Improving diesel engines performance by managing compressor surge

The demand for freight transport is growing, as is the demand for heavy-duty diesel engines, when alternative technologies for heavy vehicles, such as battery and fuel cell electric powertrains to reduce greenhouse gas emissions, have not yet become widespread. Since the development of fuel cell powertrains is slow, battery-powered powertrains have too many disadvantages, such as higher vehicle cost, limited range, long recharge times and limited cargo weight, to compete with diesel engines in the near future. On the other hand, improvements to conventional diesel powertrains are needed to meet new emission standards, including the development of turbocharging systems and on-board electronic controls. The turbocharger is an essential component for reducing fuel consumption and increasing engine power, which can be achieved by recovering energy from the exhaust gas when the combustion engine is equipped with a turbine and compressor sized to match the power rating and surge margin. The new approach to emission control strategy is based on the installation of turbochargers for diesel engines with throttle valves, which are mainly used in gasoline engines to regulate the ratio of air mass to fuel mass. The compressor impeller supplies compressed air to the engine to burn fuel more efficiently, but all dynamic compressors experience a serious unstable condition known as surge that should be avoided. Closing the throttle valve can cause the compressor to surge.

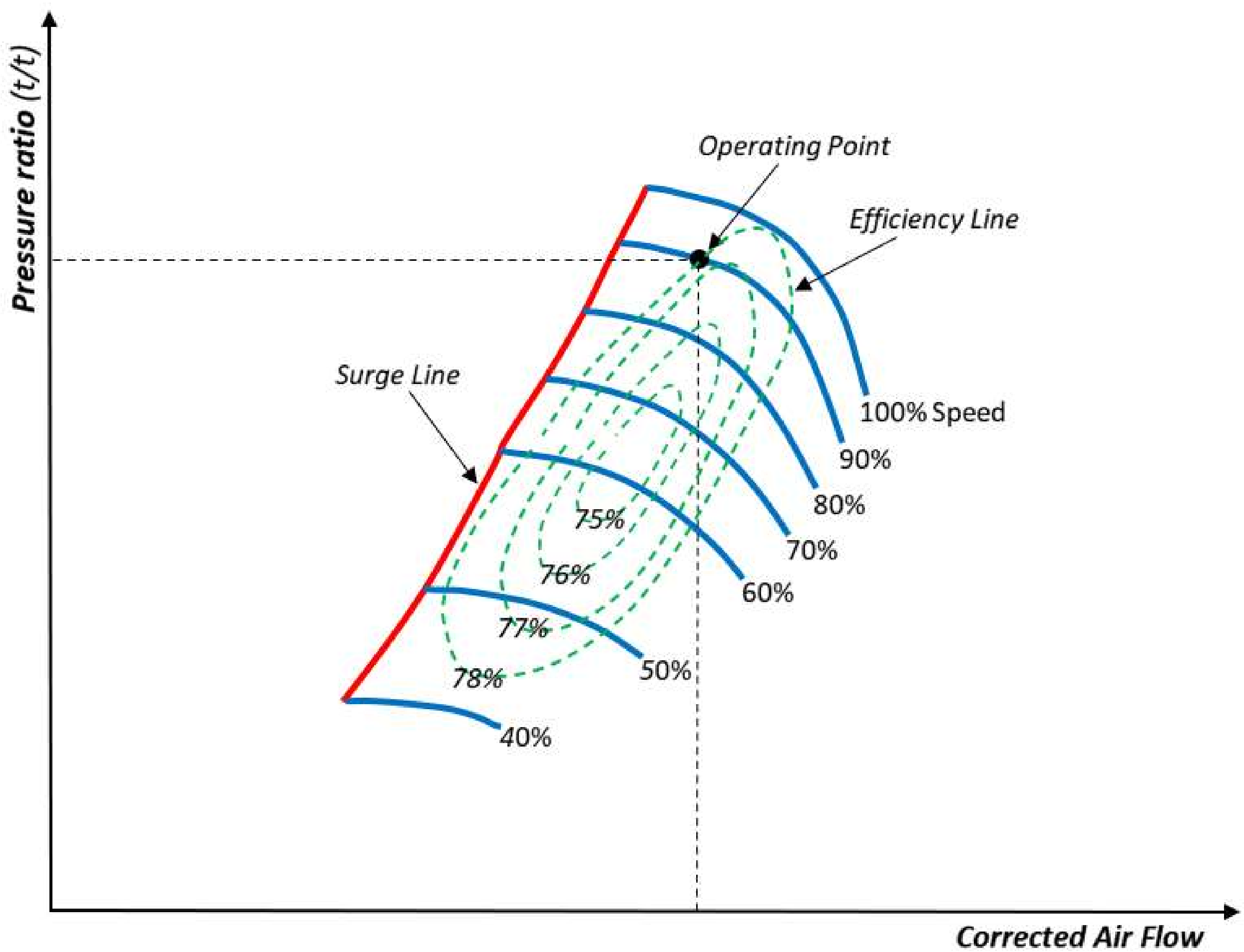

FIG. 1

