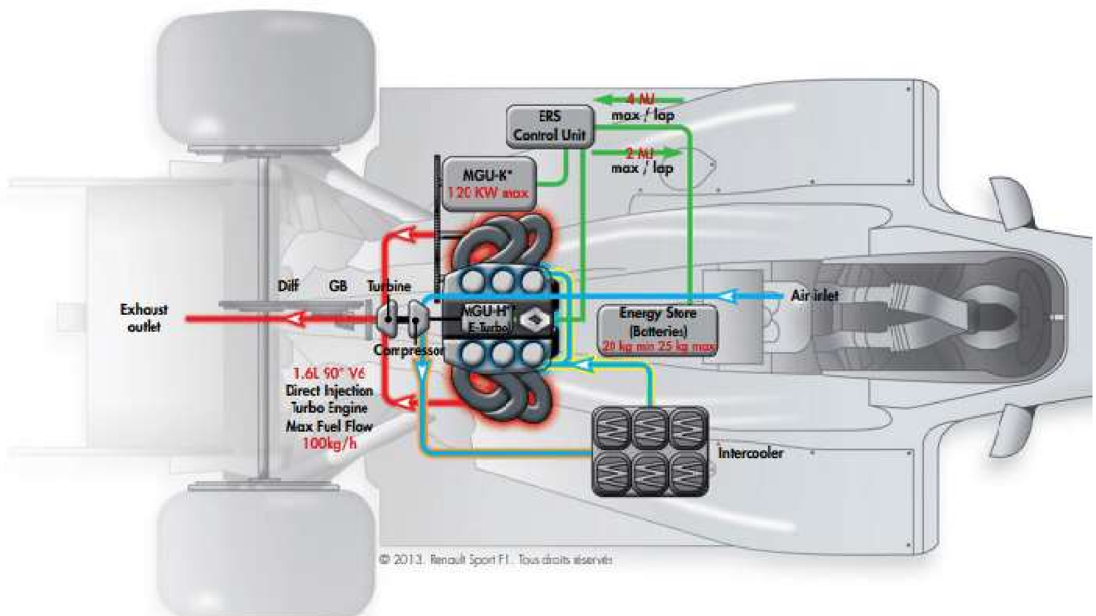
ME 352 : Applied Thermodynamics

Energy Recovery System[ERS] in F1 Cars: MGU-K and MGU-H

Het Sekhalia - 200003032

Jyotirmay Mitra - 200003038

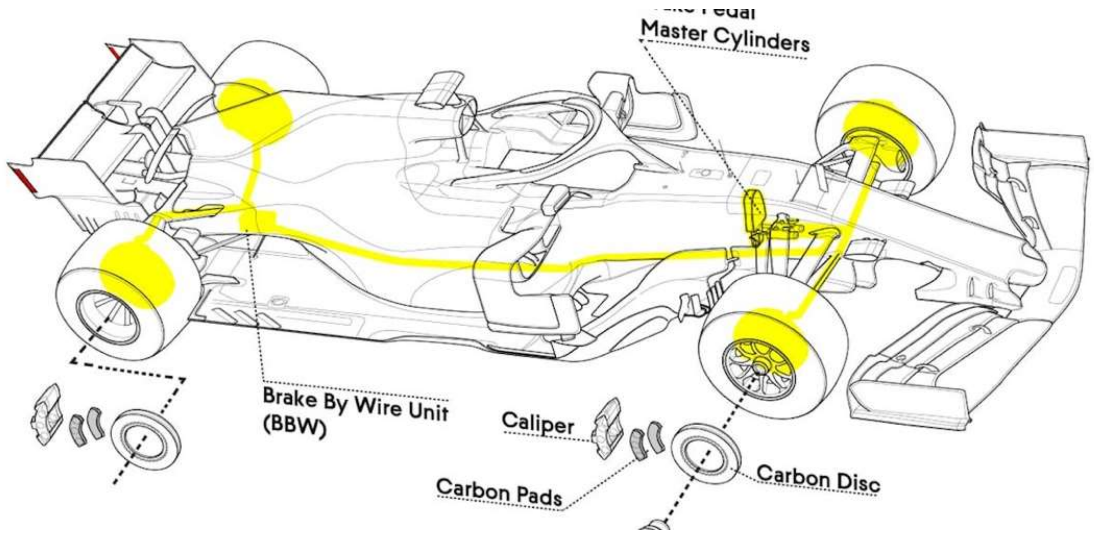


Abstract:

