CHAPTER 6 - COSWORTH ARGO-CLOSED CYCLE DIESEL

In about 1975 Cosworth Engineering took an interest in a KOH nitro-diesel that was then being worked on at Newcastle University UK. Cosworth Engineering is a firm that builds engines for Formula 1 and other racing cars and was very well connected to other sources of engineering expertise. Cosworth were attracted by the oxygen sensing and engine control system that Newcastle had designed and by the generally high standard of the university team. Cosworth eventually devised a closed cycle system that dissolved the excess CO2 in sea water and so removed the pumping losses, and which allowed the diesel to run under conditions very close to that which the manufacturers had intended. The system is shown in part in Figure CCD 1.

There are three main mechanical parts to the system : The engine, the absorber and the water management system.

The engine is fed with exhaust gas that has been treated to remove a small portion of the carbon dioxide (equal, obviously, to that made by burning the fuel) , and to add oxygen to replace that which has been used up in burning the fuel. If it were just like this, of course the compressional properties of the gas would be incorrect, the low gamma for the CO2 dragging the gamma of the mixture well below the value of 1.4 expected by the diesel which has been designed to run on air. Therefore a small amount of argon is added (gamma=1.67) so that a mixture of the gases oxygen, nitrogen, carbon dioxide and argon enter the engine. The gas has gamma=1.4 and it has 21 % of oxygen and for compressional purposes the diesel can't tell the difference between this mixture and air. The diesel starts, and in all other respects behaves very similarly to a diesel running on air.

This is a considerable advantage in a submarine, because the engineers in the submarine and at the shore bases are dealing with equipment which is very familiar to them. They know what spares to carry and so on. It also enables you to make good estimates of the time between failures and to quote other reliability data, since the usage of the diesel is hardly changed from normal.

Argon is controlled by having a pressure transducer inside a cylinder and adjusting the quantity of argon until the compression curve is similar to that which you see in air. Oxygen is controlled by a system involving a zirconia membrane. These membranes develop a voltage across themselves if there are different concentrations of oxygen on each side. The basic zirconia is modified by "alloying" with some other metallic ions to stiffen up its thermal resistance. The response time of these membranes is fast enough, some tens of milliseconds, for a decent control system to be devised. In addition to oxygen, carbon dioxide and argon, nitrogen appears in the system because the exhaust gases are contacted with the sea in an absorber. The sea is saturated with nitrogen gas and some of this is discharged into the engine gas cycle so that an equilibrium is set up according to Henry's Law.

Cosworth's team was almost exclusively made up of aircraft engineers and motor racing engineers. Not being hide bound by previous work, they thought it was obvious that the CO2 of combustion should be dissolved in the surrounding sea water. The question was how to do this. In a chemical plant you would use a counter-current absorption tower in which water trickled down from the top and gas ascended. Clean water entering the tower at the top could be more than 90 % saturated by the time it reached the bottom as sketched in CCD 2.

Calculations soon showed that you could not have such a tower in a submarine. Firstly its height would be larger than the diameter of the submarine, and secondly such a tower not only stops working if you tip it to one side, but it does not restart after you replace it in its vertical position. There is no driving force strong enough to overcome the stratification of water and gas.

Consideration was then given to the factors limiting the operation of the absorber. It appeared that the tower was limited in two ways. If the gas velocity became too large for a given quantity of water, the gas "picked up" the water and drove it back up the tower. The tower is said to "flood". Secondly, in order to allow time for the water to become saturated, a certain length of tower had to be installed.

Cosworth's engineers noted that if the water could be forced down the tower under some artificial force then the flooding criterion would take place at some higher gas flow. Essentially, the tower was turned on its side and made into a rotating device. Whereas in a tower water falls vertically under the action of 1 g and gas rises vertically past it, in the Cosworth absorber water is flung out under the action of a fictitious centripetal force of 30 g's and the gas flows radially inward. In this absorber the tower packing is replaced by a tightly would mesh. The combination of the increased amount of surface over which the water must flow and the extra power put into the water enables a "shorter tower" to be used. The rotating absorber is sketched in CCD 3 and an external view is given in CCD 4.

Such a rotating absorber had been considered earlier by an engineer working in the research laboratories of Imperial Chemical Industries. Colin Ramshaw was interested in the general field of "process intensification" by which he meant reducing the size of common items used in chemical manufacturing, such as distillation columns and absorbing towers. Ramshaw's important developments were not well supported by his employers who failed to see the great potential that they had and who did not put in the design effort that was necessary.