Compressors are usually tested for unstable conditions, then the test results are combined into a compressor map that graphically describes the performance of a particular compressor. FIG. 1 shows a typical turbocharger compressor map provided by manufacturers, including compressor surge line, constant compressor speeds and efficiency lines, where the horizontal axis represents the corrected air flow and the vertical axis represents the compressor's compression ratio. Compressor operating to the left of the surge line will cause severe fluctuations in boost pressure and output flow and may be damaged by prolonged use in this area. One way to prevent the operating point from crossing the surge line is to allow air to flow from the compressor outlet after the intercooler to the compressor inlet through the recirculation line when the controlled variable falls below the set point. Accurate determination of the operating point relative to the surge line is critical to minimizing recirculation, which maximizes efficiency and protects the compressor.
The exhaust gases of the engine can drive the turbine wheel up to 200,000 rpm and more, then the compressor wheel through the shaft can have the same speed, as a result, the air velocity can reach 100 m/sec at rated power. In such cases, the dynamic pressure can be about 10% or more of the total pressure and cannot be ignored. Then the vertical coordinate on the compressor map should be replaced by the total pressure ratio taking into account the dynamic pressure to ensure high control accuracy. Another factor to consider is that the change in air density is dependent on ambient conditions, decreases with increasing inlet temperature and as inlet pressure decreases with altitude, causing the compressor speed to increase to maintain a high boost pressure. For these reasons, it is highly desirable to measure flow and pressure at appropriate points.