Energy conservation has been a major focus in the recent decades.The Formula-one(F-1) cars use fossil fuels to power their internal combustion engines,the most common being unleaded racing gasoline petrol.As we know fossil fuels are non renewable resources so there is a need to get energy from alternative sources.This report focuses on one such way by recovering the lost energy in the friction generated in the braking system and energy lost in the exhaust gases after combustion.The former is achieved by MGU-K and the latter is achieved by MGU-H. It also shows the reduction of carbon footprint due to introduction of MGU-K in F1 cars.

Introduction:

How does the brake system on an F1 car work?



Two master brake cylinders, one for the front wheels and one for the back, are compressed when the driver pushes the brake pedal, creating fluid pressure.The technology is relatively simple to use up front. The front brake callipers receive the fluid pressure immediately. Six pistons clamp pads against the disc within each calliper, and it is this friction that causes the car to slow down.Three different forces can be used to slow down the wheels at the back: friction from the brakes, resistance from the rotating engine (also known as "engine braking"), and electrical braking from the MGU-K (Motor Generator Unit - Kinetic) hybrid electric motor.

When the driver hits the brake pedal, the three systems work together through the Brake By Wire (BBW) system to produce the total retardation that has been asked, even though the driver can individually control each of these effects on his steering wheel.An electrical pressure sensor detects the fluid pressure the driver creates in the rear brake circuit when he presses the pedal. The Electronic Control Unit (ECU) interprets the data from this sensor, which indicates the driver's total demand for rear brakes, into a series of commands to brake the vehicle's rear.The greater the signal, the more aggressively the ECU will instruct the three rear systems—the brake calipers, the engine braking, and the MGU-K—to give the desired retardation. The larger the signal, the harder the driver presses; the larger the signal, the harder the driver presses.The way the team configured the vehicle, as updated by the driver's adjustments to the switch settings on the steering wheel, determines how the ECU allocates its efforts among the three systems.

What is MGU-K?

The MGU-K (Motor Generator Unit - Kinetic) is a crucial part of the Energy Recovery System (ERS) in Formula One (F1) cars. The MGU-K is in charge of recovering and storing kinetic energy that is produced during braking and deceleration, and utilizing this stored energy to provide an extra boost of power during acceleration.The MGU-K transforms the kinetic energy created by the motion of the car into electrical energy when the driver applies the brakes. The battery of the car then stores this electrical energy for later use. When the driver accelerates again, the battery's stored energy is discharged and used to power the car's electric motor, which gives the engine a further boost.

The F1 regulations, which set the maximum power output and energy capacity of the ERS, place a ceiling on how much energy the MGU-K can collect and store. In order to prevent the car's performance from being unfairly increased for an extended period of time, the rules also call for the driver to consume the stored energy within a specific amount of time.In recent years, as the sport has transitioned towards hybrid powertrains that combine internal combustion engines with electric motors, the use of the MGU-K in F1 cars has grown in significance. The MGU-K aids in enhancing the overall performance and efficiency of the vehicle by collecting and recycling kinetic energy that would otherwise be lost during braking. It also helps to cut down on fuel consumption and pollutants.