An idea of the extreme efficacy of the rotating system can be obtained as follows: In an experimental rig the rotating absorber was used to strip CO2 from the exhaust of a 250 kW diesel engine at about 1 mole/sec. The mesh pack inside the absorber had an internal diameter of about 300 mm, a radial thickness of about 50 mm and rotated at about 400 rpm. The water saturated to about 70 % was then freed of its CO2 in a tower. (This was to reduce the amount of water taken from the mains). There were two towers, each was 1500 mm diameter and had a packing of length three metres. The time for a portion of water to fall down the tower is of the order of 600 secs whereas the time taken for a portion of water to pass through the rotating mesh is about 0.3 secs. It is thought that as the water is forced over the wires of the mesh a plethora of tiny Karman vortices are continually folding CO2 into the body of the water where dissolution proper can take place.

Whatever the detailed explanation of the workings of the rotating absorber, the invention of this device meant that water could now be used to dissolve CO2 inside the submarine. Furthermore this rotating device does not stop working if the absorber is turned on its side. The triangle of forces is such that the water hardly knows how a fighting submarine is oriented.

The argo closed cycle diesel is based on a turbocharged engine. The turbos are removed. In closed cycle mode the working pressure is allowed to rise to a pressure somewhere adjacent to the designed turbocharger pressure. In this way the diesel is running close to the conditions that the designer intended. Since more CO2 dissolves in a given body of water at higher pressure, there is a trend to run the system at as high a pressure as possible.

The absorber gas is then at 2.5 Bara and so the water passing through the absorber must also be at this pressure. However the sea pressure might be as much as 50 Bara in a modern submarine. If we had separately to depressurise 50 L/sec of water into the submarine and then re-pressurise with a pump, then we should need about (47.5*50/10) kW = 237 kW even at 100 % efficiency of compression. This is nearly all the shaft power delivered by the diesel and there would be nothing left to propel the boat. Therefore the Water Management System (the "WMS") is provided.

The function of the water management system is to take water at depth pressure, depressurise it to the few bars pressure of the engine gas loop and, after the water has been saturated with carbon dioxide inside the absorber, re-pressurise it to sea pressure. The trick is to allow the infinite reservoir of the sea to perform the re-pressurisation. The WMS system is actually quite a complicated device, but its function is simple enough : It divides up a column of water into separate portions ("cut it into logs"). The sequence of events is shown in Figure CCD 5, and an idea of how the matter is managed in practice is shown in Figure CCD 6.

The cylinder in the figure is called the Water Transfer Unit, called a WTU for short. Each WTU has two valves connecting it to the sea and two valves connecting to the low pressure system, i.e. the absorber. The WTU has a loose fitting piston inside it to separate "dirty" water (i.e. that containing CO2) from "clean" water. In operation, the sea valves are opened and the WTU is filled with clean HP water under the action of the HP circulating pump. Then all valves are shut. Then the LP valves are opened allowing depressurisation of the portion of water. This is pumped along to the absorber using the LP pump where it is mixed with CO2. Then it passes back to the WTU which is then full of dirty LP water. All the LP valves are closed. Then the HP valves are opened allowing the sea to re-pressurise the portion of water. Finally the HP pump pumps everything overboard again.

Figure CCD 7 is a fuller version of Figure CCD 1 and Figure CCD 8 shows a system assembled in a factory. It is "spread out" for ease of development work.

In the 250 kW system the total losses are mainly due to the power put into driving the rotating absorber and into the LP and HP circulating pumps. There are further thermal losses in the generator and there are a variety of other small losses. Of the original 250 shaft kW only about 45 kW is used up in such "parasitic" losses, making for a very efficient system.

The Closed Cycle Diesel, together with the hydride storage fuel cell system, does not put bubbles of exhaust gas into the sea. The CO2 goes overboard as a solution.

Another important mater is that the system does not throw any valuable oxygen overboard. Nearly all the other engineered system throw a certain amount of oxygen overboard; this is because it is impossible to burn fuel with the exact stoichiometric quantity of oxygen. The exhaust always has some oxygen in it and this gets thrown away along with the carbon dioxide.

The closed cycle diesel, like MESMA, can be made to give very large powers. It merely depends upon how large absorbers and WMS you want to make. The difficulty in the past has always arisen when people wanted smaller systems of the order of 60 kW. In such a case the design costs are unchanged from say a one-off 800 kW system but there is less revenue with which to offset these costs. The net result is that smaller systems appear to come in very expensive. Designers hope to get an order for a dozen units when the economics case might look better.

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