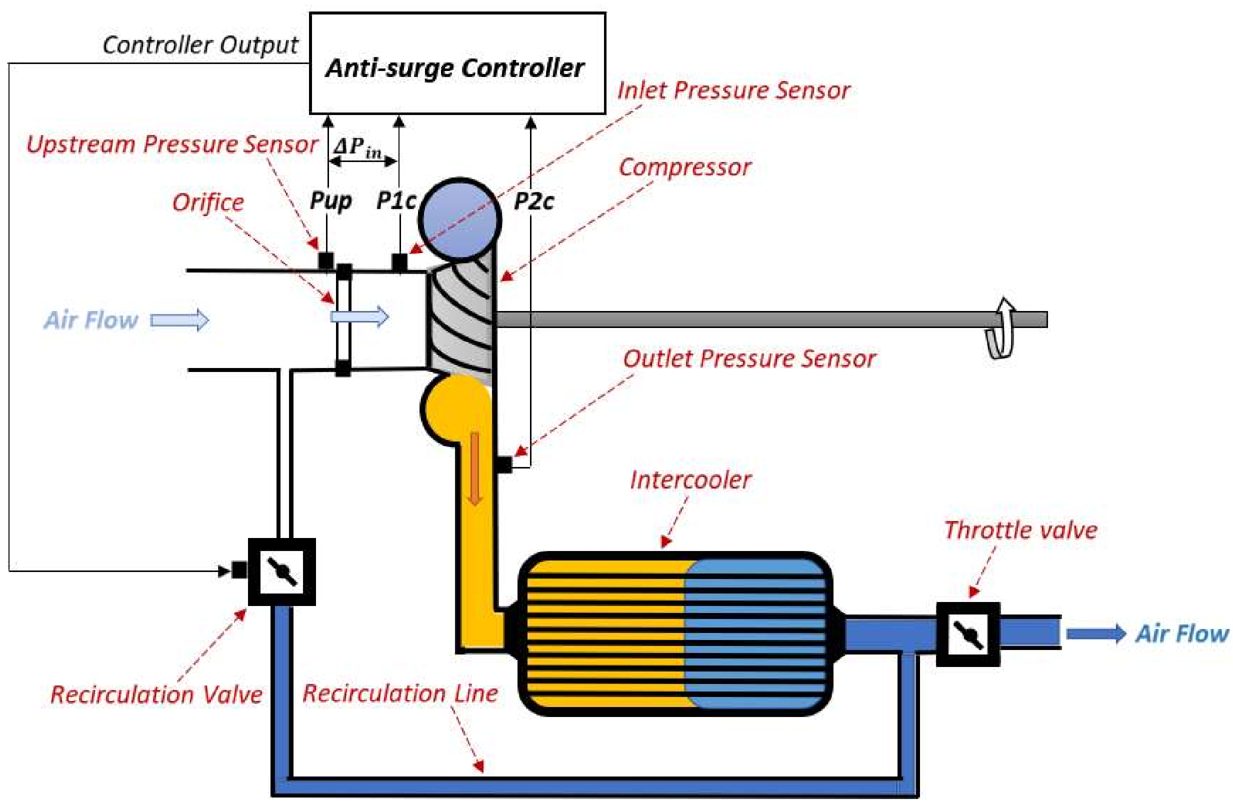

FIG. 3

FIG.2 is a schematic diagram of a turbocharger with a compressor, an orifice as a flowmeter, three pressure sensors, an intercooler, a recirculation line, a recirculation valve, a throttle valve and an anti-surge controller regulating the recirculation valve after processing the input signals. The Pup pressure sensor is located upstream of the orifice. The $P1c$ and $P2c$ are pressure sensors at the compressor inlet and outlet, respectively. The ΔP_{in} is the differential pressure across the flowmeter at the compressor inlet equal to (Pup -$P1c$), which is used to calculate the corrected air flow. Compressor total pressure is defined as static pressure plus dynamic pressure when dynamic pressure is calculated as a function of static pressure and corrected air flow.

A PID controller (proportional-integral-derivative with feedback) is typically used to regulate an anti-surge or recirculation valve to protect the compressor from crossing the surge line. The anti-surge PID controller continuously calculates the error value ER as the difference between the desired setpoint SP (%) and the input value of the controlled variable CV (%) to tune the control output. FIG.1 1 shows a surge line to be stored in the electronic engine control system as a table function of the total compressor pressure ratio and the minimum corrected air flow rate to indicate a stable operating area. The actual controlled variable CV(%) must be calculated based on the input data from the pressure sensors. Typically for centrifugal compressors in industrial applications, the minimum safety threshold, or in other words, the SP (%) set point is chosen at least 10% to the right of the surge line depending on how fast the anti-surge valve is operating.

Accurate air flow measurement is critical to maximize turbocharger boost pressure without fear of severe pressure fluctuations and maintaining an air-to-fuel ratio for emission control. Therefore, installing a differential pressure meter with appropriate pressure measurements is probably the simplest and most efficient method of calculating engine air mass flow and operating point with respect to the surge line as a controlled variable.

Optimization of turbocharger control improves the performance of diesel engines, which can be achieved by integrating an anti-surge controller into the electronic engine management system, which controls an electronic wastegate that bypasses some of the engine exhaust gases around the turbine; and an electronic throttle valve that maintains the air mass to fuel mass ratio at the selected set point.

Author Biography

Roman Bershader is an independent consultant, was born and raised in the USSR.
In 1978, he graduated from the Kazan Aerospace Technical School with a master's degree.
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