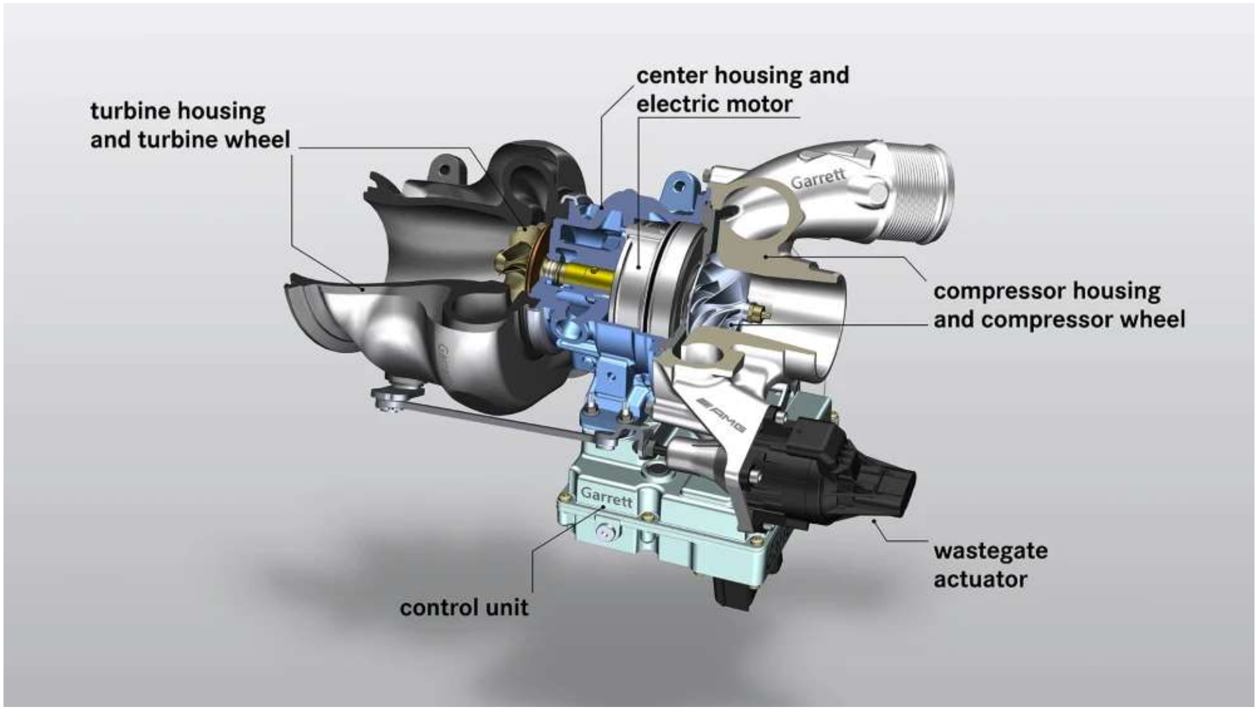
Use of exhaust gasses in Turbocharging

A shaft connects the turbine with the compressor which are the two primary parts of a turbocharger.A turbo's compressor and turbine are connected to the car's intake and exhaust, respectively. Gasses from the exhaust system enter the turbine's exhaust system and cause it to spin. The compressor, which compresses the air before sending it down the intake, is spun by the rotating turbine. More air supplied to the engine allows it to burn more fuel at once, increasing power. Thus, turbocharged engines are more fuel-efficient than natively aspirated engines since turbocharging also helps with more complete combustion.

Why use MGU-H?

The MGU-H is affixed to the turbocharger between the compressor and the turbine in a Formula 1 car. The MGU-H is powered by the same exhaust gas that powers the turbocharger; some of the gas that would typically pass through the turbine is instead sent into the MGU-H.When exhaust reaches the MGU-H, a number of magnets inside the MGU-H begin to spin around one another. The actual source of electricity is this. The car's energy reserves receive this power, where it stays until it is required again.

