_1 = 1\ bar = 10^5 Pa$

The piston lifts up only when the pressure inside becomes 1.5 bar. Till then, the process is constant volume process. Let's call this state at the end of the constant volume process as state 2.

$p_2 = 1.5\ bar$

$V_2 = V_1$

After this, the piston moves 10 cm and hits the spring. It moves against a constant atmospheric pressure of 1 bar and constant weight of piston. Hence, this expansion process is a constant pressure process. Let's call the state after this constant pressure process as state 3.

$p_3 = p_2 = 1.5\ bar$

$$V_3 = V_2 + Volume\ swept\ during\ the\ movement\ of\ the\ piston\ by\ 10\ cm$$
$$= V_2 + \frac{\pi}{4} d_{cyl}^2 (0.1) = 2.74 \times 10^{-3}\ m^3$$

Heating of the gas is still continued till the spring is compressed by 1 cm. This is state 4.

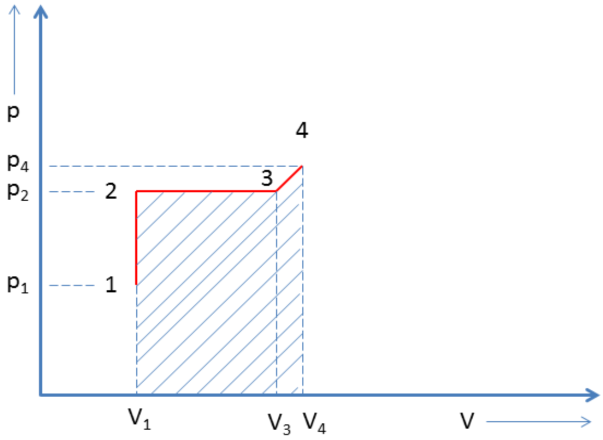
$$V_4 = V_3 + \frac{\pi}{4} d_{cyl}^2 (0.01) = 2.82 \times 10^{-3}\ m^3$$

The spring is linear. As it gets compressed, it applies force on the piston which is proportional to its movement. Hence, the pressure of the gas also varies linearly.

$$Pressure\ of\ the\ gas\ at\ state\ 4 = p_3 + \frac{Force\ on\ the\ piston\ due\ to\ spring\ at\ state\ 4}{Area\ of\ the\ piston}$$

$$p_4 = p_3 + \frac{0.5kx^2}{\frac{\pi}{4} d_{cyl}^2} = p_3 + \frac{0.5 \times 10 \times 10^3 \times 0.01^2}{7.85 \times 10^{-3}} = 1.5 \times 10^5 + 63.69$$
$$= 150063.69\ Pa$$

The total work interaction for the gas is the hatched area shown in the following figure:



Total work interaction = Area of the rectangle $V_1 23 V_3$ + Area of the trapezium $V_3 34 V_4$

$$= p_2(V_3 - V_2) + 0.5 \times (p_2 + p_4) \times (V_4 - V_3) = 1.5 \times 10^5 \times 0.78 \times 0.001 + 0.5 \times (150000 + 150063.69) \times (0.08 \times 0.001) = 117 + 12 = 129\, J$$

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