However, when the MGU-H runs as a motor, it doesn't drive the wheels; instead, it gives the turbo extra power. "Turbo lag" refers to the time it typically takes for the turbine to start spinning up after the driver presses the gas pedal. The engine typically produces a significant amount less power than usual while experiencing turbo lag.In order to make up for this, the MGU-H uses its secondary duty as a motor to continue to operate the turbo's compressor even when the driver isn't pressing the accelerator. Consequently, turbo lag is virtually eliminated as a result.



Reduction of carbon emissions

In numerous ways, Formula One (F1) cars' use of MGU-K (Motor Generator Unit - Kinetic) and MGU-H (Motor Generator Unit - Heat) helps to lower their carbon footprint:

1)Improved Energy Efficiency: The MGU-K and MGU-H contribute to a vehicle's powertrain's overall efficiency by recovering and recycling kinetic and thermal energy that would otherwise be lost during braking and deceleration. As a result, less gasoline is used to provide the same amount of power, which lowers the car's carbon emissions.

2)Reduced Fuel Consumption: The MGU-K and MGU-H can contribute more power during acceleration, allowing the car's engine to run at a lower RPM (revolutions per minute) and use less fuel. As a result, the car emits fewer greenhouse gases.

3)Promotion of Sustainable Technology: The usage of MGU-K and MGU-H in F1 cars pushes manufacturers to make investments in the creation of more effective and environmentally friendly powertrain systems. This may have a favorable effect on the larger automotive sector and aid in lowering road vehicle carbon emissions.

4)Energy Recovery: The MGU-K and MGU-H enable F1 cars to capture and store lost energy, reducing the need for additional power production and, ultimately, lowering carbon emissions from power plants.

MGU-K and MGU-H technology are used in F1 cars to improve competitiveness on the track while also promoting sustainability and energy efficiency in the motorsports industry.F1 racing can lead by example for the larger automotive industry and aid in the drive to address climate change by decreasing the carbon footprint of its cars.

Methodology:

Analysis of MGU-K impact on efficiency:

$$\eta = \frac{W_{out}}{Q_{in}}$$

where η is the efficiency, W_out is the power output, and Q_in is the heat input.

In this case, the heat input is the energy released by the combustion of fuel, which can be calculated as:

$$\dot{Q}_{in} = \dot{m}_f \cdot LVH$$

where m_fuel is the mass of fuel consumed and LHV is the lower heating value of the fuel. Let's assume that the fuel used in the F1 car has a LHV of 44.4 MJ/kg.

For a race distance of 300 km, the car consumes 100 kg/hr of fuel for a given rpm of ICE greater than 10,500. Therefore, the heat input is:

$$\dot{Q}_{in} = 100\ \frac{kg}{hr} \cdot 44.4\ \frac{MJ}{kg}$$

$$= \frac{4440}{3600}\ MW \ = \ 1233.333\ kW$$

Now let's calculate the power output of the engine when the MGU-K is in use. The engine produces 850 bhp, and the MGU can provide an additional 120 kW or approximately 160 bhp. Therefore, the total power output is:

$$\dot{W}_{mgu} = \ 120\ kW$$

Now we can calculate the efficiency:

$$\eta \ = \ \frac{W_{out}}{Q_{in}} = \ \frac{120}{1233.33}$$

$$= \ 0.0973$$

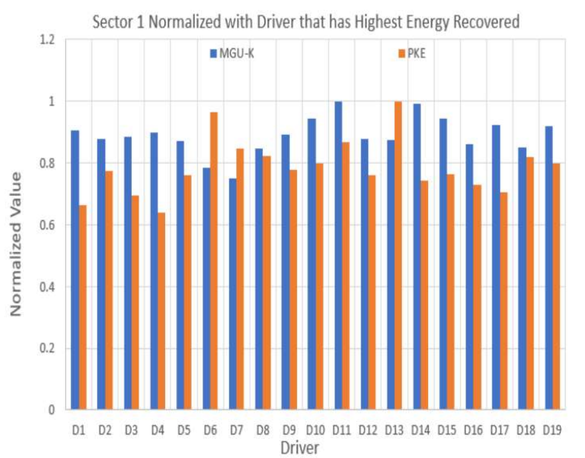
$$= \ 9.73\ \%$$

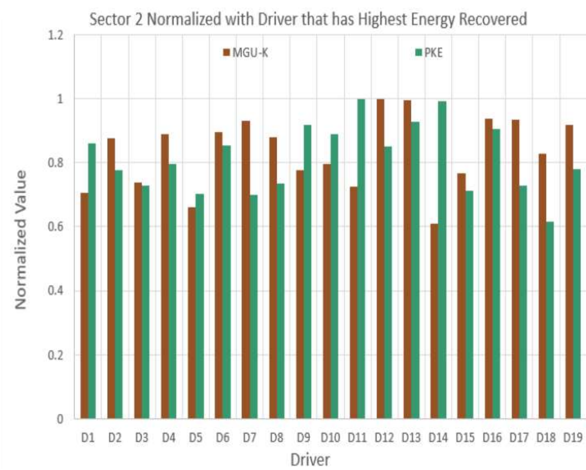
Carbon emissions: Since the car is using less fuel, it will also emit less carbon dioxide (CO_2) per kilometer traveled. Let's assume that the car's CO_2 emissions are directly proportional to its fuel consumption. The car's fuel consumption is reduced by 10%, so its CO_2 emissions should also be reduced by the same amount. According to the U.S. Environmental Protection Agency, the combustion of 1 kg of gasoline produces 8.887 kg of CO_2. Therefore, the car's CO_2 emissions for the race distance of 300 km are

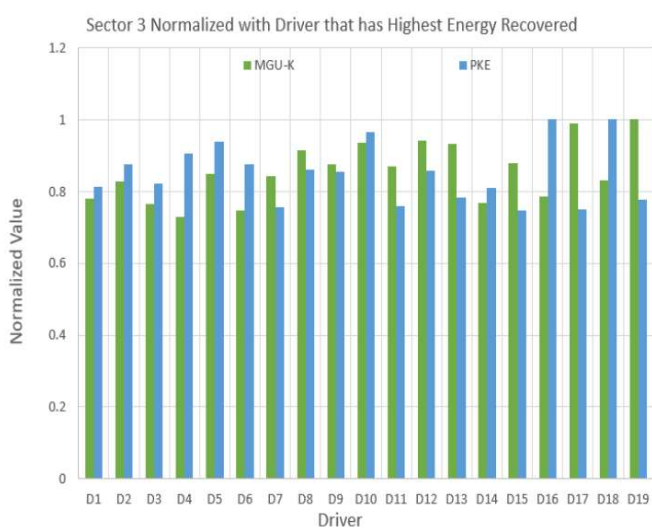
Without the MGU-K: 100 kg fuel x 8.887 kg CO_2/kg fuel = 888.7 kg CO_2

With the MGU-K: 90 kg fuel x 8.887 kg CO_2/kg fuel = 800.8 kg CO_2

This corresponds to a reduction in carbon emissions of 10%.







Figures: Comparative analysis of MGU-K and PKE potential of all the drivers for all three sectors of the track

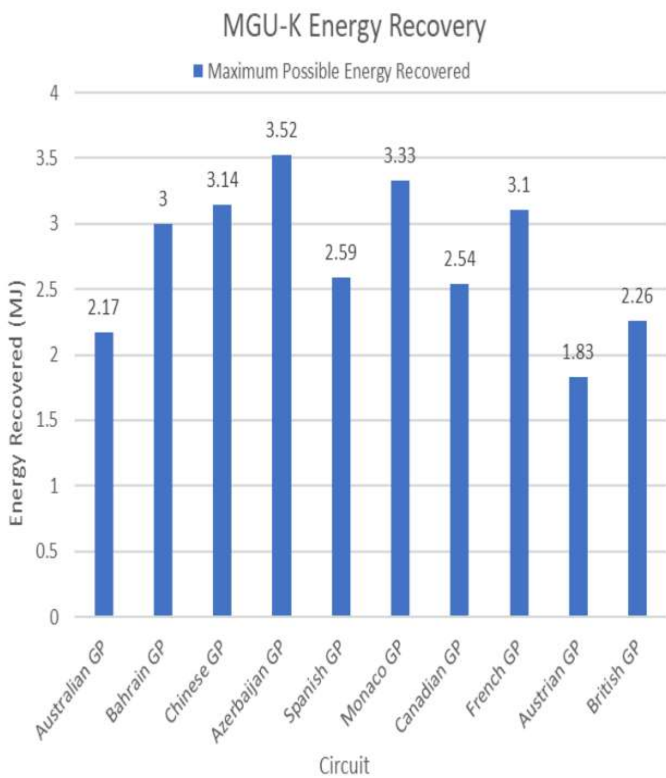


Fig: Circuit Specific MGU-K Energy Recovery Values for Qualification.

Analysis of MGU-H:

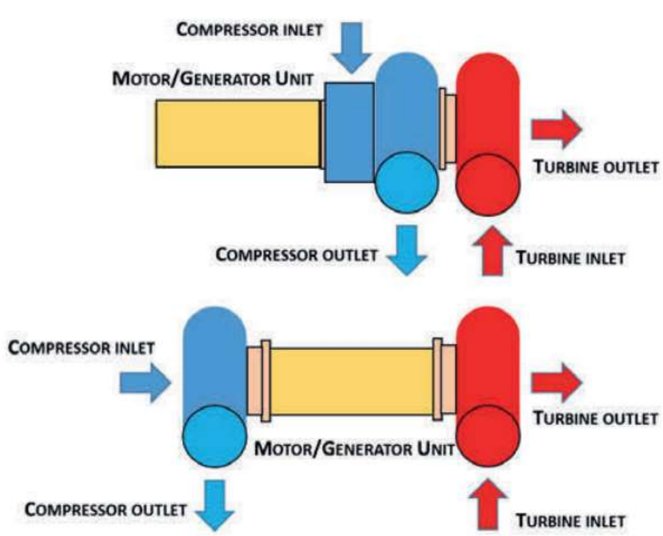
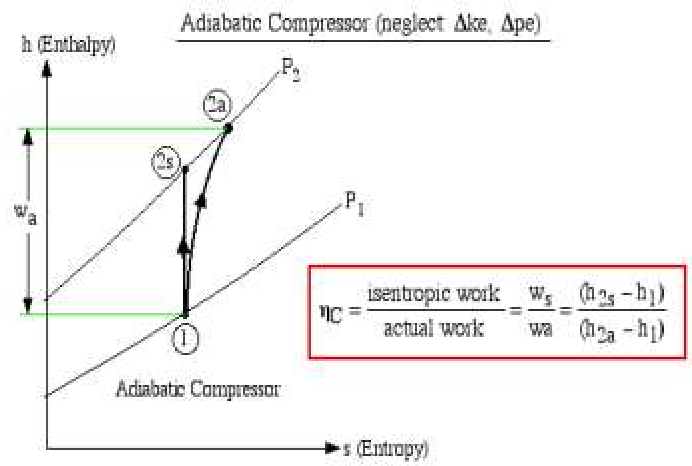


Fig. Schematic of a turbocharger with a motor/generator unit side of compressor (top) or between compressor and turbine (bottom) as used in F1

<u>For the Compressor</u>:



$$\eta_c = \frac{isentropic\,work}{actual\,work} = \frac{\dot{W}_s}{\dot{W}_a}$$

$$\dot{W}_a = \frac{\dot{W}_s}{\eta_c} = \frac{\dot{m}_a c_{p,a}\left(T_{2s} - T_1\right)}{\eta_c}$$

$$= \frac{\dot{m}_a \cdot c_{p,a} \cdot T_1}{\eta_c}\left(\frac{T_{2s}}{T_1} - 1\right)$$

As it is a isentropic process :

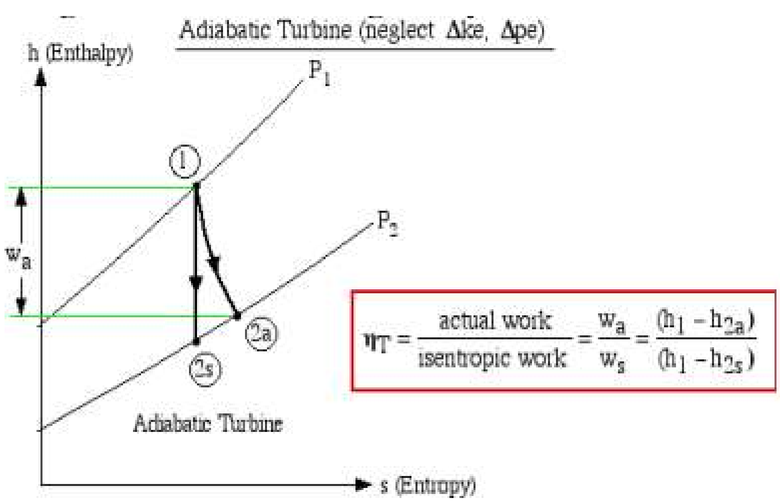
$$\frac{T_{2s}}{T_1} = \left(\frac{P_{2s}}{P_1}\right)^{\frac{(\gamma-1)}{\gamma}}$$

$$\dot{W}_a = \frac{\dot{m}_a \cdot c_{p,a} \cdot T_1}{\eta_c}\left[\left(\frac{P_{2s}}{P_1}\right)^{\frac{(\gamma-1)}{\gamma}}\right]$$

keeping $T_1 = 303\text{K}$, $\gamma = 1.4$

$P_c = 16.76559\ kW$

For the turbine



$$\eta_t = \frac{actual\ work}{isentropic\ work} = \frac{\dot{W}_a}{\dot{W}_s}$$

Therefore, $\dot{W}_a = \eta_T \cdot \dot{W}_s$

$$= \left(\dot{m}_a + \dot{m}_f\right)\eta_T \cdot c_{p,g} \cdot T_1\left(1 - \frac{T_{2s}}{T_1}\right)$$

As it is a isentropic process:

$$\frac{T_{2s}}{T_1} = \left(\frac{P_{2s}}{P_1}\right)^{\frac{(\gamma-1)}{\gamma}}$$

$$P_T = \left(\dot{m}_a + \dot{m}_f\right)\eta_T \cdot c_{p,g} \cdot T_1\left[1 - \left(\frac{P_{2s}}{P_1}\right)^{\frac{(\gamma-1)}{\gamma}}\right]$$

$$P_T = 32.3026\, kW$$

Energy balance equation: $P_T - P_c \pm P_{MGU-H} = T\omega$

$T\omega = 2.9952\, kW$

$P_{MGU-H} = 12.651\, kW$

Therefore, the percentage energy recovered from exhaust = $\frac{P_{MGU-H}}{P_T}$ = 0.3916

Hence 39.16 % is the efficiency of the MGU-H unit.

Conclusion and Future Scope:

The results are as follows-

1)When the MGU-K is being used in F1 cars,the net efficiency of its engines increase by **9.73%**.

2)The carbon emissions due to the introduction of MGU-K in F1 cars is quite a considerable amount of about **10%.**

3)Introduction of MGU-H allows us to recover about 12.651W of exhaust energy and store it in the form of electrical energy which can be used to prevent **turbo-lag.**This is about 39.16% of total exhaust energy.

Today,the MGU-K and MGU-H systems available are quite expensive and thus the future scope can be to develop comparatively cheaper MGU-K and MGU-H systems to allow them to be used more often.

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